DETAIL DESIGN 详 细 设 计	63,600DWT BULK CARRIER 63,600 吨散货船	SC4622(WH)-230-01JS

CURRENT REVISION 当前版本	A	CURRENT STATUS 当前状态	S	RUDDER CALCULATION 舵系计算书	HULL NO.: AVIC398/AVIC399			
DESIGNED 设 绘		DATE 日 期			WEIGHT 重 量	kg	SCALE 比 例	
CHECKED 校 对		DATE 日 期			PAGE 页 数	1 / 19	TOT. AREA 总面积	1.2 m^2
VERIFIED 审 核		DATE 日 期			SHANGHAI MERCHANT SHIP DESIGN & RESEARCH INSTITUTE 上海船舶研究设计院			
APPROVED 批 准		DATE 日 期						

面积AREA: 0.0625 m^2

1. Principal dimensions

Length between perpendiculars	L_{pp} = 194.50m
Length of water line at T	L_{wl} = 197.974m
Rule Length	L = 192.035m
Breath	B = 32.26 m
Depth	H = 18.50m
Scantling draught	T = 13.30 m
Designed draught	T = 11.30 m
Block coefficient	C_b = 0.877
Speed (at 85% C.M.C.R.)	V = 14.3kn
Service Speed (at 100% C.M.C.R./deepest seagoing draught)	V_o = 15.0kn
Restricted service	Unlimited range
Rudder profile	HSVA0018
Type of ship	Bulk Carrier ship

2. Size of rudder area

2.1 $A_{min} = C_1 C_2 C_3 C_4 \dfrac{1.75\,L\,T}{100}$

$= 0.9 \times 0.9 \times 0.8 \times 1.0 \times \dfrac{1.75 \times 192.035 \times 13.3}{100}$

$= 28.96 m^2$

A_{min} — The minimum rudder area to achieve sufficient manoeuvring.

$C_1 = 0.9$

$C_2 = 0.9$

$C_3 = 0.8$

$C_4 = 1.0$

2.2 The actual rudder area A. (see figure 1)

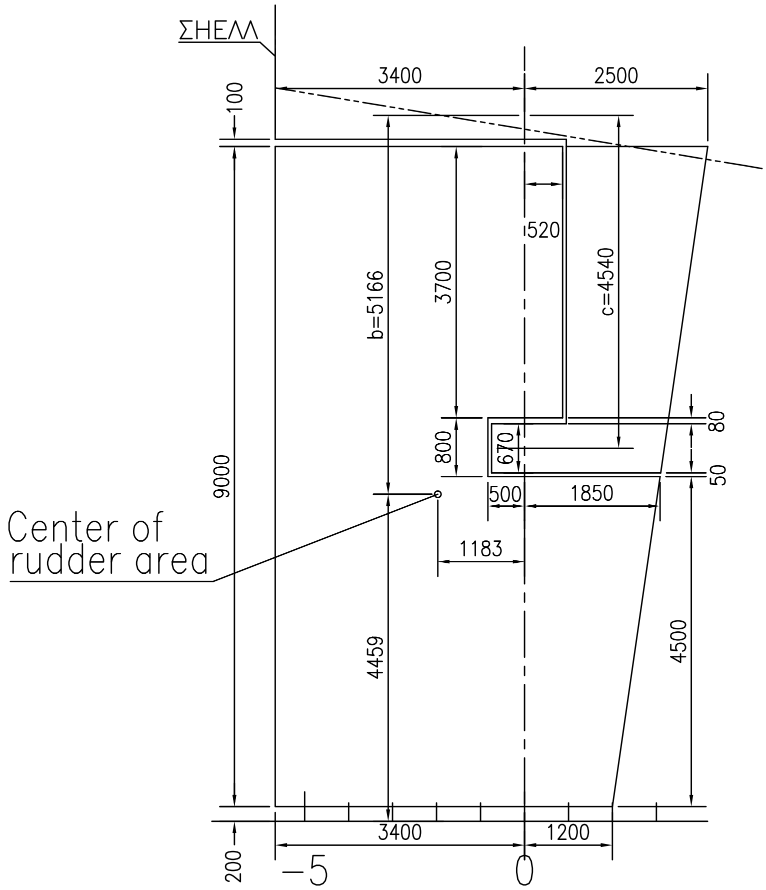

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figure 1

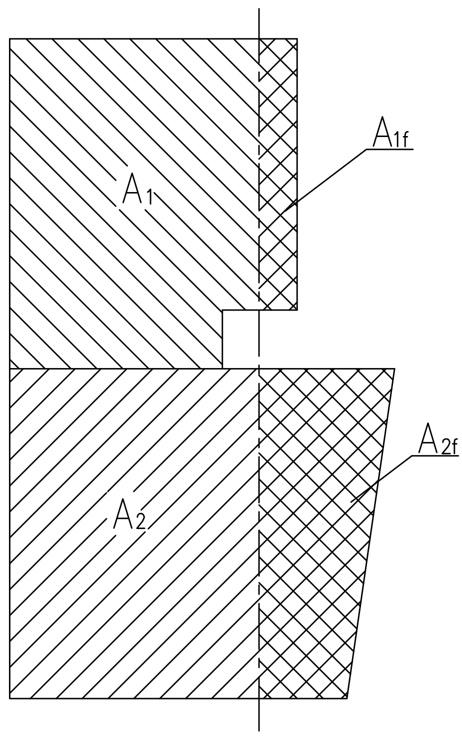

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figure 2

AREA: 面积 0.0625 m^2

$A = 38.9865 m^2$

$A' = 38.9865 m^2 + 0.5 x 7.840 m = 42.9065 m^2 > A_{min} = 28.96 m^2$

$$\frac{A'}{LxT} = \frac{42.9065}{192.035x13.3} \approx \frac{1}{60} > \frac{1}{65}$$

A+ area of the rudder horn $A_t = 46.8265 m^2$

Partial area $A_f = 8.7865 m^2$

A_f — portion area located ahead of the rudder stock axis.

Partial area (see figure 1) $A_1 = 16.824 m^2$

Partial area (see figure 1) $A_2 = 22.1625 m^2$

Partial area (see figure 1) $A_{1f} = 1.924 m^2$

Partial area (see figure 1) $A_{2f} = 6.8625 m^2$

Balancing ratio $k = 8.7865/38.9865 = 22.54\%$

3. Lateral force on rudder blade

3.1 Rudder force for ahead condition

$C_R = 132AV^2K_1K_2K_3K_t$

Where

$$\lambda = \frac{b^2}{A_t} = \frac{9.0^2}{46.8265} = 1.7297898$$

$$K_1 = \frac{\lambda+2}{3} = \frac{1.7297898+2}{3} = 1.2432633$$

$K_2 = 1.21$

$K_3 = 1$

$K_t = 1$

$A = 38.9865 m^2$

$V = V_0 = 15.0 kn$

$C_R = 132x38.9865x15.0^2x1.2432633x1.21x1x1$

$= 1741883.8 (N)$

3.2 Rudder force for astern condition

$C_R' = 132AV'^2K_1K_2K_3K_t$

Where

$$\lambda = \frac{b^2}{A_t} = \frac{9.0^2}{46.8265} = 1.7297898$$

$$K_1 = \frac{\lambda+2}{3} = \frac{1.7297898+2}{3} = 1.2432633$$

$K_2 = 0.9$

$K_3 = 1$

$K_t = 1$

$A = 38.9865 m^2$

$V = V_a = 14.4/2 = 7.2 (kn)$

$$C_R' = 132 x 38.9865 x 7.2^2 x 1.2432633 x 0.9 x 1 x 1$$
$$= 298509.939 (N)$$

4. Rudder torque calculation for rudders

4.1 Rudder torque for ahead condition

$Q_{R1} = C_{R1} \cdot r_1 \qquad Q_{R2} = C_{R2} \cdot r_2$

$$C_{R1} = C_R \frac{A_1}{A} = 1741883.8 x \frac{16.824}{38.9865} = 751682.071 (N)$$

$$C_{R2} = C_R \frac{A_2}{A} = 1741883.8 x \frac{22.1625}{38.9865} = 990201.729 (N)$$

Where

$r_1 = C_1(\alpha_1 - K_{b1})$

$r_2 = C_2(\alpha_2 - K_{b2})$

$$K_{b1} = \frac{A_{1f}}{A_1} = \frac{1.924}{16.824} = 0.1143604$$

$$K_{b2} = \frac{A_{2f}}{A_2} = \frac{6.8625}{22.1625} = 0.3096447$$

$$C_1 = \frac{A_1}{b_1} = \frac{16.824}{4.5} = 3.7386667(m)$$

$$C_2 = \frac{A_2}{b_2} = \frac{22.1625}{4.5} = 4.925(m)$$

$\alpha_1 = 0.25$ $\alpha_2 = 0.33$

$$r_1 = 3.7386667x(0.25-0.1143604)$$
$$= 0.5071113(m)$$

$$r_2 = 4.925x(0.33-0.3096447)$$
$$= 0.1002499(m)$$

$$Q_{R1} = 751682.071x0.5071113 = 381186.472(Nm)$$

$$Q_{R2} = 990201.729x0.1002499 = 99267.624(Nm)$$

$$Q_R = Q_{R1} + Q_{R2}$$
$$= 381186.472 + 99267.624$$
$$= 480454.096(Nm)$$

For ahead condition Q_R is not to be taken less than

$$Q_{Rmin} = C_R \cdot r_{1,2min}$$

$$r_{1,2min} = \frac{0.1}{A}(c_1 A_1 + c_2 A_2)$$
$$= \frac{0.1}{38.9865} x(3.7386667x16.824 + 4.925x22.1625)$$
$$= 0.441305684(m)$$

$$Q_{Rmin} = 1741883.8x0.441305684$$
$$= 768703.22(Nm)$$

4.2 Rudder torque for astern condition

$Q'_{R1} = C'_{R1} \cdot r'_1 \qquad Q'_{R2} = C'_{R2} \cdot r'_2$

$$C'_{R1} = C'_R \frac{A_1}{A} = 298509.939 \times \frac{16.824}{38.9865} = 128817.1858(N)$$

$$C'_{R2} = C'_R \frac{A_2}{A} = 298509.939 \times \frac{22.1625}{38.9865} = 169692.7532(N)$$

Where

$r'_1 = C_1(\alpha'_1 - K_{b1})$

$r'_2 = C_2(\alpha'_2 - K_{b2})$

$$K_{b1} = \frac{A_{1f}}{A_1} = \frac{1.924}{16.824} = 0.1143604$$

$$K_{b2} = \frac{A_{2f}}{A_2} = \frac{6.8625}{22.1625} = 0.3096447$$

$$C_1 = \frac{A_1}{b_1} = \frac{16.824}{4.5} = 3.7386667(m)$$

$$C_2 = \frac{A_2}{b_2} = \frac{22.1625}{4.5} = 4.925(m)$$

$\alpha'_1 = 0.55 \qquad \alpha'_2 = 0.66$

$r'_1 = 3.7386667 \times (0.55 - 0.1143604)$
$= 1.628711251(m)$

$r'_2 = 4.925 \times (0.66 - 0.3096447)$
$= 1.7254998525(m)$

$Q'_{R1} = 128817.1858 \times 1.628711251 = 209806.0(Nm)$

$Q'_{R2} = 169692.7532 \times 1.72549985255 = 292804.82(Nm)$

$Q'_R = Q'_{R1} + Q'_{R2}$
$= 209806.0 + 292804.82$
$= 502610.82(Nm)$

AREA: 面积 0.0625 m²

5. Selection of Steering Gear

Steering Gear type selected:

Proof Factor=960/768.7=1.248

6. Rudder stock diameter

$$D_t = 4.2\sqrt[3]{Q_R \cdot k_r}$$

$R_{eH} = 260 N/mm^2$

$$k_r = \left(\frac{235}{R_{eH}}\right)^{0.75} = \left(\frac{235}{260}\right)^{0.75} = 0.9269811$$

$Q_R = 768703.22 Nm$

$$D_t = 4.2\sqrt[3]{Q_R \cdot k_r}$$

$$= 4.2 x \sqrt[3]{768703.22 x 0.9269811}$$

$$= 375.14 (mm)$$

D_1—— increased rudder stock diameter

$$D_1 = 0.1 D_t \sqrt[6]{1 + \frac{4}{3}\left(\frac{M_b}{Q_R}\right)^2}$$

REFER LR RULE RECOMMEND:

$$M_b = \frac{h_R}{10(1+C^r)} C_R \qquad C_r = \frac{{b_R}^2}{A}$$

$$b_R = \frac{A}{9.0} = \frac{38.9865}{9.0} = 4.3318333$$

$$C_r = \frac{{b_R}^2}{A} = \frac{4.3318333^2}{38.9865} = 0.4813148 \qquad h_R = 9.0 (m)$$

$$M_b = \frac{h_R}{10(1+C_r)} C_R = \frac{9.0}{10x(1+0.4813148)} x1741883.8$$

$$= 1058313.479 (Nm)$$

$$D_1 = 0.1 x 375.14 x \sqrt[6]{1 + \frac{4}{3}\left(\frac{1058313.5}{768703.22}\right)^2}$$

$$= 46.28 (cm)$$

The actual D_1 adopted is 480mm

$$\sigma_V = \sqrt{\sigma_b^2 + 3\tau^2}$$

$$\sigma_b = \frac{10.2M_b}{D_1^3}$$

$$= \frac{10.2x1058314}{48^3} = 97.61(N/mm^2)$$

$$\tau = \frac{5.1Q_R}{D_1^3}$$

$$= \frac{5.1x768703.22}{48^3} = 35.45(N/mm^2)$$

$$\sigma_e = \sqrt{97.61^2 + 3x35.45^2}$$

$$= 115.32(N/mm^2) < 127.29(N/mm^2)$$

$$\frac{118}{k_r} = \frac{118}{0.9269811} = 127.29(N/mm^2)$$

7. Pintle diameter

$$d = 0.35x\sqrt{B_1 \cdot k_r}$$

$$B_1 = C_R \cdot \frac{b}{c}$$

C_R=1741883.8N

b=5166mm

c=4540mm

R_{eH}=260N/mm^2

$$k_r = \left(\frac{235}{R_{eH}}\right)^{0.75} = \left(\frac{235}{260}\right)^{0.75} = 0.9269811$$

$$B_1 = 1741883.8x\frac{5166}{4540}$$

$$= 1982064(N)$$

$$d = 0.35x\sqrt{1982064x0.9269811}$$

$$= 474.42(mm)$$

The actual d adopted is 500mm

8. Required mean grip stress-keyless connection

8.1 Push-up pressure

$$P_{req1}=\frac{2Q_F}{d_m^2 L\pi\mu_o}x10^3$$

$$P_{req2}=\frac{6M_b}{L^2 d_m}x10^3$$

Selete $D_t=D_{ta}$ $k_r=0.9269811$

$$Q_F=0.02664\ \frac{D_t^3}{K_r}$$

$$Q_F=0.02664x\frac{480^3}{0.9269811}=3178242.7(Nm)$$

$d_m=451.34mm$

$L=850mm$

$\mu_o=0.15$

$M_b=1058314Nm$

$$P_{req1}=\frac{2x3178242.7}{451.34^2x850x3.14x0.15}\ x10^3$$

$$=77.94(N/mm^2)$$

$$P_{req2}=\frac{6x1058314}{850^2x451.34}\ x10^3$$

$$=19.47(N/mm^2)$$

$$P_{perm}=\frac{0.8R_{eH}(1-\alpha^2)}{\sqrt{3+\alpha^4}}$$

$R_{eH}=230(N/mm^2)$ $d_a=990mm$

$$\alpha=\frac{d_m}{d_a}=\frac{451.34}{990}=0.4558989$$

$$P_{perm}=\frac{0.8x230x(1-0.4558989^2)}{\sqrt{3+0.4558989^4}}$$

$$=83.55\ (N/mm^2)$$

$$P_{req2}<P_{req1}<P_{perm}$$

8.2 Push-up length

$$\triangle L_1=\frac{P_{req}\,d_m}{E(\frac{1-\alpha^2}{2})c}+\frac{0.8R_{tm}}{c}$$

$R_{tm}=0.01mm$

$c=\frac{1}{15}$

$E=2.06x10^2$

$$\triangle L_1=\frac{77.94x451.34}{2.06x10^5x(\frac{1-0.4558989^2}{2})x\frac{1}{15}}+\frac{0.8x0.01}{\frac{1}{15}}$$

$= 6.587(mm)$

$$\triangle L_2=\frac{1.6R_{eH}d_m}{Ec\sqrt{3+\alpha^4}}+\frac{0.8R_{tm}}{c}$$

$$\triangle L_2=\frac{1.6x230x451.3}{}$$

pintle bearing

$B_1=1982064N$ $d_m=478mm$

$d_0=500mm$ $L=650mm$

$$P_{req}=0.4x\frac{1982064x500}{478^2x650}$$

$= 2.67(N/mm^2)$

AREA: 面积 0.0625 m²

8.5 Shear area of flat bar

$$A_S = \frac{P_S\sqrt{3}}{R_{eH}}$$

$$P_S = \frac{P_e}{2} m_1 [\frac{d1}{dg} - 0.6]$$

$P_e = 5007391.3(N)$ $d1 = 550$

$m_1 = 0.3$ $dg = 380$

$R_{eH} = 355 N/mm^2$

$$A_S = \frac{\frac{5007391.3}{2} x0.3x(\frac{550}{380} - 0.6)x\sqrt{3}}{355}$$

$= 3105(mm^2)$

The actual A_S adopted is $100x35=3500(mm)^2$

9. The section at 4700 to B.L.

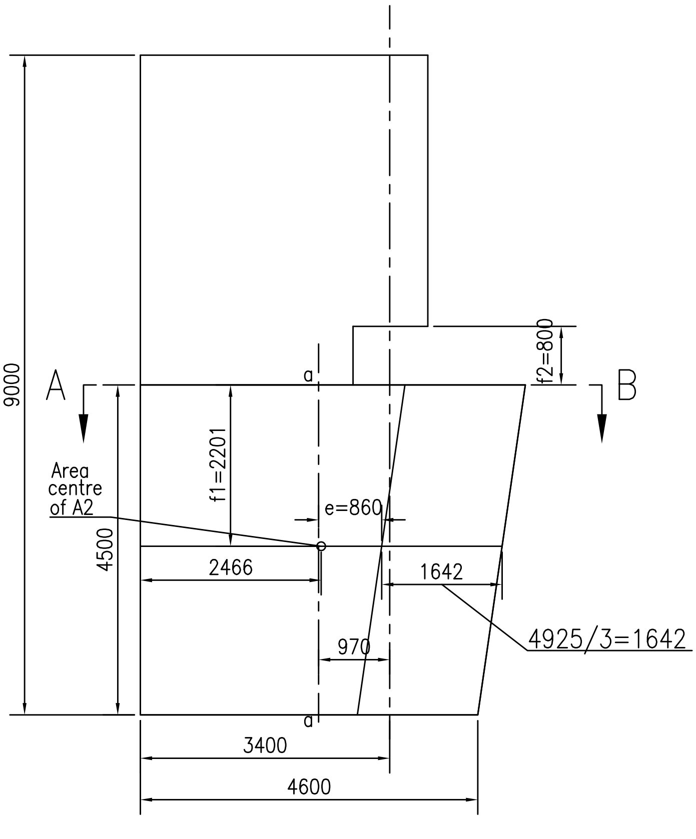

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figure 3

AREA: 面积 $0.0625 m^2$

A-B

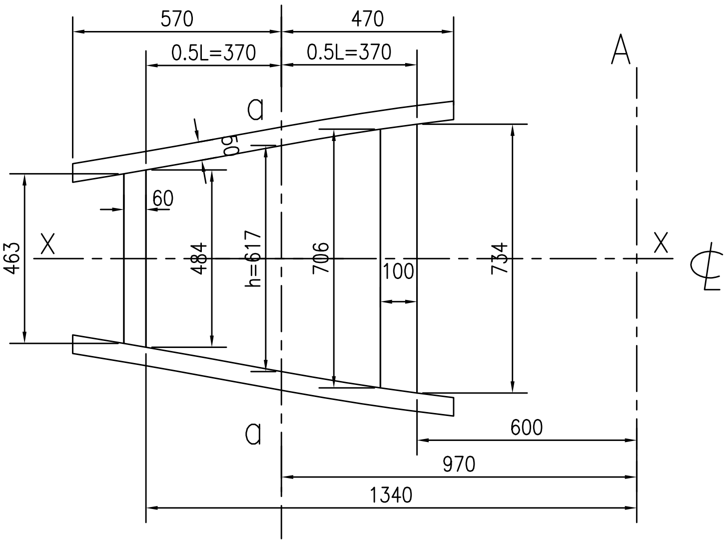

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figure 4

Section moment of inertia: $I_{4700}=1492883.85cm^4$

$h=61.7cm$

$L=74cm<61.7*1.2=74.04cm$

$t=5.0cm$

$$M_R=C_{R2}\,x f_1+B_1\,x0.5f_2$$

$C_{R2}=990201.729N$

$f_1=2201mm$

$f_2=800mm$

$B_1=1982064N$

$$M_R=990201.729x2201+1982064x0.5x800$$
$$=2972259606(Nmm)$$

The torsional stress

$$\tau_t=\frac{M_t}{2Lht} \qquad e=0.860m$$

$$M_t=C_{R2}\,e=990201.729x0.860=851573.487\ (Nm)$$

$$\tau_t=\frac{851573.487}{2x74x61.7x5.0}=18.65(N/mm^2)<50(N/mm^2)$$

area of vertical plate

$A_1=(70.6+73.4)\times10/2=720$

$A_2=(48.4+46.3)\times6/2=284.1$

$A'=A_1+A_2=1004.1$

Bending stress

$$W_x=\frac{I_{4700}}{73.4/2}=\frac{1492883.85}{73.4/2}=40678.034\ (cm^3)$$

$$\sigma_b=\frac{M_R}{W_x}=\frac{2972259606}{40678.034}=73.07(N/mm^2)<75(N/mm^2)$$

Shear stress

$$\tau=\frac{C_{r2}}{A'}=\frac{990201.729}{(720+284.1)\times100}=9.86(N/mm^2)<50(N/mm^2)$$

$$\sigma_{v1}=\sqrt{\sigma_b^2+3\tau^2}=\sqrt{73.07^2+3\times9.86^2}=75.04<100(N/mm^2)$$

$$\sigma_{v2}=\sqrt{\sigma_b^2+3\tau_t^2}=\sqrt{73.07^2+3\times18.65^2}=79.89<100(N/mm^2)$$

10. Rudder plating

10.1 Rudder side, top and bottom plate

$$t_p=1.74a\sqrt{P_R k}+2.5$$

$$P_R=10T+\frac{C_R}{10^3 A}$$

$a=0.630m$ $k=1$

$T=13.30m$

$C_R=1741883.8N$

$A=38.987m^2$

$$P_R=10x13.3+\frac{1741883.8}{10^3 x38.987}$$

$$=177.68[kN/m^2]$$

$$t_p=1.74x0.630x\sqrt{177.68x1}+2.5$$

$$=17.11(mm)$$

10.2 Webs (vertical and horizontal)

$$t_W=0.7t_p=0.7x17.11=11.977(mm)$$

11. Connections of rudder blade structure with solid parts in forged or cast steel

11.1 Minimum section modulus of the connection with the rudder stock housing

$$W_s=c_s D_1^3\left(\frac{H_E-H_X}{H_E}\right)^2\frac{K}{K_1}10^{-4}$$

$c_s=1.5$

$D_1=480mm$

$H_E=9.00m$

$H_X=1.10m$

$K=1$

$K_1=0.9269811$

$$W_s=1.5x480^3x\left(\frac{9.00-1.10}{9.00}\right)^2x\frac{1}{0.9269811}x10^{-4}$$

$$=13788.4(cm^3)$$

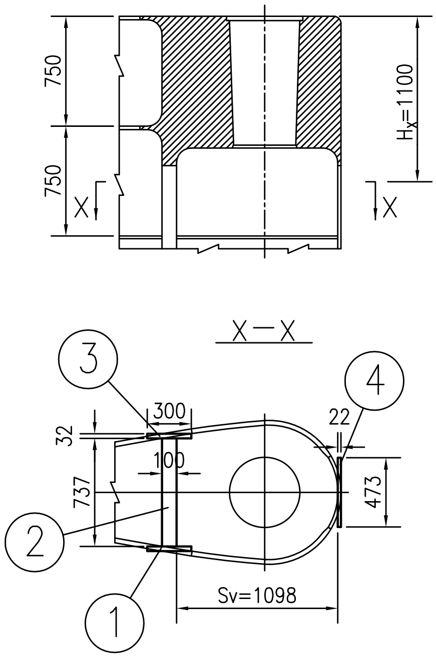

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figure 5

	Length x Breath	Area	Area center to center line of rudder ℄	Inertia to center line of rudder ℄
	cm x cm	cm^2	cm	cm^4
①	30x3.2	96	38.5	142377.92
②	10x73.7	737	0	333596.3
③	30x3.2	96	38.5	142377.92
④	2.2x47.3	104.06	0	19401.033
Total				637753.17

Section moment of inertia: $I_{x-x} = 637753.17 cm^4$

$$W_{x-x} = \frac{637753.17}{73.7/2} = 17306.735$$

11.2 Minimum section modulus of the connection with the rudder pintle housing

$$W_s = c_s D_1^3 \left(\frac{H_E - H_X}{H_E}\right)^2 \frac{K}{K_1} 10^{-4}$$

$c_s = 1.5$

$D_1 = 500mm$

$H_E = 9.00m$

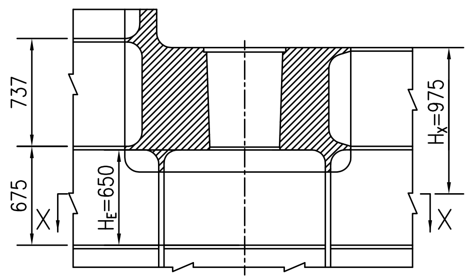
$H_X = 0.975m$

$K = 1$

$K_1 = 0.9269811$

$$W_s = 1.5 x 500^3 x \left(\frac{9.00 - 0.975}{9.00}\right)^2 x \frac{1}{0.9269811} x 10^{-4}$$

$$= 16081.83 (cm^3)$$



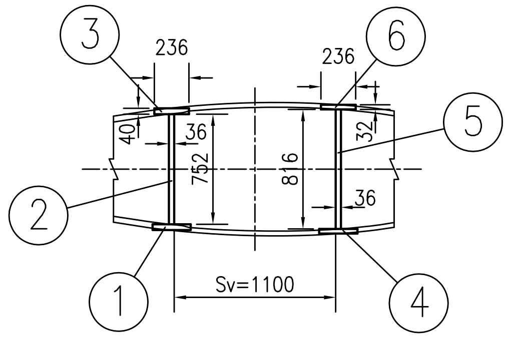


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figure 6

	Length x Breath	Area	Area center to center line of rudder ℄	Inertia to center line of rudder ℄
	cm x cm	cm^2	cm	cm^4
①	23.6x4.0	94.4	39.6	148160.17
②	3.6x75.2	270.72	0	127577.7
③	23.6x4.0	94.4	39.6	148160.17
④	23.6x3.2	75.52	42.4	135831.28
⑤	3.6x81.6	293.76	0	163001.5
⑥	23.6x3.2	75.52	42.4	135831.28
Total				858562.1

Section moment of inertia: I_{x-x} =858562.1cm^4

$$W_{x-x}=\frac{858562.1}{81.6/2}=21043.189$$

11.3 Calculation of the actual section modulus of the connection with the rudder stock

$$b=s_v+2\frac{H_x}{m}$$

Sv=1.098m

Hx=0.3m

m=3

$$b=1.098+2x\frac{0.3}{3}$$

$=1.298(m)$

11.4 Calculation of the actual section modulus of the connection with the rudder pintle

$$b=s_v+2\frac{H_x}{m}$$

$S_v=1.1m$

$H_X=0.3m$

$m=3$

$$b=1.1+2\times\frac{0.3}{3}$$

$$=1.3(m)$$

11.5 Thickness of horizontal web plates

$t_H=1.2t_P$ $\quad t_H=0.045\frac{d_s^2}{S_H}$ $\quad t_P=17.11mm$

$d_s=480mm$

$S_H=750mm$

$$t_H=1.2\times17.11=20.532(mm)$$

t_H for the solid part connected to the stock

$$t_H=0.045\times\frac{480^2}{750}$$

$$=13.824(mm)$$

t_H for the solid part connected to the pintle

$$t_H=0.045\times\frac{500^2}{675}$$

$$=16.67(mm)$$