Rudders

Amended Rules and Guidance

Rules for the Survey and Construction of Steel Ships Parts C and CS
Guidance for the Survey and Construction of Steel Ships Parts C and CS

Reason for Amendment

IACS Unified Requirement (UR) S10 stipulates requirements regarding rudders, sole pieces and rudder horns, and these requirements have already been incorporated into the NK rules.

In recent years, as a result of review of UR S10 in IACS, several IACS members pointed out some points which are to be amended. In this context, IACS reviewed requirements for ladder trunks, cone couplings, etc. and then amended them by adopting UR S10(Rev.7) in February 2023.

Relevant requirements are, therefore, amended in accordance with UR S10(Rev.7).

Outline of Amendment

The main contents of this amendment are as follows:

(1) Clarifies requirements regarding the fillet shoulder radius of rudder trunks extending below shell or skeg.
(2) Amends requirements regarding welds in the rudder side plating and welds between plates and heavy pieces (solid parts in forged or cast steel or very thick plating).
(3) Amends shear forces and bending moments for spade rudder with trunk extending inside the rudder.
(4) Adds requirements regarding the push-up pressure and the push up length for pintle in case of oil injection fitting (wet fitting).
(5) Clarifies requirements regarding sleeves for rudder stocks and pintles having diameter less than 200 *mm*.

“Rules for the survey and construction of steel ships” has been partly amended as follows:

Part C HULL CONSTRUCTION AND EQUIPMENT

Part 1 GENERAL HULL REQUIREMENTS

Chapter 11 STRUCTURES OUTSIDE CARGO REGION

11.5 Stern Construction

11.5.1 Stern Frames

11.5.1.8 Rudder Trunk

Sub-paragraph -2 has been amended as follows.

2 The material, welding, and connection to the hull are to be in accordance with the following **(1)** to **(4)**.

(1) The steel used for the rudder trunk is to be of weldable quality, with a carbon content not exceeding 0.23 % or carbon equivalent (*CEQ*) not exceeding 0.41 %.

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

(3) For rudder trunks extending below shell or skeg, ~~T~~the fillet shoulder radius r (*mm*) (*See* **Fig. 11.5.1-5**) is to be as large as practicable and to comply with the following formula:

$r = 0.1 d_l / K_T$

However, this value is not to be less than:

When $\sigma \geq 40/K_{ST}$ *N/mm*^{2} $r = 60$ *mm*

When $\sigma < 40/K_{ST}$ *N/mm*^{2} $r = 30$ *mm*

d_l: Diameter of the rudder stock defined in **13.2.5.2**.

σ: Bending stress (*N/mm*^{2}) of the rudder trunk

K_{ST}: Material factor ~~of the rudder stock determined~~ for the rudder trunk as given in **13.2.1.2**.

The fillet radius may be obtained by grinding. If disk grinding is carried out, score marks are to be avoided in the direction of welding. The fillet radius is to be checked with a template for accuracy. At least four profiles are to be checked. A report is to be submitted to the Surveyor.

(4) Rudder trunks comprising materials other than steel are to be specially considered by the Society.

Sub-paragraph -3 has been amended as follows.

3 The scantlings of the rudder trunk are to be in accordance with the following:

(1) The equivalent stress due to bending and shearing is not to exceed $0.35\sigma_Y$ of the material used.

(2) The bending stress on the welded rudder trunk is to comply with the following formula:

$\sigma \leq 80/K_{ST}$

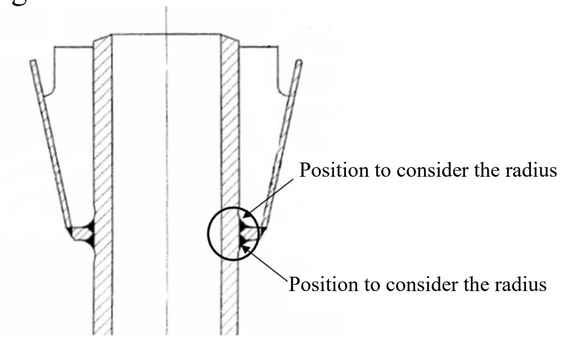
σ: As specified in **-2** above.

K_{ST}: Material factor ~~of~~for the rudder ~~stock~~ trunk as given by **13.2.1.2**, not to be taken less than 0.7.

σ_Y: Specified minimum yield stress (N/mm^2) of the material used.

For calculation of bending stress, the span to be considered is the distance between the mid-height of the lower rudder stock bearing and the point where the trunk is clamped into the shell or the bottom of the skeg.

Fig. 11.5.1-5 Fillet Radius of Fillet Weld



Chapter 13 RUDDERS

13.2 Rudders

13.2.1 General

13.2.1.3 Welding and Design Details

Sub-paragraph -3 has been amended as follows.

3 Welds in the rudder side plating subjected to significant stresses from rudder bending, and welds between plates and heavy pieces (solid parts in forged or cast steel or very thick plating) are to comply with the following **(1)** to **(3)**:

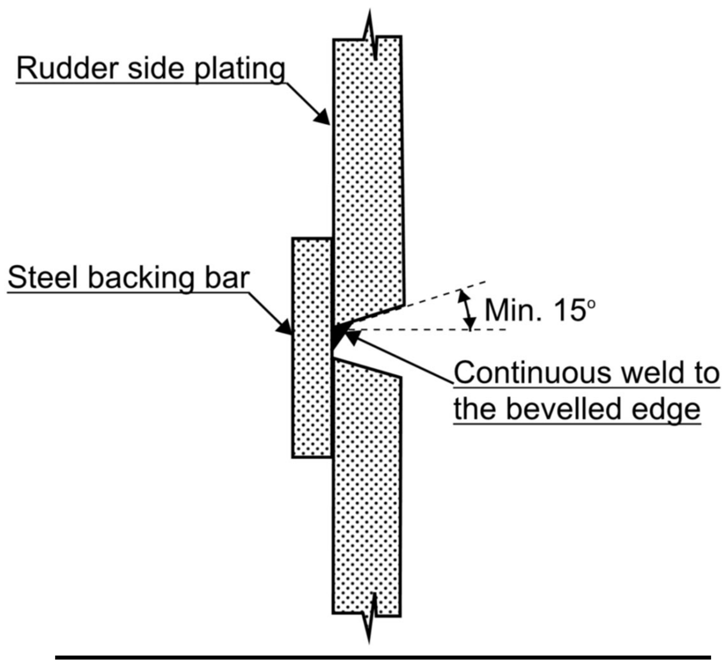
(1) ~~Welds between plates and heavy pieces (solid parts in forged or cast steel or very thick plating)~~ These are to be made as full penetration welds.

(2) In way of highly stressed areas e.g. cut-out of Type *A*, *D* and *E* rudders and upper part of Type *C* rudders, cast or welding on ribs is to be arranged.

(3) Two sided full penetration welding is normally to be arranged. Where back welding is impossible, one side welding using steel backing bars is, in principle, to be performed. In such cases, one- sided continuous welding is to be used to weld the steel backing bars to ~~heavy pieces~~ bevelled edge (*See* **Fig. 13.2.1-3**). The bevel angle is to be at least 15 *degrees* for one sided welding. Other welding procedures, however, may be approved when deemed appropriate by the Society.

Fig. 13.2.1-3 has been added as follows.

Fig.13.2.1-3 Use of Steel Backing Bar in way of Full Penetration Welding of Rudder Side Plating



13.2.2 Rudder Force

Paragraph 13.2.2.1 has been amended as follows.

13.2.2.1

The rudder force FR is used to determine the rudder scantlings and is obtained from the following formula, for ahead and astern conditions. However, when the rudder is arranged behind the propeller that produces an especially great thrust, the rudder force is to be appropriately increased.

$F_R = 132 K_1 K_2 K_3 A V^2$ (*N*)

Where:

A: Area of rudder plate (*m*^{2})

V: Speed of ship (*kt*)

When the speed is less than 10 *knots*, V is to be replaced by $V_{\min}$ obtained from the following formula:

$$V_{\min} = \frac{V + 20}{3} \ (kt)$$

For the astern condition, the astern speed V_a as defined in **2.1.30, Part A** is to be obtained from the following formula. However, when the maximum astern speed is designed to exceed V_a, the design maximum astern speed is to be used.

$$V_a = 0.5V \ (kt)$$

Where:

K_1: Factor depending on the aspect ratio Λ of the rudder area obtained by the following formula.

$$K_1 = \frac{\Lambda + 2}{3}$$

Λ: As obtained from the following formula, however, Λ is not required to be greater than 2

$$\Lambda = \frac{h^2}{A_t}$$

h: Mean height of rudder (*m*), which is determined according to the coordinate system in **Fig. 13.2.2-1**.

A_t: Sum of rudder plate area A (*m*^{2}) and area of rudder post or rudder horn, if any, within the mean height of Rudder *h*

K_2: Factor depending on the rudder profile (*See* **Table 13.2.2-1**)

K_3: Factor depending on the location of rudder, as specified below:

For rudders outside the propeller jet: 0.8

For rudders behind a fixed propeller nozzle: 1.15

Otherwise: 1.0

13.2.5 Rudder Stocks

Paragraph 13.2.5.2 has been amended as follows.

13.2.5.2 Lower Stocks

The diameter d_l of the lower stock, which is the stock below the bearing centre of the rudder carrier subject to the combined forces of torque and bending moment, is to be determined such that the equivalent stress in the rudder stock does not exceed $118/K_S$ (*N/mm*^{2})

The equivalent stress σ_e is to be obtained from the following formula.

$$\sigma_e = \sqrt{{\sigma_b}^2 + 3{\tau_t}^2} \ (N/mm^2)$$

σ_b and τ_t: The bending stress and torsional stress acting on the lower stock are to be determined as follows:

Bending stress: $\sigma_b = \dfrac{10.2M}{{d_l}^3} \times 10^3$ (*N/mm*^{2})

Torsional stress: $\tau_t = \dfrac{5.1T_R}{{d_l}^3} \times 10^3$ (*N/mm*^{2})

Where:

M:Bending moment (*N-m*) at the section of rudder stock considered

T_R: As specified in **13.2.3**

When the horizontal section of the lower stock forms a circle, the lower stock diameter d_l may be determined by the following formula:

$$d_l = d_u \cdot \sqrt[6]{1 + \frac{4}{3}\left(\frac{M}{T_R}\right)^2} \quad (mm)$$

d_u: Diameter of upper stock (*mm*) as given in **13.2.5.1**

For a spade rudder with trunk extending inside the rudder, the rudder stock scantlings are to be checked for the following two cases:

(1) pressure applied on the entire rudder area; and

(2) pressure applied only on rudder area below the middle of the neck bearing.

13.2.6 Rudder Plates, Rudder Frames and Rudder Main Pieces

Paragraph 13.2.6.1 has been amended as follows.

13.2.6.1 Rudder Plate

The rudder plate thickness t_{gr} is not to be less than that obtained from the following formula. The thickness of rudder plating in way of the solid part is to be increased in accordance with **13.2.7.4**.

$$t_{gr} = 5.5S\beta\sqrt{\left(\cancel{d}\,\underline{T_{SC}} + \frac{F_R \times 10^{-4}}{A}\right)K_{pl}} + 2.5 \; (mm)$$

T_{SC}: Scantling draught (*m*) (*See* **1.4.3.1-5**)

A and F_R: As specified in **13.2.2.1**

K_{pl}: Material factor for the rudder plate as given in **13.2.1.2**

β:To be obtained from the following formula:

$$\beta = \sqrt{1.1 - 0.5\left(\frac{S}{a}\right)^2},$$

but need not exceed 1.0 $\left(\frac{a}{S} \geq 2.5\right)$

Where:

S: Spacing (*m*) of horizontal or vertical rudder frames, whichever is smaller

a: Spacing (*m*) of horizontal or vertical rudder frames, whichever is greater

13.2.8.4 Cone Couplings with Special Arrangements for Mounting and Dismounting the Couplings

Sub-paragraph -2 has been amended as follows.

2 Push-up pressure is to comply with the following requirements.

(1) The push-up pressure is not to be less than the greater of the two following values:

$$p_{req1} = \frac{2M_Y}{{d_m}^2 l\pi\mu_0} \times 10^3 \ (N/mm^2)$$

$$p_{req2} = \frac{6M_{bc}}{l^2 d_m} \times 10^3 \ (N/mm^2)$$

Where:

M_Y: Design yield moment of rudder stock, as defined in **13.2.8.3-2**. (N-m)

d_m: Mean cone diameter (mm) (*See* **Fig. 13.2.8-2**)

l: Coupling length (mm)

μ_0: Frictional coefficient, equal to 0.15

M_{bc}: Bending moment in rudder stock at the top of the cone coupling (e.g. in case of spade rudders) (N-m)

For spade rudder with trunk extending inside the rudder, the coupling is to be checked for the following two cases:

(1) pressure applied on the entire rudder area; and

(2) pressure applied only on rudder area below the middle of the neck bearing.

(2) It has to be proved by the designer that the push-up pressure does not exceed the permissible surface pressure in the cone. The permissible surface pressure is to be determined by the following formula:

$$p_{perm} = \frac{0.95\sigma_Y(1-\alpha^2)}{\sqrt{3+\alpha^4}} - p_b$$

$$p_b = \frac{3.5M_{bc}}{d_m l^2} \times 10^3$$

σ_Y: Specified minimum yield stress (N/mm^2) of the material of the gudgeon

$$\alpha = \frac{d_m}{d_a}$$

d_m: Mean cone diameter (mm) (*See* **Fig. 13.2.8-2**)

d_a: Outer diameter of the gudgeon (mm) (*See* **Fig. 13.2.8-2** and **Fig. 13.2.8-3**. The least diameter is to be considered.) The outer diameter of gudgeon d_a is recommended to be taken at the same plane in which the mean cone diameter d_m.

(3) The outer diameter of the gudgeon is not to be less than 1.25 d_0 (mm), with d_0 defined in **Fig. 13.2.8-2**

3 The push-up length is to comply with the following requirements.

(1) The push-up length Δl (mm) is to comply with the following formula:

$$\Delta l_1 \le \Delta l \le \Delta l_2$$

$$\Delta l_1 = \frac{p_{req} d_m}{E\left(\frac{1-\alpha^2}{2}\right)c} + \frac{0.8R_{tm}}{c} \ (mm)$$

$$\Delta l_2 = \frac{p_{perm} d_m}{E\left(\frac{1-\alpha^2}{2}\right)c} + \frac{0.8R_{tm}}{c} \ (mm)$$

R_{tm}: Mean roughness (*mm*) taken equal to about 0.01 *mm*

c: Taper on diameter according to **13.2.8.3-1**

E: Young's modulus (N/mm^2) , to be taken as 2.06×10^5

(2) In case of hydraulic pressure connections the required push-up force P_e for the cone (*N*) may be determined by the following formula:

$$P_e = p_{req} d_m \pi l \left(\frac{c}{2} + 0.02\right)$$

The value 0.02 is a reference for the friction coefficient using oil pressure. It varies and depends on the mechanical treatment and roughness of the details to be fixed. Where due to the fitting procedure a partial push-up effect caused by the rudder weight is given, this may be taken into account when fixing the required push-up length, subject to approval by the Society.

13.2.9 Pintles

13.2.9.2 Construction of Pintles*

Sub-paragraph -2 has been amended as follows.

2 The required push-up pressure for pintle in case of dry fitting (N/mm^2) is to be determined by p_{req1} as given below. The required push-up pressure for pintle in case of oil injection fitting (N/mm^2) is to be determined by the ~~following formula~~ maximum pressures of p_{req1} and p_{req2} as given below. The required push up length Δl_1 is to be calculated similarly as in **13.2.8.4-3**, using the required push-up pressure (as defined below) and properties for the pintle.

$$p_{req1} = 0.4 \frac{B d_0}{{d_m}^2 l} \ (N/mm^2)$$

$$p_{req2} = \frac{6M_{bp}}{l^2 d_m} \times 10^3 \ (N/mm^2)$$

B: As defined in **13.2.9.1**

d_m, l: As defined in **13.2.8.4-2**

d_0: Pintle diameter (*mm*) (*See* **Fig. 13.2.8-2**)

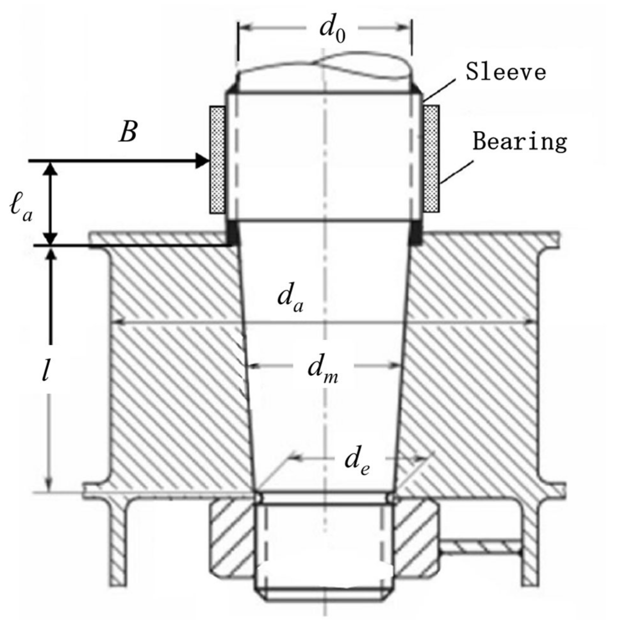
M_{bp}: bending moment in the pintle cone coupling (*N-m*) to be determined as follows

$$M_{bp} = B \ell_a$$

ℓ_a: length between middle of pintle-bearing and top of contact surface between cone coupling and pintle (*m*) (*See* **Fig. 13.2.9-1**)

Fig. 13.2.9-3 has been added as follows.

Fig. 13.2.9-3 Pintle Cone Coupling Indicating ℓ_a



13.2.10 Bearings of Rudder Stocks and Pintles

Paragraph 13.2.10.1 has been amended as follows.

13.2.10.1 Sleeves and Bushes

1 Sleeves and bushes are to be fitted in way of rudder stock bearing. For rudder stocks and pintles having diameter less than 200 *mm*, sleeves in way of bushes may be provided optionally. The minimum thickness of sleeves and bushes is to be equal to:

(1) $t_{\min} = 8$ *mm* for metallic materials and synthetic material

(2) $t_{\min} = 22$ *mm* for lignum material

2 Sleeves and bushes are to be fitted in way of pintle bearings. The minimum thickness of sleeves and bushes is to be equal to:

$t = 0.01\sqrt{B}$ (*mm*)

B: As specified in **13.2.9.1**

13.2.11 Rudder Accessories

13.2.11.1 Rudder Carriers*

Sub-paragraph -2 has been amended as follows.

2 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 at scantling draught (without trim), two separate watertight seals or stuffing boxes are to be provided.

Part CS HULL CONSTRUCTION AND EQUIPMENT OF SMALL SHIPS

Chapter 2 STEMS AND STERN FRAMES

2.2 Stern Frames

2.2.7 Rudder ~~t~~Trunk

Sub-paragraph -2 has been amended as follows.

2 Materials, welding and connection to hull

The steel used for the rudder trunk is to be of weldable quality, with a carbon content not exceeding 0.23 % on ladle analysis or a carbon equivalent C_{EQ} not exceeding 0.41 %.

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

For rudder trunks extending below shells or skegs, ~~T~~the fillet shoulder radius r (*mm*) (*See* **Fig. CS2.3**) is to be as large as practicable and to comply with the following formulae:

$r = 0.1 d_l / K_T$

without being less than:

$r = 60$ when $\sigma \geq 40 / K_{ST}$ (*N/mm*^{2})

$r = 30$ when $\sigma < 40 / K_{ST}$ (*N/mm*^{2})

Where:

d_l: rudder stock diameter axis defined in **3.5.2**.

σ: bending stress in the rudder trunk (*N/mm*^{2}).

K_{ST}: material factor for the rudder trunk as given in **3.1.2**.

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.

Rudder trunks comprising of materials other than steel are to be specially considered by the Society.

Sub-paragraph -3 has been amended as follows.

3 Scantlings

The scantlings of the trunk are to be such that:

- the equivalent stress due to bending and shear does not exceed $0.35\,\sigma_Y$,
- the bending stress on welded rudder trunk is to be in compliance with the following formula:

  $\sigma \leq 80 / K_{ST}$ (*N/mm*^{2})

  with:

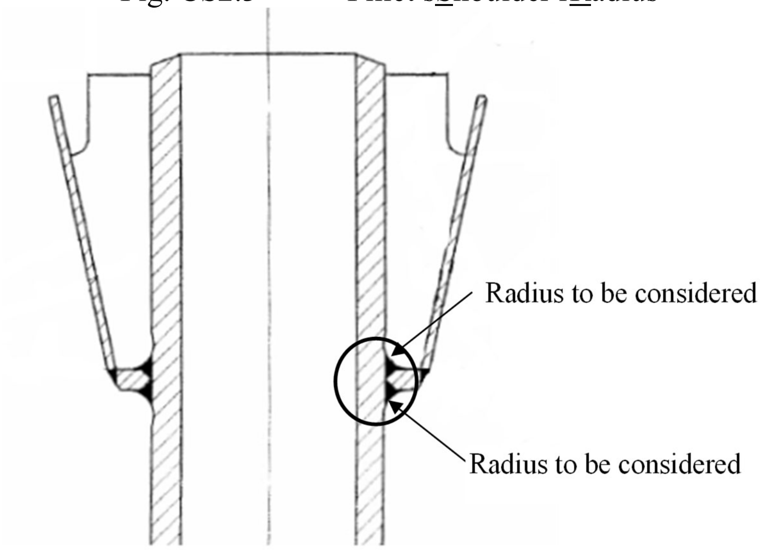
  σ: As defined in **-2**.

  K_{ST}: Material factor for the rudder trunk as given in **3.1.2**, not to be taken less than 0.7

  σ_Y: Specified minimum yield stress (*N/mm*^{2}) of the material used

For calculation of bending stress, the span to be considered is the distance between the mid-height of the lower rudder stock bearing and the point where the trunk is clamped into the shell or the bottom of the skeg.

Fig. CS2.3 Fillet ~~s~~Shoulder ~~r~~Radius



Chapter 3 RUDDERS

3.1 General

Paragraph 3.1.1 has been amended as follows.

3.1.1 Application*

1 (Omitted)

2 This chapter applies to rudders made of steel for ships with $L_1 \geq 24$ *m*

~~2~~3 The construction of rudders having three or more pintles and of those having special shape or sectional form will be specially considered by the Society.

~~3~~4 The construction of rudders designed to move more than 35 *degrees* on each side will be specially considered by the Society.

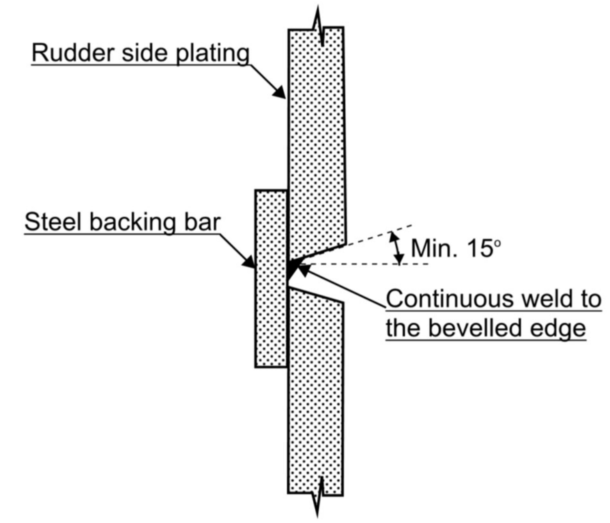
3.1.3 Welding and Design Details

Sub-paragraph -3 has been amended as follows.

3 Welds in the rudder side plating subjected to significant stresses from rudder bending and welds between plates and heavy pieces (solid parts in forged or cast steel or very thick plating) are to be made as full penetration welds. In way of highly stressed areas (e.g. cut-out of Type *A* rudders and upper part of Type *C* rudders), cast or welding on ribs is to be arranged. Two sided full penetration welding is normally to be arranged. Where back welding is impossible, one side welding using steel backing bars is, in principle, to be performed. In such cases, one~~-~~ sided continuous welding is to be used to weld the steel backing bars to ~~heavy pieces~~bevelled edge (*See* **Fig. CS3.3**). The bevel angle is to be at least 15 *degrees* for one sided welding. Other welding procedures, however, may be approved when deemed appropriate by the Society.

Fig. CS3.3 has been added as follows.

Fig. CS3.3 Use of Steel Backing Bar in Way of Full Penetration Welding of Rudder Side Plating



Section 3.2 has been amended as follows.

3.2 Rudder Force*

The rudder force F_R is used to determine the rudder scantlings and is obtained from the following formula, for ahead and astern conditions. However, when the rudder is arranged behind the propeller that produces an especially great thrust, the rudder force is to be appropriately increased.

$F_R = K_1 K_2 K_3 132 A V^2$ (N)

Where:

A: Area of rudder plate (m^2)

V: Speed of ship (kt)

When the speed is less than 10 *knots*, V is to be replaced by V_{min} determined from the following formula.

$$V_{min} = \frac{V+20}{3} \ (kt)$$

For the astern condition, the astern speed V_a as defined in **2.1.30, Part A** is to be obtained from the following formula. However, when the maximum astern speed is designed to exceed V_a, the design maximum astern speed is to be used.

$V_a = 0.5V$ (kt)

Where:

K_1: Factor depending on the aspect ratio Λ of the rudder area obtained from the following formula.

$$K_1 = \frac{\Lambda+2}{3}$$

Λ: As obtained from the following formula

However, Λ is not required to be greater than 2.

$$\Lambda = \frac{h^2}{A_t}$$

h: Mean height of rudder (m), which is determined according to the coordinate system in **Fig. CS3.~~3~~4**

A_t: Sum of rudder plate area A (m^2) and area of rudder post or rudder horn, if any, within the mean height of rudder h

K_2: Factor depending on the type of rudder profile (*See* **Table CS3.1**)

K_3: Factor depending on the location of rudder, as specified below:

For rudders outside the propeller jet ~~....~~: 0.8

For rudders behind a fixed propeller nozzle ~~....~~: 1.15

Otherwise ~~....~~: 1.0

Fig. CS3.~~3~~4 Coordinate System of Rudders

(Omitted)

3.3 Rudder Torque

Paragraph 3.3.1 has been amended as follows.

3.3.1 Rudder Torque of Type *B* and *C* Rudders

The rudder torque T_R of Type *B* and *C* rudders is to be obtained for ahead and astern conditions, respectively, according to the following formula.

$T_R = F_R r$ (*N-m*)

Where:

F_R: As specified in **3.2**

r: Distance (*m*) from the centre of the rudder force on the rudder to the centreline of the rudder stock, determined by the following formula

$r = b(\alpha - e)$

For the ahead condition, r is not to be less than r_{min} obtained from the following formula.

$r_{min} = 0.1b$ (*m*)

Where:

b: Mean breadth (*m*) of rudder determined by the coordinate system in **Fig. CS3.~~3~~4**

α: To be as follows:

For ahead condition: 0.33

For astern condition: 0.66

e: Balance factor of the rudder obtained from the following formula.

$$e = \frac{A_f}{A}$$

Where:

A_f: Portion of the rudder plate area (m^2) situated ahead of the centreline of the rudder stock

A: As specified in **3.2**

Paragraph 3.3.2 has been amended as follows.

3.3.2 Rudder Torque of Type *A* Rudder

The rudder torque T_R of Type *A* rudders is to be obtained for the ahead and astern condition, respectively, according to the following formula:

$T_R = T_{R1} + T_{R2}$ (*N-m*)

For the ahead condition, T_R is not to be less than T_{Rmin} obtained from the following formula:

$T_{Rmin} = 0.1 F_R \frac{A_1 b_1 + A_2 b_2}{A}$ (*N-m*)

Where~~.~~:

T_{R1} and T_{R2}: Rudder torque (*N-m*) of portions A_1 and A_2, respectively

A_1 and A_2: Areas of respective rectangles (m^2) determined by dividing the rudder area into two parts so that $A = A_1 + A_2$ (A_1 and A_2 include A_{1f} and A_{2f} respectively), as specified in **Fig. CS3.~~4~~5**. A_{1f} and A_{2f} are areas situated ahead of the centreline of the rudder stock.

b_1 and b_2: Mean breadth (*m*) of portions A_1 and A_2 respectively determined by applying **Fig. CS3.~~3~~4**

F_R and A: As specified in **3.2**

T_{R1} and T_{R2}, the rudder torque of portions A_1 and A_2 respectively, are to be obtained from the following formulae.

$T_{R1} = F_{R1} r_1$ (*N-m*)

$T_{R2} = F_{R2} r_2$ (*N-m*)

F_{R1} and F_{R2}, the rudder force of portions A_1 and A_2, are to be obtained from the following formulae.

$F_{R1} = F_R \frac{A_1}{A}$ (N)

$F_{R2} = F_R \frac{A_2}{A}$ (N)

r_1 and r_2, the distances from each centre of rudder force of portions A_1 and A_2 to the centreline of the rudder stock, are to be determined from the following formulae.

$r_1 = b_1(\alpha - e_1)$ (m)

$r_2 = b_2(\alpha - e_2)$ (m)

e_1 and e_2, the balance factors of portions A_1 and A_2 respectively, are to be determined from the following formulae.

$e_1 = \frac{A_{1f}}{A_1}$, $e_2 = \frac{A_{2f}}{A_2}$

α is to be as follows:

For parts of a rudder not behind a fixed structure such as the rudder horn:
For ahead condition: 0.33
For astern condition: 0.66

For parts of a rudder behind a fixed structure such as the rudder horn:
For ahead condition: 0.25
For astern condition: 0.55

Fig. CS3.~~4~~5 Division of Rudder
(Omitted)

3.5 Rudder Stocks

Paragraph 3.5.2 has been amended as follows.

3.5.2 Lower Stocks

The diameter d_l of the lower stock, which is the stock below the bearing centre of the rudder carrier subject to the combined forces of torque and bending moment, is to be determined such that the equivalent stress in the rudder stock does not exceed 118~~=~~/K_S (N/mm^2).

The equivalent stress σ_e is to be obtained from the following formula.

$$\sigma_e = \sqrt{\sigma_b{}^2 + 3\tau_t{}^2} \quad (N/mm^2)$$

The bending stress and torsional stress acting on the lower stock are to be determined as follows:

Bending stress: $\sigma_b = \frac{10.2M}{d_l{}^3} \times 10^3$ (N/mm^2)

Torsional stress: $\tau_t = \frac{5.1T_R}{d_l{}^3} \times 10^3$ (N/mm^2)

Where:

M: Bending moment (N-m) at the section of rudder stock considered

T_R: As specified in **3.3**

When the horizontal section of the lower stock forms a circle, the lower stock diameter d_l may be determined by the following formula:

$$d_l = d_u \cdot \sqrt[6]{1 + \frac{4}{3}\left[\frac{M}{T_R}\right]^2} \quad (mm)$$

Where:

d_u: Diameter of upper stock (*mm*) as given in **3.5.1**

For a spade rudder with trunk extending inside the rudder, the rudder stock scantlings are to be checked against the following two cases:

(1) pressure applied on the entire rudder area; and

(2) pressure applied only on rudder area below the middle of neck bearing.

3.6 Rudder Plates, Rudder Frames and Rudder Main Pieces of Double Plate Rudders

Paragraph 3.6.1 has been amended as follows.

3.6.1 Rudder Plate

The rudder plate thickness t is not to be less than that obtained from the following formula:

$$t = 5.5S\beta\sqrt{\left(\cancel{d}\,\underline{d_s} + \frac{F_R \times 10^{-4}}{A}\right)K_{p1}} + 2.5 \quad (mm)$$

Where:

d_s: Scantling draught (*m*) (*See* **15.2.1-1**)

A and F_R: As specified in **3.2**

K_{pl}: Material factor for rudder plate as given in **3.1.2**

β: To be obtained from the following formula:

$$\beta = \sqrt{1.1 - 0.5\left(\frac{S}{a}\right)^2} \quad maximum\ 1.0\ (\frac{a}{S} \geq 2.5)$$

Where:

S: Spacing (*m*) of horizontal or vertical rudder frames, whichever is smaller

a: Spacing (*m*) of horizontal or vertical rudder frames, whichever is greater

The rudder plating in way of the solid part is to be of increased thickness per **3.7.4**.

3.7 Connections of Rudder Blade Structure with Solid Parts

Paragraph 3.7.3 has been amended as follows.

3.7.3 Minimum Section Modulus of the Connection with the Rudder Stock Housing

The section modulus of the cross-section of the structure of the rudder blade (cm^3) formed by vertical web plates and rudder plating, which is connected with the solid part where the rudder stock is housed is to be not less than:

$$c_s {d_l}^3 \left(\frac{H_E - H_X}{H_E}\right)^2 \frac{K_{pl}}{K_S} 10^{-4} (cm^3)$$

Where:

c_S :Coefficient, to be taken equal to:

c_S = 1.0 if there is no opening in the rudder plating or if such openings are closed by a full penetration welded plate

c_S = 1.5 if there is an opening in the considered cross-section of the rudder

d_l :Rudder stock diameter (*mm*)

H_E : Vertical distance between the lower edge of the rudder blade and the upper edge of the solid part (*mm*)

H_X : Vertical distance between the considered cross-section and the upper edge of the solid part (*mm*)

K_{pl} : Material factor for the rudder blade plating as given in **3.1.2**.

K_s: Material factor for the rudder stock as given in **3.1.2**.

The actual section modulus of the cross-section of the structure of the rudder blade is to be calculated with respect to the symmetrical axis of the rudder.

The breadth of the rudder plating (*m*) to be considered for the calculation of section modulus is to be not greater than:

$$b = s_V + 2\frac{H_X}{3}$$

Where:

s_V=: spacing between the two vertical webs (*m*) (*See* **Fig. CS3.56**)

Where openings for access to the rudder stock nut are not closed by a full penetration welded plate, they are to be deducted (*See* **Fig. CS3.56**).

Fig. CS3.56 Cross-section of the Connection between Rudder Blade Structure and Rudder Stock Housing (in cases where there is an opening on only one side)

(Omitted)

3.9 Couplings between Rudder Stocks and Main Pieces

3.9.1 Horizontal Flange Couplings*

Sub-paragraph -5 has been amended as follows.

5 The welded joint between the rudder stock and the flange is to be made in accordance with **Fig.CS3.67** or equivalent.

Fig. CS3.6 has been renumbered to Fig. CS3.7.

Fig. CS3.67 Welded Joint between Rudder Stock and Coupling Flange

(Omitted)

Paragraph 3.9.3 has been amended as follows.

3.9.3 Cone Couplings with Key

1 Tapering and coupling length

Cone couplings that are mounted or dismounted without hydraulic arrangements (e.g. oil injection and hydraulic nut) are to have a taper *c* on diameter of 1:8 ~ 1:12. (*See* **Fig. CS3.78** and **Fig.CS3.910**)

Where:

$$c = (d_0 - d_e)/\ell_c$$

The diameters d_0 and d_u are shown in **Fig. CS3.78** and the cone length ℓ_c is defined in **Fig. CS3.910**.

The cone coupling is to be secured by a slugging nut. The nut is to be secured, e.g. by a securing plate.

The cone shapes are to fit exactly. The coupling length ℓ is to be, in general, not less than $1.5d_0$.

2 (Omitted)

3 The dimensions of the slugging nut as specified in **-1** are to be as follows (*See* **Fig. CS3.78**):

External thread diameter: $d_g \geq 0.65d_0$ (*mm*)

Height: $h_n \geq 0.6d_g$ (*mm*)

Outside diameter: $d_n \geq 1.2d_e$ or $1.5d_g$ (*mm*), whichever is greater

(-4 to -7 are omitted.)

Fig. CS3.7 has been renumbered to Fig. CS3.8.

Fig. CS3.~~7~~8 Cone Coupling with Key
(Omitted)

Fig. CS3.8 has been renumbered to Fig. CS3.9.

Fig. CS3.~~8~~9 Gudgeon Outer Diameter
(Omitted)

Fig. CS3.9 has been renumbered to Fig. CS3.10.

Fig. CS3.~~9~~10 Cone Length and Coupling Length
(Omitted)

3.9.4 Cone Couplings with Special Arrangements for Mounting and Dismounting the Couplings*

Fig. CS3.10 has been renumbered to Fig. CS3.11.

Fig. CS3.~~10~~11 Cone Coupling without Key
(Omitted)

Sub-paragraph -2 has been amended as follows.

2 Push-up pressure

The push-up pressure is not to be less than the greater of the two following values:

$$p_{req1} = \frac{2M_Y}{d_m^2 \, \ell \, \pi \, \mu_0} 10^3 \quad (N/mm^2)$$

$$p_{req2} = \frac{6M_{\sout{b}c}}{\ell^2 \, d_m} 10^3 \quad (N/mm^2)$$

Where:

M_Y : Design yield moment of rudder stock, as defined in **3.9.3-2** (*N-m*)

d_m : Mean cone diameter (*mm*) (*See* **Fig. CS3.~~7~~8**)

ℓ : Coupling length (*mm*)

μ_0 : Frictional coefficient, equal to 0.15

$M_{\sout{b}c}$: Bending moment in rudder stock at the top of the cone coupling (e.g. in case of spade rudders) (*N-m*)

For spade rudder with trunk extending inside the rudder, the coupling is to be checked against the following two cases:

(1) pressure applied on the entire rudder area; and

(2) pressure applied only on rudder area below the middle of neck bearing.

It has to be proved by the designer that the push-up pressure does not exceed the permissible surface pressure in the cone. The permissible surface pressure is to be determined by the following formula:

$$p_{perm} = \frac{0.95\sigma_Y(1-\alpha^2)}{\sqrt{3+\alpha^4}} - p_b$$

$$p_b = \frac{3.5M_{\not{b}\underline{c}}}{d_m \ell^2} 10^3$$

Where:

σ_Y : Specified minimum yield stress (*N/mm*^{2}) of the material of the gudgeon

$$\alpha = \frac{d_m}{d_a}$$

d_m : Mean cone diameter (*mm*) (*See* **Fig. CS3.~~7~~8**)

d_a : Outer diameter of the gudgeon (*See* **Fig. CS3.~~7~~8** and **Fig. CS3.~~8~~9**. The least diameter is to be considered.) (*mm*)

The outer diameter of the gudgeon is not to be less than 1.25 d_0, with d_0 defined in **Fig. CS3.~~7~~8**.

3 Push-up length

The push-up length $\Delta\ell$ (*mm*) is to comply with the following formula:

$$\Delta\ell_1 \leq \Delta\ell \leq \Delta\ell_2$$

Where:

$$\Delta\ell_1 = \frac{p_{req} d_m}{E\left(\frac{1-\alpha^2}{2}\right)c} + \frac{0.8R_{tm}}{c}$$

$$\Delta\ell_2 = \frac{p_{perm} d_m}{E\left(\frac{1-\alpha^2}{2}\right)c} + \frac{0.8R_{tm}}{c}$$

R_{tm} : Mean roughness (*mm*) taken equal to about 0.01 *mm*

c : Taper on diameter according to **3.9.3-1**

E : Young's modulus (*N/mm*^{2}), to be taken as 2.06×10^5

Note: In case of hydraulic pressure connections the required push-up force P_e for the cone (*N*) may be determined by the following formula:

$$P_e = p_{req}\, d_m \pi\, \ell \left(\frac{c}{2} + 0.02\right)$$

The value 0.02 is a reference for the friction coefficient using oil pressure. It varies and depends on the mechanical treatment and roughness of the details to be fixed.

Where due to the fitting procedure a partial push-up effect caused by the rudder weight is given, this may be taken into account when fixing the required push-up length, subject to approval by the Society.

3.10 Pintles

3.10.2 Construction of Pintles

Sub-paragraph -2 has been amended as follows.

2 Push-up pressure for pintle

The required push-up pressure for pintle in case of dry fitting (*N/mm*^{2}) is to be determined by p_{req1} as given below. The required push-up pressure for pintle in case of oil injection fitting (*N/mm*^{2}) is to be determined by the ~~following formula:~~ maximum pressure of p_{req1} and p_{req2} as given below.

$$p_{req1} = 0.4\frac{Bd_0}{d_m^2\,\ell}$$

$$p_{req2} = \frac{6M_{bp}}{\ell^2 d_m}\times 10^3\ (N/mm^2)$$

Where:

B : As defined in **3.10.1**

d_m, ℓ: As defined in **3.9.4-2**

d_0: Pintle diameter (*mm*) (*See* **Fig. CS3.~~7~~8**)

M_{bp}: bending moment in the pintle cone coupling (*N-m*) to be determined by:

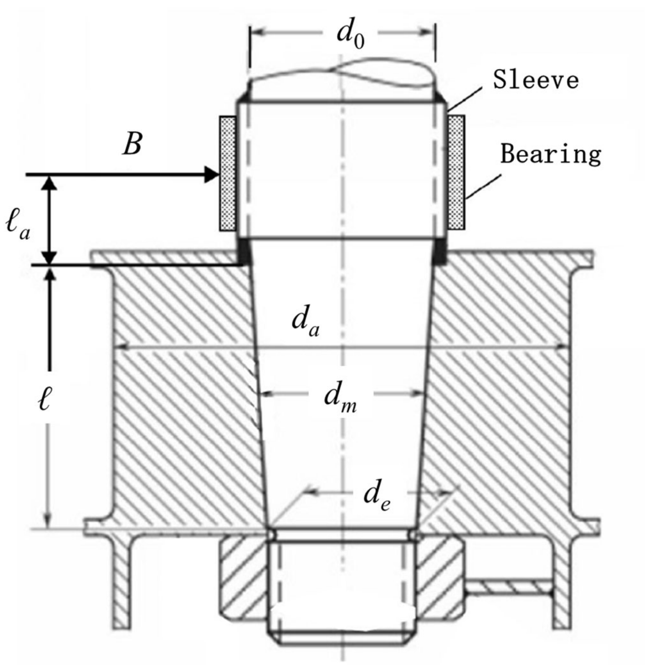
$M_{bp} = B\ell_a$

ℓ_a: Length between middle of pintle-bearing and top of contact surface between cone coupling and pintle (*m*) (*See* **Fig. CS3.12**)

The required push up length $\Delta\ell_1$ is to be calculated similarly as in **3.9.4-3**, using the required push-up pressure (as defined above) and properties for the pintle.

Fig. CS3.12 has been added as follows.

Fig. CS3.12 Pintle Cone Coupling Indicating ℓ_a



3.11 Bearings of Rudder Stocks and Pintles

3.11.1 Sleeves and Bushes

Sub-paragraph -1 has been amended as follows.

1 Rudder stock bearing

Sleeves and bushes are to be fitted in way of bearings. For rudder stocks and pintles having diameter less than 200 *mm*, sleeves in way of bushes may be provided optionally. The minimum thickness of sleeves and bushes is to be equal to:

- $t_{min} = 8$ *mm* for metallic materials and synthetic material
- $t_{min} = 22$ *mm* for lignum material

"Guidance for the survey and construction of steel ships" has been partly amended as follows:

Part C HULL CONSTRUCTION AND EQUIPMENT

Part 1 GENERAL HULL REQUIREMENTS

C13 RUDDERS

C13.2 Rudders

C13.2.4 Rudder Strength Calculation

C13.2.4.1 Rudder Strength Calculation

Sub-paragraph -3 has been amended as follows.

3 The method of evaluating moments and forces is to be as in the following **(1)** to **(3)** below. Notwithstanding the above, for Type *D* rudders with 2-conjugate elastic supports by rudder horns, the method of evaluating moments and forces is to be as in **4**.

((1) and (2) are omitted.)

(3) Simplified method

The moments and forces for rudders of each type may be obtained from the following formulae.

(a) Type *A* rudders

$$M_R = \frac{{B_1}^2(\ell_{10} + \ell_{30})}{2F_R}\ (N\text{-}m)$$

$$M_b = \frac{B_3(\ell_{30} + \ell_{40})(\ell_{10} + \ell_{30})^2}{{\ell_{10}}^2}\ (N\text{-}m)$$

$$M_s = B_3\ell_{40}\ (N\text{-}m)$$

$$B_1 = \frac{F_R h_c}{\ell_{10}}\ (N)$$

$$B_2 = F_R - 0.8B_1 + B_3\ \ (N)$$

$$B_3 = \frac{F_R{\ell_{10}}^2}{8\ell_{40}(\ell_{10} + \ell_{30} + \ell_{40})}\ (N)$$

(b) Type *B* rudders

$$M_R = \frac{{B_1}^2\ell_{10}}{2F_R}\ (N\text{-}m)$$

$$M_b = B_3\ell_{40}\ \ (N\text{-}m)$$

$$M_s = \frac{3M_R\ell_{30}}{\ell_{10} + \ell_{30}}\ \ (N\text{-}m)$$

$$B_1 = \frac{F_R h_c}{\ell_{10} + \ell_{30}}\ (N)$$

$$B_2 = F_R - 0.8B_1 + B_3\ \ (N)$$

$$B_3 = \frac{F_R(\ell_{10} + \ell_{30})^2}{8\ell_{40}(\ell_{10} + \ell_{30} + \ell_{40})} \ (N)$$

(c) Type *C* rudders

$M_b = F_R h_c$ (*N-m*)

$B_2 = F_R + B_3$ (*N*)

$$B_3 = \frac{M_b}{\ell_{40}} \ (N)$$

The maximum moment M_c in top of the cone coupling (as shown in **Fig.13.2.4-3)** is applicable for the connection between the rudder and the rudder stock.

Notwithstanding the above, ~~the value is as follow~~ the strength is to be checked against the following two cases for rudders with rudder trunks supporting rudder stocks.

i) pressure applied on the entire rudder area; and

ii) pressure applied only on rudder area below the middle of neck bearing.

The moments and forces for the two cases defined above may be determined according to **Fig. C13.2.4-6** and **Fig. C13.2.4-7**, respectively.

~~M_R is the greatest of the following values:~~

$M_{FR1} = F_{R1}(CG_{1Z} - \ell_{10})$

$M_{FR2} = F_{R2}(\ell_{10} - CG_{2Z})$

where A_1 and A_2 are the rudder blade area which are above the lower bearing and below respectively and symbols are as follows (*See* **Fig. C13.2.4-6** and **Fig. C13.2.4-7**)

F_{R1} : Rudder force over the rudder blade area A_1

F_{R2} : Rudder force over the rudder blade area A_2

CG_{1Z} : Vertical position of the centre of gravity of the rudder blade area A_1 from base

CG_{2Z} : Vertical position of the centre of gravity of the rudder blade area A_2 from base

$F_R = F_{R1} + F_{R2}$

$B_2 = F_R + B_3$

$$B_3 = \frac{M_{FR2} - M_{FR1}}{\ell_{20} + \ell_{40}}$$

(d) Type *D* rudders

$$M_R = \frac{F_{R2}\ell_{10}}{2} \ (N\text{-}m)$$

$$M_b = \frac{F_R {\ell_{10}}^2}{10(\ell_{20} + \ell_{30})} \ (N\text{-}m)$$

$$M_s = \frac{2M_R\ell_{10}\ell_{30}}{(\ell_{20} + \ell_{30})^2} \ (N\text{-}m)$$

$$B_1 = \frac{F_R h_c}{\ell_{20} + \ell_{30}} \ (N)$$

$B_2 = F_R - B_1$, $\min B_2 = F_R/4$ (*N*)

$$B_3 = \frac{M_b}{\ell_{40}} \ (N)$$

$Q_1 = F_{R2}$ (*N*)

(e) Type *E* rudders

$$M_R = \frac{F_{R2}\ell_{10}}{2}\ (N\text{-}m)$$

$$M_b = \frac{F_R{\ell_{10}}^2}{10\ell_{20}}\ (N\text{-}m)$$

$$B_1 = \frac{F_R h_c}{\ell_{20}}\ (N)$$

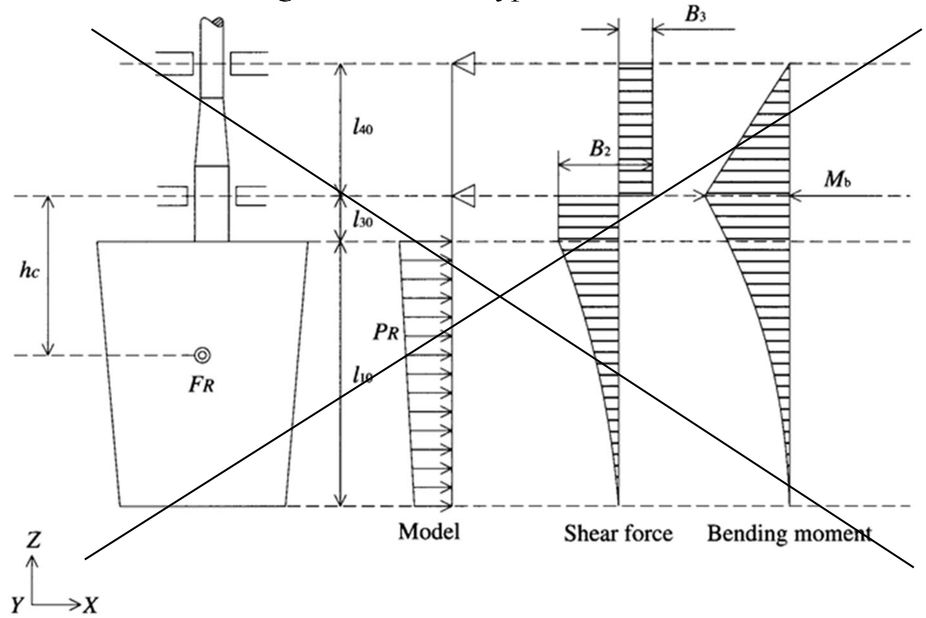
$$B_2 = F_R - B_1,\quad \min B_2 = F_R/4\ (N)$$

$$B_3 = \frac{M_b}{\ell_{40}}\ (N)$$

$$Q_1 = F_{R2}\ (N)$$

Fig. C13.2.4-3 has been amended as follows.

Fig. C13.2.4-3 Type *C* Rudder



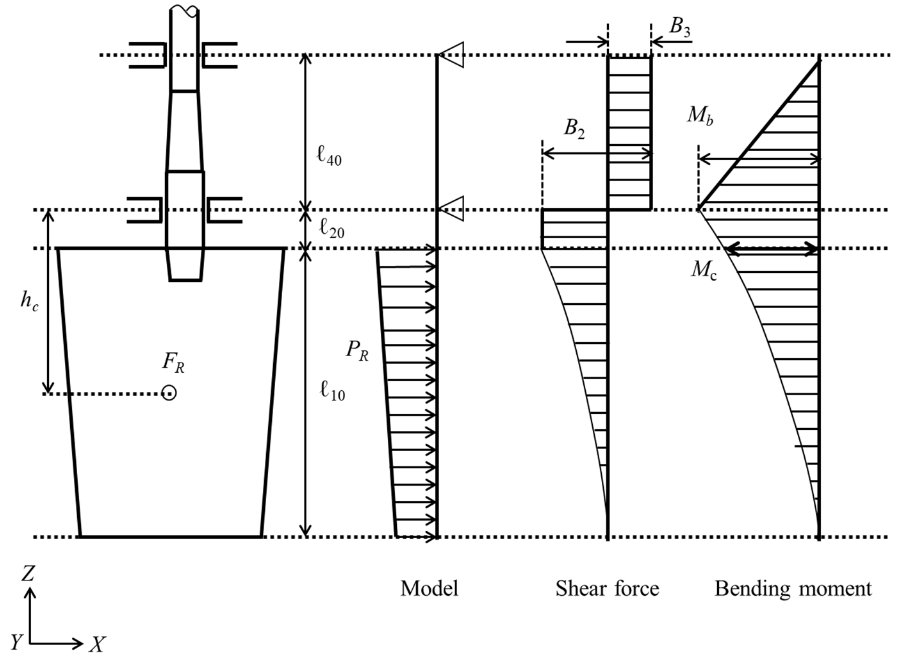


Fig. C13.2.4-4 Type *D* Rudder

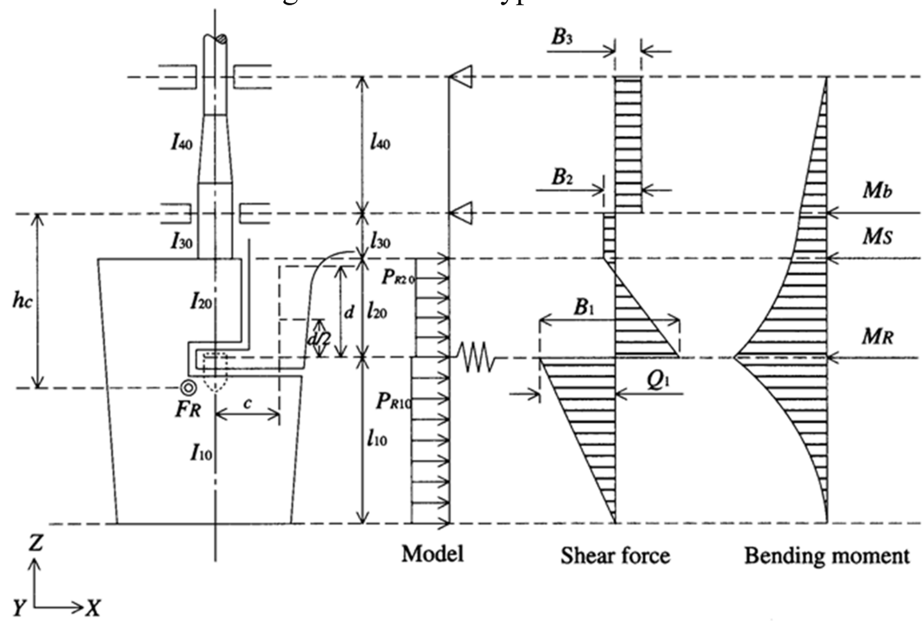
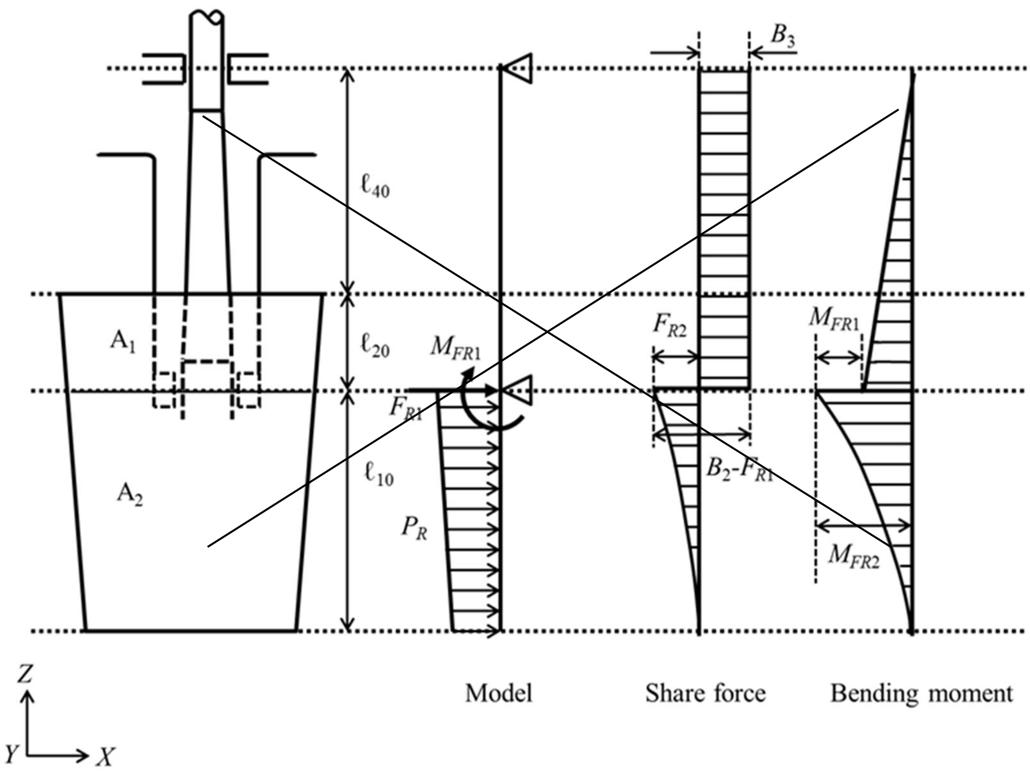


Fig. C13.2.4-6 has been amended as follows.

Fig. C13.2.4-6 Type *C* Rudder with Rudder Trunk Supporting Rudder Stock
(Pressure Applied on the Entire Rudder Area)



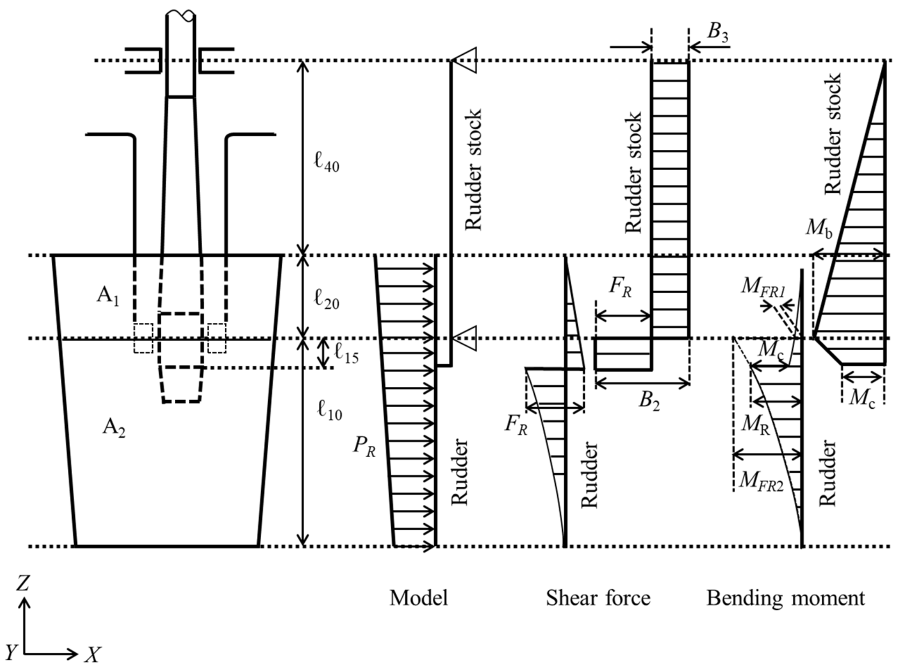


Fig. C13.2.4-7 has been renumbered to Fig. C13.2.4-8, and Fig. C13.2.4-7 has been added as follows.

Fig. C13.2.4-7 Type *C* Rudder with Rudder Trunk Supporting Rudder Stock (Pressure Applied only on Rudder Area below the Middle of Neck Bearing)

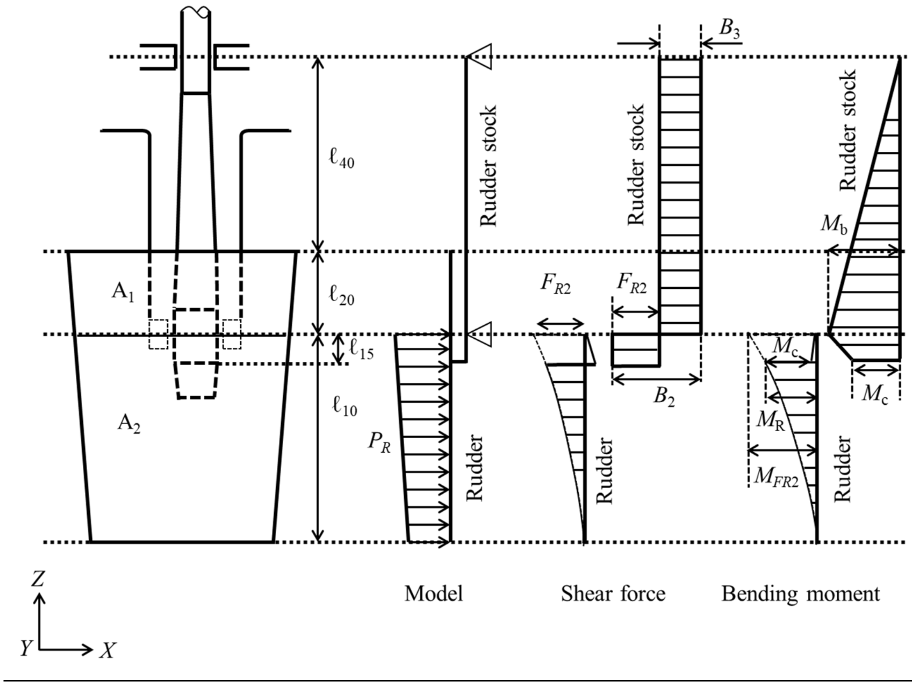


Fig. C13.2.4-~~7~~8 Type *D* Rudder with 2-conjugate Elastic Supports (Omitted)

C13.2.9 Pintles

Paragraph C13.2.9.2 has been amended as follows.

C13.2.9.2 Construction of Pintles

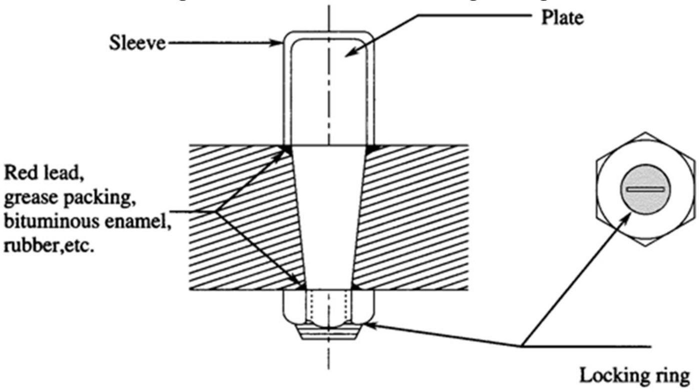
1 Split pins are not recommendable as the locking device for pintle nuts. Locking rings or other equivalent devices are to be used, as shown in **Fig. C13.2.9.~~2~~1**.

2 To prevent corrosion of pintles, the end of the sleeve is to be filled with red lead, grease packing, bituminous enamel, rubber, etc. as shown in **Fig. C13.2.9.~~2~~1**.

3 Combining pintles and rudder frames into monoblocks is not recommended.

4 For the reaction force in bearing *B* specified in **13.2.9.2-2, Part 1**, for example, B_1 defined in **Fig. C13.2.4-4** is used for Type *D* rudders.

Fig. C13.2.9-1 Locking Ring



Part CS HULL CONSTRUCTION AND EQUIPMENT OF SMALL SHIPS

CS3 RUDDERS

CS3.4 Rudder Strength Calculation

CS3.4.1 Rudder Strength Calculation

Sub-paragraph -3 has been amended as follows.

3 Method of evaluating moments and forces

The method of evaluating moments and forces is to be as in the following **(1)** to **(3)** below.

((1) and (2) are omitted.)

(3) Simplified method

The moments and forces for rudders of each type may be obtained from the following formulae.

(a) Type *A* rudders

$M_R = \frac{{B_1}^2(l_{10}+l_{30})}{2F_R}$ (*N*-*m*)

$M_b = \frac{B_3(l_{30}+l_{40})(l_{10}+l_{30})^2}{l_{10}^2}$ (*N*-*m*)

$M_s = B_3 l_{40}$ (*N*-*m*)

$B_1 = \frac{F_R h_c}{l_{10}}$ (*N*)

$B_2 = F_R - 0.8B_1 + B_3$ (*N*)

$B_3 = \frac{F_R {l_{10}}^2}{8l_{40}(l_{10}+l_{30}+l_{40})}$ (*N*)

(b) Type *B* rudders

$M_R = \frac{{B_1}^2 l_{10}}{2F_R}$ (*N*-*m*)

$M_b = B_3 l_{40}$ (*N*-*m*)

$M_s = \frac{3M_R l_{30}}{l_{10}+l_{30}}$ (*N*-*m*)

$B_1 = \frac{F_R h_c}{l_{10}+l_{30}}$ (*N*)

$B_2 = F_R - 0.8B_1 + B_3$

$B_3 = \frac{F_R(l_{10}+l_{30})^2}{8l_{40}(l_{10}+l_{30}+l_{40})}$ (*N*)

(c) Type *C* rudders

$M_b = F_R h_c$ (*N*-*m*)

$B_2 = F_R + B_3$ (*N*)

$B_3 = \frac{M_b}{l_{40}}$ (*N*)

The maximum moment M_c in top of the cone coupling (as shown in **Fig.13.2.4-3**) is applicable for the connection between the rudder and the rudder stocks.

Notwithstanding the above, ~~the value is as follow~~ the strength is to be checked against the following two cases for rudders with rudder trunks supporting rudder stocks.

i) pressure applied on the entire rudder area;

ii) pressure applied only on rudder area below the middle of the neck bearing.

The moments and forces for the two cases defined above may be determined according to **Fig. CS3.4.1-4** and **Fig. CS3.4.1-5**, respectively.

~~M_R is the greatest of the following values:~~

$M_{FR1} = F_{R1}\ (CG_{1Z} - l_{10})$

$M_{FR2} = F_{R2}\ (l_{10} - CG_{2Z})$

where A_1 and A_2 are the rudder blade area which are above the lower bearing and below respectively and symbols are as follows (*See* **Fig. CS3.4.1-4** and **Fig. CS3.4.1-5**)

F_{R1} : Rudder force over the rudder blade area A_1

F_{R2} : Rudder force over the rudder blade area A_2

CG_{1Z}: Vertical position of the centre of gravity of the rudder blade area A_1 from base

CG_{2Z}: Vertical position of the centre of gravity of the rudder blade area A_2 from base

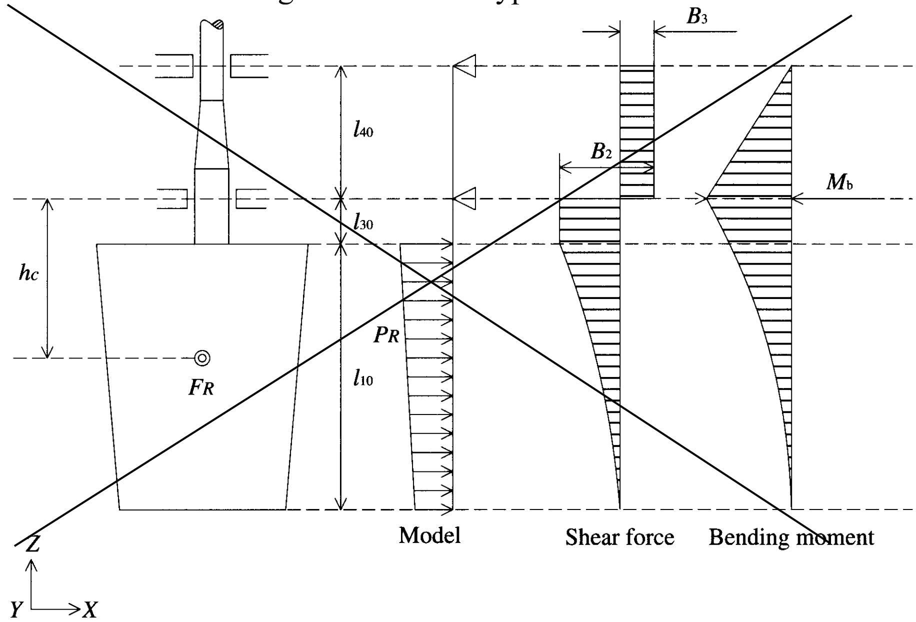
$F_R = F_{R1} + F_{R2}$

$B_2 = F_R + B_3$

$$B_3 = \frac{M_{FR2} - M_{FR1}}{\ell_{20} + \ell_{40}}$$

Fig. CS3.4.1-3 has been amended as follows.

Fig. CS3.4.1-3 Type *C* Rudder



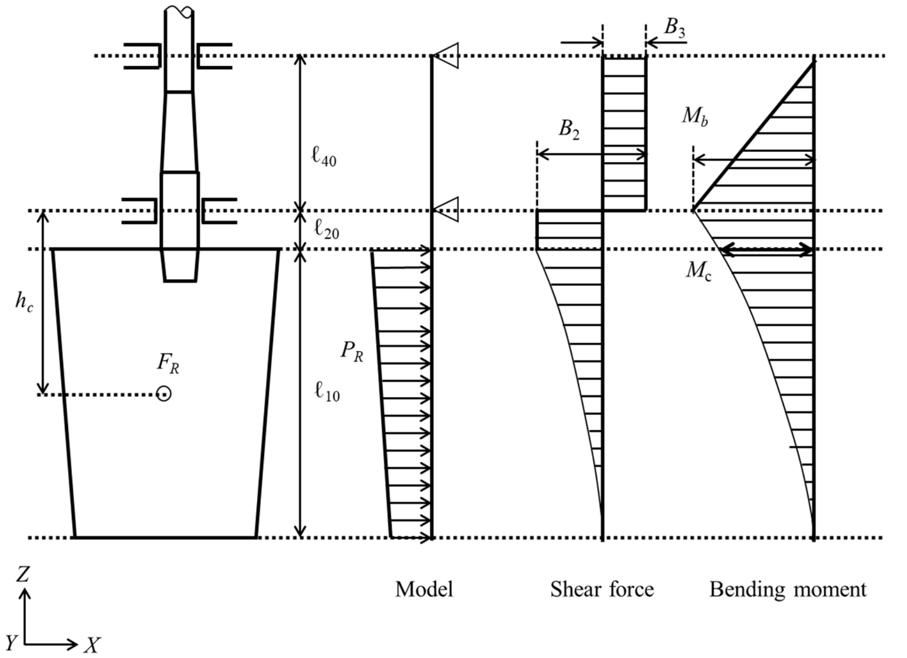
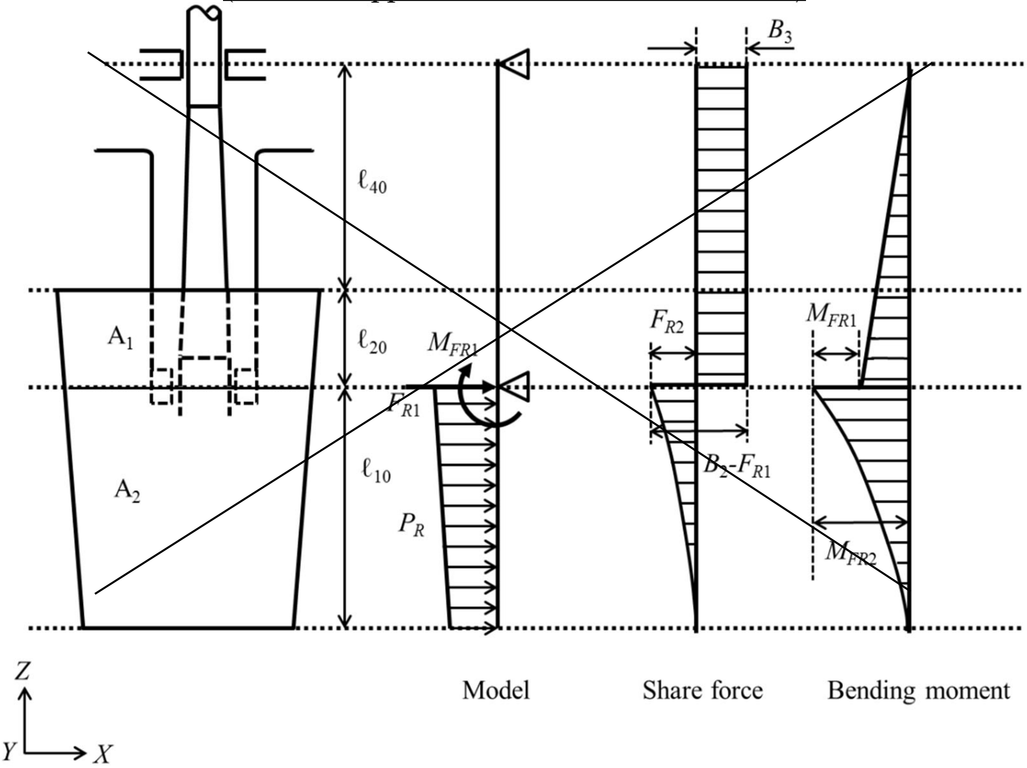


Fig. CS3.4.1-4 has been amended as follows.

Fig. CS3.4.1-4 Type *C* Rudder with Rudder Trunk Supporting Rudder Stock
(Pressure Applied on the Entire Rudder Area)



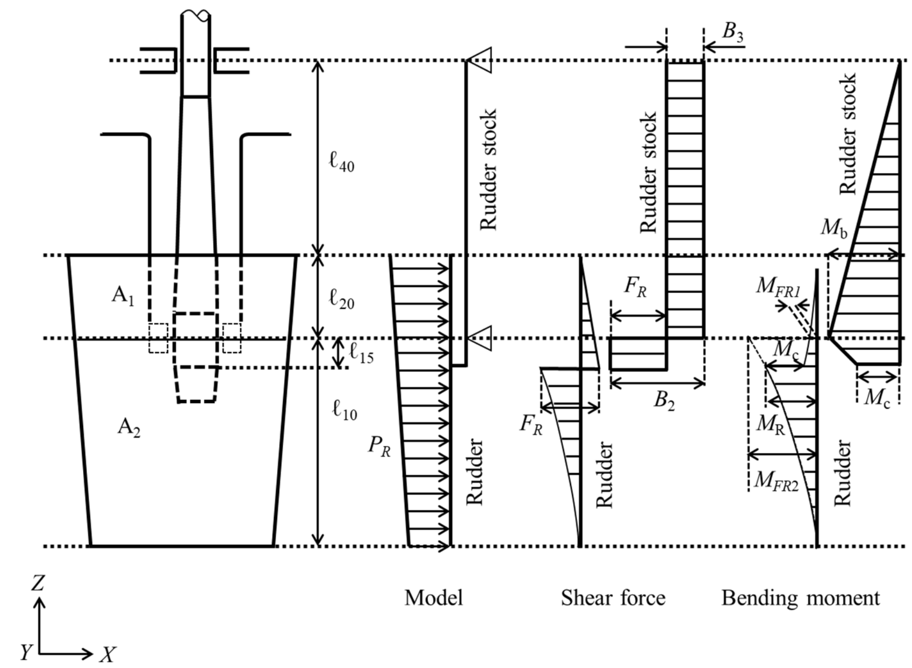
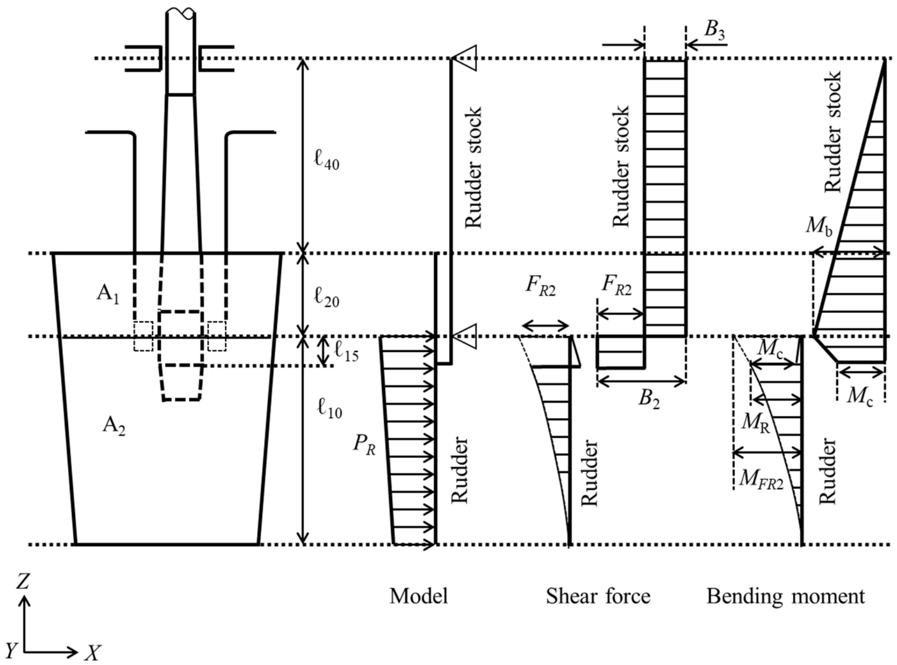


Fig. CS3.4.1-5 has been added as follows.

Fig. CS3.4.1-5 Type *C* Rudder with Rudder Trunk Supporting Rudder Stock
(Pressure applied only on rudder area below the middle of neck bearing)



CS3.12 Rudder Accessories

CS3.12.1 Rudder Carriers

Sub-paragraph -3 has been amended as follows.

3 Watertightness of rudder carrier part

(1) 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 at scantling draught (without trim), two separate watertight seals or stuffing boxes are to be provided.

(2) It is recommended that the packing gland in the stuffing box have an appropriate clearance from the rudder stock corresponding to the position of the stuffing box. The standard clearance is to be 4 *mm* for the stuffing box provided at the neck or intermediate bearing, and 2 *mm* for the stuffing box at the upper stock bearing.