

Kevlar/Glass Hybrid 艇への適用 (その 1)

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Application to K/G Hybrid FRP Craft Strength Design Part I

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Abstract

In this Paper application of our computational formulae to the design of 23 meter Kevlar/Glass Hybrid crafts is described in detail. Availability of these formulae must be examined by trial tests and follow-up test results after constructed in future.

1. 概 要

この論文は、前述した船殻構造設計法の諸計算式を用いて Kevlar/Glass Hybrid 艇 (その 1) を設計する場合、その手順について詳しく述べることにする。この場合、適用の合理性については、将来もし建造された場合、その艇の試運転成績と船体の強度につき継続的な計測結果を検討し、それら成果の良否によるものと考えられる。

2. 序 論

東大金原研究室、東レ KK、日本板硝子 KK、日本硝子繊維 KK、の合同研究により下記の資料を発表している。

題目：船艇用ケブラーハイブリッド積層板の力学特性と材料設計

〔静的特性：S 63 年 10 月、動的特性：H 02 年 11 月、静的特性：H 04 年 02 月〕

此の中の日本硝子繊維試作品の K/G Hybrid Cloth の材料記号 H1(G) についての強度特性を主に、研究未了の G_{LT} を推定値とした材料特性を使用して、23 m 30 KT 哨戒艇を試設計した。

Bottom Longitudinal, Deck・Side Shell Transverse

の Combined System にて、Balsa Coa Sandwich Panel を全面的に使用した。Trans Bulkhead のみ K/G Hybrid FRP 単板である。全構造は橋本の設計式を用いて計算する。

Kevlar 繊維は、hand layup では比重差による含浸性の不良により、施工法を検討する必要がある。

又、圧縮強度のみが GFRP と大差なく低いため、構造材として曲げ強度を適用できる分野を解明する必要がある。厚手の織物の作製も考慮すれば、素材、加工、設計の面で将来性を期待される新素材である。

3. 要 目 等

$LBDd = 23.0 \text{ m} \times 5.5 \text{ m} \times 2.5 \text{ m} \times 0.85 \text{ m}$

$WVA_F = 31 \text{ T} \times 30 \text{ KT} \times 6 \text{ g}$

主機関 MTU8V331 TC71~81 MAX900HP×2

3.1 重量配分

$C \times LBD = W_n$

船殻 $0.04120 \times 316.25 = 13.032 \text{ (Ton)}$

縦材：671.37 (cm²/m)、横材：50.40 (cm²/m)、小計：721.77 (cm²/m)、

$W_h = 721.77 \times L \cdot \rho_m / 2,000 = 13.037 \text{ (Ton)}$

ぎ装 $0.00886 \times 316.25 = 2.801 \text{ (Ton)}$

固斉 $0.00154 \times 316.25 = 0.487 \text{ (Ton)}$

機関 $0.00172 \times 1,800 = 3.092 \text{ (Ton)}$

機関ぎ装 $0.000295 \times 1,800 = 0.531 \text{ (Ton)}$

一般斉備 1.440 (Ton)

1992 年 9 月 24 日受理

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航海光学	0.080 (Ton)
銃砲	1.136 (Ton)
電気	1.435 (Ton)
通信情報	0.200 (Ton)
燃料	5.137 (Ton)
小計	29.371 (Ton)
余裕 (5.25%)	1.629 (Ton)
合計	31.000 (Ton)

3.2 区画長さ 主機械室=6.000 (m),

科員室=6.000 (m) 横肋骨心距=1.500 (m)

3.3 K/G Hybrid FRP (G シリーズ) 強度特性

$$E_{t0}^{\circ}, E_{c0}^{\circ}, E_{b0}^{\circ} = E_{f0}^{\circ} = 2.5 \times 10^5 \text{ (kgf/cm}^2\text{)}$$

$$G_f = 0.27 \times 10^5 \text{ (kgf/cm}^2\text{)},$$

(アンダーラインは推定値を示す)

$$\sigma_{fT0}^{\circ} = 4,230 \text{ (kgf/cm}^2\text{)}, \sigma_{fc0}^{\circ} = 1,840 \text{ (kgf/cm}^2\text{)}$$

$$\sigma_{fB0}^{\circ} = 2,980 \text{ (kgf/cm}^2\text{)}, \tau_{EW0}^{\circ} = 1,560 \text{ (kgf/cm}^2\text{)}$$

$$\tau_{IL0}^{\circ} = 250 \text{ (kgf/cm}^2\text{)},$$

$$E_{t90}^{\circ}, E_{c90}^{\circ}, E_{b90}^{\circ} = E_{f90}^{\circ} = 2.0 \times 10^5 \text{ (kgf/cm}^2\text{)}$$

$$\sigma_{fT90}^{\circ} = 3,480 \text{ (kgf/cm}^2\text{)},$$

$$\sigma_{fc90}^{\circ} = 1,610 \text{ (kgf/cm}^2\text{)},$$

$$\sigma_{fB90}^{\circ} = 2,640 \text{ (kgf/cm}^2\text{)},$$

$$\tau_{EW90}^{\circ} = 1,400 \text{ (kgf/cm}^2\text{)},$$

$$\tau_{IL90}^{\circ} = 195 \text{ (kgf/cm}^2\text{)},$$

$$\mu_0^{\circ} \times \mu_{90}^{\circ} = 0.150 \times 0.090, \lambda = 0.9865$$

$$\rho_m = 1.57 \times 10^{-3} \text{ (kgf/cm}^3\text{)}, H = 0.0674 \text{ (cm)}$$

3.4 Balsa Coa 強度特性

$$E_{CT} = 1500 \text{ (kgf/cm}^2\text{)}, F_{CL} = 0.45 \times 10^5 \text{ (kgf/cm}^2\text{)}$$

$$G_C = 562 \text{ (kgf/cm}^2\text{)}, \rho_C = 0.15 \times 10^{-3} \text{ (kgf/cm}^3\text{)}$$

4. 規定荷重

4.1 船底衝撃水圧: P_1 (丹羽式)

$$\beta_t = 12.92^{\circ}, B_c = 5.25 \text{ (m)}, V/W^{1/6} = 16.93$$

$$L \cdot V/W^{1/6} = 389, \alpha = 1 + 0.05(\beta_t - 5) = 1.396$$

$$l_N = (L/10)[4 + (V/10W^{1/6})] = 9.68 \text{ (m)} = 0.42L$$

$$C_T = V/25W^{1/6} = 0.6772$$

$$C_X = [1 - (1 - C_T)(x - l_N)/(L - l_N)] = 0.847$$

$$X = 16\text{cm} \text{ 主機械室中央}$$

$$(1) \text{ 式より, } P_0 = (V^2/1,000) + [(1 + \alpha \cdot A_F)W/(L \cdot B_c)] \\ = 3.307 \text{ (kgf/cm}^2\text{)}$$

$$(2) \text{ 式より, } P_1 = [(30^2/1,000) + (1 + 1.396 \times 6) \times 31 \\ \div (23 \times 5.25)] \times K \cdot C_X \text{ (kgf/cm}^2\text{)}$$

Table 1. 船底衝撃水圧値

Panel No.	2	3
β (deg)	24.25°	
$K_{1\beta} = (5/(\beta - 5))^{2/3}$	0.4071	
$K_{2\beta} = (5/(\beta - \beta_t - 5))^{2/3}$	0.8545	
$K = K_{1\beta} + [(K_{2\beta} - K_{1\beta})(V/W^{1/6}) - 1.0]/15$	0.6138	
主機械室 P_{1E} (kgf/cm ²) ($C_X = 0.847$)	1.719	
科員室 P_{1C} (kgf/cm ²) ($C_X = 1.0$)	2.030	

4.2 甲板水圧: P_2 (kgf/cm²)

$$P_2 = 0.026(0.02L + 0.76) = 0.032$$

4.3 船側水圧: P_3 (kgf/cm²)

$$P_3 = (1/4)(P_1 + 2P_2) = (1/4)(P_1 + 0.064)$$

Table 2. 船体衝撃水圧荷重 単位(kgf/cm²)

	$P_0 = 3.307$	P_2	P_3
	P_1		
主機械室	1.719	0.032	0.446
科員区画	2.030		0.524

4.4 船体縦曲げモーメント

$$F_{\beta} = (29 - \beta_t)/(39 - \beta_t) = 0.6166, \beta_t = 12.92^{\circ}$$

$$M_s = [W \cdot L(A_F + 1)/60F_{\beta}]$$

$$= [31 \times 23 \times (6 + 1)/(60 \times 0.6166)]$$

$$= 134.9 \text{ (Tonf} \cdot \text{m)}$$

$$M_H = 0.45M_s = 60.7 \text{ (Ton} \cdot \text{m)}$$

4.5 最大剪断力

$$F_H = [W(A_F + 1)/60F_{\beta}]$$

$$= [31 \times (6 + 1)/(60 \times 0.6166)] = 5.87 \text{ (Tonf)}$$

4.6 船体縦曲げ応力

Table 3. 船体縦曲げ応力 単位(kgf/cm²)

	σ_{TH}	σ_{BK}	$\sigma_{x1.4} = 0.75\sigma_{BK}$
σ_H (Sag)	+154	-126	-94.5
σ_H (Hog)	-69.4	+56.6	+42.5

5. 船底サンドイッチパネル外板設計

$$\begin{aligned}
 P_1 &= 2.03 \text{ (kgf/cm}^2\text{)}, l_0 = b = a_L = 600 \text{ (cm)}, \\
 S &= b_T = a = 114 \text{ (cm)}, V/W^{1/6} = 16.93, \\
 L \cdot V/W^{1/6} &= 389 \\
 \beta_t &= 12.92^\circ, V = 30 \text{ (KT)} \\
 \text{Table 4 より, } C_2 &= 0.04(41.25 - V) = 0.45 \overline{C_{2\min}} \\
 \text{Table 5 より, } K_X &= 0.316/(E_{f0}^\circ \times 10^{-5})^{0.123} \\
 &= 0.316/(2.5)^{0.123} = 0.282
 \end{aligned}$$

5.1 船底サンドイッチ寸法

$$\overline{SF}_1 = 2.5K_E = 2.5$$

$$\begin{aligned}
 \text{Table 23. より, } N_1 &= 340K_E/(V/W^{1/6})^{0.29} \\
 &= 340 \times 1/(16.93)^{0.29} = 150
 \end{aligned}$$

$$K_E = \sqrt[3]{E_{f0}^\circ \times 10^{-5}/2.5} = \sqrt[3]{2.5/2.5} = 1$$

(57) 式より,

$$\begin{aligned}
 t_F &= 0.35K_X \cdot S \cdot \overline{C_n} \sqrt{P_1 \cdot \overline{SF}_1 / \sigma_{FB}^\circ} \\
 &= 0.35 \times 0.282 \times 114 \times 0.45 \sqrt{2.03 \times 2.5 / 2,980} \\
 &= 0.209 \text{ (cm)}
 \end{aligned}$$

表皮厚設計値 $t_{Fd} = H3 = 0.202 \text{ (cm)}$

$$t_{\min} = 2.7 t_{Fd} = 0.545 \text{ (cm)}$$

$$\begin{aligned}
 \text{(56) 式より, } \sigma_{HC1} &= \sigma_{fC0}^\circ / \overline{SF}_1 = (1,840/2.5) \\
 &= 736 \text{ (kgf/cm}^2\text{)}
 \end{aligned}$$

$$\overline{SF}_1 = 2.5K_E = 2.5$$

(59) 式より,

$$\begin{aligned}
 t &= (C_1 \cdot a \cdot \sigma_{fC0}^\circ \cdot N_1) / (C_7 \cdot E_{f0}^\circ \cdot \overline{SF}_1) \\
 &= (12 \times 114 \times 1,840 \times 150) / (192 \times 2.5 \times 10^5 \times 2.5) \\
 &= 3.147 \text{ (cm)} > t_{\min} = 0.545 \text{ (cm)}
 \end{aligned}$$

$$\begin{aligned}
 \text{(60) 式より, } t_c &= (t - 2t_{Fd}) = 3.147 - (2 \times 0.202) \\
 &= 2.74 \text{ (cm)}
 \end{aligned}$$

$$\begin{aligned}
 t_{Cd} &= (1.58\text{Balsa}) + 0.12 + (1.58\text{Balsa}) \\
 &= 3.28 \text{ (cm)}
 \end{aligned}$$

$$\text{(61) 式より, } t_d = (t_{Cd} + 2t_{Fd}) = 3.684 \text{ (cm)}$$

$$\text{(62) 式より, } e_{1d} = (1/2)(t_{Cd} + t_{Fd}) = 1.741 \text{ (cm)}$$

$$\begin{aligned}
 t_d &= (t_{Fd} + t_{Cd} + t_{Fd}) \\
 &= (2.02 + 32.80 + 2.02) \\
 &= 36.84 \text{ (mm)}
 \end{aligned}$$

船底サンドイッチ有効板厚合計値

$$T_F = 2 \times 0.202 = 0.404 \text{ (cm)}$$

5.2 サンドイッチ縦座屈安全率計算

(63) 式より,

$$\begin{aligned}
 D_S &= (E_{f90}^\circ t_{Fd} / 6\lambda)(t_{Fd}^2 + 3e_{1d}^2) \\
 &= \frac{2 \times 10^5 \times 0.202}{6 \times 0.9865} \times (0.202^2 + 3 \times 1.741^2) \\
 &= 0.623 \times 10^5
 \end{aligned}$$

(64) 式より,

$$\begin{aligned}
 V_S &= [D_S / (t_{Cd} \cdot G_c)](\pi/b_T)^2 \\
 &= [(0.623 \times 10^5) / (3.28 \times 562)](\pi/114)^2 \\
 &= 2.57 \times 10^{-2} \\
 (b/a) &= (600/114) = 5.26, K_C = 3.83
 \end{aligned}$$

(65) 式より,

$$\begin{aligned}
 \overline{SF}_2 &= [(K_C \cdot D_S) / (2t_{Fd} \cdot \sigma_{HCd})](\pi/b_T)^2 \\
 &= [(3.83 \times 0.623 \times 10^5) / (2 \times 0.202 \sigma_{HCd})] \\
 &\quad \times (\pi/114)^2 \\
 &= (449/\sigma_{HCd}) \geq 2
 \end{aligned}$$

5.3 船底サンドイッチ動荷重係数と設計水圧: L_d , P_d

$$\begin{aligned}
 \text{(67) 式より, } E_e &= 12\lambda \cdot D_S / t_d^3 \\
 &= 12 \times 0.9865 \times 0.623 \times 10^5 / 3.684^3 \\
 &= 0.148 \times 10^5 \text{ (kgf/cm}^2\text{)}
 \end{aligned}$$

Hybrid FRP Base の Sandwich Panel の板厚。

$$\begin{aligned}
 \text{(68) 式より, } T &= t_d \sqrt[3]{E_e / E_{f0}^\circ} = 3.684 \sqrt[3]{0.148 / 2.5} \\
 &= 1.436 \text{ (cm)}
 \end{aligned}$$

Sandwich 有効密度。

(69) 式より,

$$\begin{aligned}
 \rho_e &= (2t_{Fd} \cdot \rho_m + t_{Cd} \cdot \rho_c) / T \\
 &= [(2 \times 0.262 \times 1.57) \\
 &\quad + (3.28 \times 0.15)] \times 10^{-3} / 1.436 \\
 &= 0.784 \times 10^{-3} \text{ (kgf/cm}^3\text{)}
 \end{aligned}$$

$$l_0 = 600 \text{ (cm)}, l_B = 280 \text{ (cm)}$$

$$J_2 = [(1/l_0^2) + (1/l_B^2)] \times 10^4 = 0.1553$$

片玄ロンジ本数 $n = 2$

$$\text{(70) 式より, } N_{WL} = 0.234 \sqrt{I_L / (66.93 + A_{0L})}$$

Table 4. 動荷重係数及び設計水圧値

	科員室	主機室
I_L (cm ⁴)	11.405	20.769
A_{eL} (cm ²)	86.7	277.5
N_{uL}	2.016	1.817
Δ (sec) ※1	0.0192	
(ΔN_{uL}) ※2	0.0387	0.0349
L_{eL}	0.1374	0.1239
P_1 (kgf/cm ²)	2.030	1.719
$P_d = P_1 \cdot L_{eL}$ (kgf/cm ²)	0.279	0.213

※1 $L \cdot V / W^{1/6} = 389$, $V / W_1^{1/6} = 16.93$

Table 9 より, $\Delta_2 = [677 - (L \cdot V / W^{1/6})] / 15,000$
 $= 0.0192(\text{sec})$

※2 Table 7 より,

$$\begin{aligned} 0.06 > \Delta N_w > 0, L_d &= 3.55(\Delta N_w)_x \\ 0.14 \geq \Delta N_w \geq 0.06, L_d &= (1/70)[1 + 229(\Delta N_w)_x] \\ 0.24 > \Delta N_w \geq 0.14, \\ L_d &= (1/9.63)[1 + 25.3(\Delta N_w)_x] \\ 0.36 > \Delta N_w \geq 0.24, \\ L_d &= (1/5.15)[1 + 11.76(\Delta N_w)_x] \end{aligned}$$

5.4 Sandwich Panel 水圧曲げ応力安全率 (Longi System)

$$\sigma_{fT0} = 4,230 > \sigma_{fC0} = 1,840 \text{ (kgf/cm}^2\text{)}$$

(76) 式より,

$$\begin{aligned} \overline{SF}_3 &= (C_1 \cdot \sigma_{fC0} \cdot t_{Fd} \cdot t_d) / (P_d \cdot a^2) \\ &= (12 \times 1,840 \times 0.202 \times 3.684) / (P_d \times 114^2) \\ &= (1.264 / P_d) \geq 4 \end{aligned}$$

Table 23. より, $\overline{SF}_3 = 520 / (V / W^{1/6})^{1.72} = 4.0$

5.5 Sandwich Panel 水圧撓み指数

(73) 式より,

$$\begin{aligned} N_1 &= \frac{C_7 \cdot E_{f0} \cdot G_C \cdot (t_d)^2}{P_d \cdot a[(C_8 \cdot E_{f0} \cdot t_{Fd} \cdot t_d) + (G_C \cdot a^2)]} \\ &= 192 \times 2.5 \times 10^5 \times 562 \times 0.202 \times (3.684)^2 / \\ &\quad \{P_d \times 114[(24 \times 2.5 \times 10^5 \times 0.202 \times 3.684) \\ &\quad + (5.2 \times 114^2)]\} = (55.12 / P_d) \geq 150 \end{aligned}$$

Table 23 より,

$$N_1 = (340 \sqrt{E_0 \cdot 10^{-5} / 2.5}) / (V / W^{1/6})^{0.29} = 150$$

5.6 船底サンドイッチパネル安全率及び撓み指数

Table 5. 船底サンドイッチパネル安全率, 撓み指数

	科員室	主機室
$P_d = P_1 \cdot L_{eL}$ (kgf/cm ²)	0.279	0.213
σ_{Hcd} (kgf/cm ²)	69.4	55.5
サンドイッチ板座屈安全率 $SF_2 = 4.49 / H_{cd}$	6.47 > 2	8.09 > 2
サンドイッチ板応力安全率 $SF_3 = 1.264 / P_d$	4.53 > 4	5.93 > 4
サンドイッチ水圧撓み指数 $N_1 = 55.12 / P_d$	198 > 150	259 > 150

5.7 船底サンドイッチ外板寸法

$$\begin{aligned} t_d &= (t_{Fd} \cdot t_{Cd} \cdot t_{Fd}) = (2.02 + 32.80 + 2.02) \\ &= 36.84 \text{ (mm)} \end{aligned}$$

$$\begin{aligned} t_{Cd} &= (Balsa + M600 + Balsa) = (15.8 + 1.2 + 15.8) \\ &= 32.80 \text{ (mm)} \end{aligned}$$

$$T_F = 2 \times 0.202 = 0.404 \text{ (cm)}$$

5.8 船底サンドイッチ外板の座屈発生安全率

5.8.1 近似座屈発生式による値

近似座屈発生式による応力

(81) 式より,

$$\begin{aligned} (\sigma_{Cr})_w &= 0.43 \sqrt[3]{E_{f90} \cdot E_{CT} \cdot G_C} \\ &= 0.43 \sqrt[3]{2 \times 10^5 \times 1,500 \times 562} \\ &= 2,375 \text{ (kgf/cm}^2\text{)} \end{aligned}$$

最大負荷応力

(82) 式より,

$$\begin{aligned} \sigma_{\max} &= [C_7 \cdot E_{f90} \cdot t_d / (C_1 \cdot a_L \cdot N_1)] + \sigma_{Hcd} \\ &= \frac{192 \times 2 \times 10^5 \times 3.684}{12 \times 600 \times 150} + 69.4 = 200 \text{ (kgf/cm}^2\text{)} \end{aligned}$$

座屈発生安全率

$$\overline{SF}_{w1} = (\sigma_{Cr})_w / \sigma_{\max} = 11.88 > 3 \text{ 安全である。}$$

5.8.2 表皮材の初期撓みに基づく値

$$\sigma_{fT90} > \sigma_{fC90} = 1,610 \text{ (kgf/cm}^2\text{)}$$

(84) 式より,

$$\begin{aligned} Q &= \sigma_{fC90} \sqrt[3]{(1 - \mu^2) / (E_{f90} \cdot E_{CT} \cdot G_C)} \\ &= 1,610 \sqrt[3]{0.9865 / (2 \times 10^5 \times 1,500 \times 562)} = 0.290 \end{aligned}$$

(85) 式より,

$$\begin{aligned} q &= (t_{Cd} \cdot G_C \cdot Q) / (t_{Fd} \cdot \sigma_{fC90}) \\ &= (3.28 \times 562 \times 0.29) / (0.202 \times 1,610) = 1.64 \end{aligned}$$

座屈発生安全率 パラメータ: $K=0.477$

$$\begin{aligned}\overline{SF}_{w2} &= (\sigma_{pe} \cdot t_{cd} \cdot K) / (\alpha_w \cdot t_{Fd} \cdot E_{CT}) \\ &= (25 \times 3.28 \times 0.477) / (0.05 \times 0.202 \times 1,500) \\ &= 2.85 > 1.5 \quad \text{安全である。}\end{aligned}$$

6. 円弧キール・サンドイッチパネル設計

平板船底パネル寸法

$$\begin{aligned}t_{Fd} &= H3 = 0.202 \text{ (cm)} \\ t_{cd} &= (\text{Balsa} + \text{M600} + \text{Balsa}) = (1.58 + 0.12 + 1.58) \\ &= 3.28 \text{ (cm)}\end{aligned}$$

円弧キールパネル寸法 (平板船底パネルより 1 段増)

$$\begin{aligned}t_{Fd} &= H5 = 0.337 \text{ (cm)} \\ t_{cd} &= \text{Balsa} + (2 \times \text{M600}) + \text{Balsa} \\ &= (1.90 + 0.24 + 1.90) = 4.04 \text{ (cm)} \\ t_d &= 2t_{Fd} + t_{cd} = 4.714 \text{ (cm)} \\ e_{1d} &= (1/2)(t_{cd} + t_{Fd}) = 2.189 \text{ (cm)}\end{aligned}$$

(63) 式より,

$$\begin{aligned}D_s &= [(E_{f0} \cdot t_{Fd}) / 6\lambda_f] (t_{Fd}^2 + 3e_{1d}^2) \\ &= [(2.5 \times 10^5 \times 0.337) / (6 \times 0.9865)] \times \\ &\quad (0.337^2 + 3 \times 2.189^2) \\ &= 2.06 \times 10^5 \text{ (kgf} \cdot \text{cm)}\end{aligned}$$

(67) 式より,

$$\begin{aligned}E_e &= 12\lambda \cdot D_s / t_d^3 = 12 \times 0.9865 \times 2.06 \times 10^5 / 4.714^3 \\ &= 0.233 \times 10^5 \text{ (kgf/cm}^2\text{)}\end{aligned}$$

(68) 式より,

$$T = t_d \sqrt[3]{E_e / E_{f0}} = 4.714 \sqrt[3]{0.233 / 2.5} = 2.14 \text{ (cm)}$$

(69) 式より,

$$\begin{aligned}\rho_e &= (2t_{Fd} \cdot \rho_m + t_{cd} \cdot \rho_c) / T \\ &= (2 \times 0.337 \times 1.57) + (4.04 \times 0.15) \\ &\quad / 2.14 \times 10^3 \\ &= 0.778 \times 10^{-3} \text{ (kgf/cm}^3\text{)}\end{aligned}$$

近似平板片面接水振動数計算

$$\begin{aligned}J_1 &= [(1/87^2) + (1/600^2)] \times 10^4 = 1.349 \\ (b/a) &= (600/87) = 6.9, \alpha_r = 1.10\end{aligned}$$

(71) 式より, $N_{WP} = 4.21 \text{ (Hz)}$

Table 9 より,

$$\begin{aligned}\Delta_2 &= [677 - (L \cdot V / W^{1/6})] / 15,000 = 0.0192 \text{ (sec)} \\ \Delta_2 N_{WP} &= 0.0809, 0.14 > (\Delta_2 N_{WP}) \geq 0.06\end{aligned}$$

Table 7 より,

$$\begin{aligned}L_{dP} &= (1/70)(1 + 229\Delta_2 N_{WP}) = 0.279 > 0.1 \\ P_d &= P_0 \cdot L_{dP} = 3.307 \times 0.279 = 0.922 \text{ (kgf/cm}^2\text{)}\end{aligned}$$

円弧キャンパー値

$$\begin{aligned}f &= 6 \text{ (cm)}, a = b_T = 87 \text{ (cm)}, b = a_L = 600 \text{ (cm)} \\ (28) \text{ 式より, } R_0 &= (f/8)[4 + (a/f)^2] = 161 \text{ (cm)} \\ (29) \text{ 式より, } \xi &= \sin^{-1}(a/2R_0) = 15.68^\circ \\ \text{Table 16 より, } \beta_f &= 16.56\end{aligned}$$

円弧座屈安全率

(27) 式より

$$\begin{aligned}\overline{SF}_B &= [E_e(\beta_f^2 - 1) / (12\lambda \cdot P_d)] (T/R_0)^3 \\ &= \frac{0.233 \times 10^5 (16.56^2 - 1) \times (2.14/161)^3}{12 \times 0.9865 \times 0.922} = 1.27\end{aligned}$$

Table 15 より, $1.27 > 1.25$

円弧キール・サンドイッチ構成

$$\begin{aligned}t_d &= (t_{Fd} + t_{cd} + t_{Fd}) = 3.37 + 40.4 + 3.37 = 47.1 \text{ (mm)} \\ t_{cd} &= \text{Balsa} + (2 \times \text{M600}) + \text{Balsa} \\ &= 19.0 + 2.40 + 19.0 = 40.4 \text{ (mm)}\end{aligned}$$

キールサンドイッチ表皮合計板厚

$$T_F = 2 \times 0.337 = 0.674 \text{ (cm)}$$

7. 船底ロンジハット ($\sigma_H = 0$)

7.1 科員室船底ロンジ ($l_0/S = 5.26 > 4$)

$$\begin{aligned}P_1 &= 2.03 \text{ (kgf/cm}^2\text{)}, S = 114 \text{ (cm)}, l_0 = 600 \text{ (cm)}, \\ \overline{SF}_{L\min} &= 2, N_L = 250, C_1 = 12, C_2 = 384, \\ V &= 30 \text{ (KT)},\end{aligned}$$

$$L \cdot V / W^{1/6} = 389 > 300,$$

Table 24 より, $\sigma_Y = \sigma_{rc0} = 1,840 \text{ (kgf/cm}^2\text{)},$

$$E_{f0} = 2.5 \times 10^5 \text{ (kgf/cm}^2\text{)},$$

Table 6 Table 8 より,

$$L_d = k_d = k_2 = 0.12 \{1 - [(V - 22)/28]\} = 0.0857$$

(87) 式より,

$$\begin{aligned}I_L &= (P_1 \cdot S \cdot l_0^3 \cdot N_L \cdot L_d) / (C_2 \cdot E_{f0}) \\ &= 11,156 \text{ (cm}^4\text{)}\end{aligned}$$

(89) 式より,

$$\begin{aligned}Z_L &= (P_1 \cdot S \cdot l_0^2 \cdot \overline{SF}_L \cdot L_d) / (C_1 \cdot \sigma_{rc0}) \\ &= 647 \text{ (cm}^3\text{)}\end{aligned}$$

ロンジ寸法

$$I_{\text{Req}}=11,200 \text{ (cm}^4\text{)}, Z_{\text{Req}}=650 \text{ (cm}^3\text{)}$$

$$H_w \text{ (cm)} \quad 28 = 28$$

$$t_f \text{ (cm)} \quad 1.325 < 1.475 \quad b_2=20 \text{ (cm)}$$

$$A_f \text{ (cm}^2\text{)} \quad 11.5 < 14.5 \quad b_f=18 \text{ (cm)}$$

(93) 式より,

$$\begin{aligned} t_{fc} &= \{t_f + 12(A_f/H_w)\} / \{1 + 12(b_f/H_w)\} \\ &= \{1.475 + 12(14.5/28)\} / \{1 + 12(18/28)\} \\ &= 0.882 \text{ (cm)} \end{aligned}$$

$$t_{fd}=0.876 \text{ (cm)}=t_{wd}, H=n=13$$

(95) 式より,

$$b_e=3\{1+(n/4)(n+0.1)/(n+0.5)\}=12.46 \text{ (cm)}$$

(96) 式より,

$$b_p=40t_p+b_2=(40 \times 0.202)+20=28.1 \text{ (cm)}$$

Table 6. 船底ロンジ寸法

	a	l	m	i	i'
①0.202×28.1	5.67	-0.101	-0.6	0.1	
②0.876×12.46×2	21.83	0.438	9.6	4.2	
③28×0.876×2	49.06	14	686.8	9615.8	3205.3
④0.876×18	15.77	28.438	448.5	12753.5	
	92.33		Σ 1144.3	25578.8	
			12.39		

$$I_d=11,405(\text{cm}^4), I_{\text{Req}}=11,156(\text{cm}^4), Y_F=16.49(\text{cm}), \\ Z_d=692(\text{cm}^3), Z_{\text{Req}}=647(\text{cm}^3)$$

船底ロンジハット寸法 (科員室)

$$H_w \times (b_f/b_2) \times (t_f/t_w)$$

$$=280 \times (180/200) \times (8.76/8.76) \text{ (mm)}$$

$$I_d=11,405 \text{ (cm}^4\text{)}, Y_F=16.49 \text{ (cm)}, Z_d=692 \text{ (cm}^3\text{)}$$

$$\text{ハット部断面積: } a_0=86.66 \text{ (cm}^2\text{)}$$

$$\text{ハット部モーメント: } m_0=1,144.9 \text{ (cm}^3\text{)}$$

$$\text{ハット部中立軸外板下面よりの高さ:}$$

$$e_0=(m_0/a_0)+t_d=13.21 \text{ (cm)}+3.684 \text{ (cm)}$$

$$=0.169 \text{ (m)}$$

(e_0 は, 中央横断面係数計算の I 値を設定するのに使用する。)

7.2 主機室船底ロンジハット ($\sigma_H=0$)

$$P_{12}=1.719 \text{ (kgf/cm}^2\text{)}, S=114 \text{ (cm)}, l_0=600 \text{ (cm)},$$

$$\overline{SF}_1=4, N_L=280L^{0.03}=308, L_d=k_d=0.0857,$$

$$E_{w0}^\circ=1.35 \times 10^3 \text{ (kgf/cm}^2\text{)},$$

(87) 式より,

$$\begin{aligned} I_{\text{Req}} &= (P_1 \cdot S \cdot l^3 \cdot N_L \cdot L_d) / (C_1 \cdot E_{f0}^\circ) \\ &= 11,638 \text{ (cm}^4\text{)} \end{aligned}$$

(89) 式より,

$$\begin{aligned} Z_{\text{Req}} &= (P_1 \cdot S \cdot l^2 \cdot \overline{SF}_1 \cdot L_d) / (C_1 \cdot \sigma_{fc0}^\circ) \\ &= 1,095 \text{ (cm}^3\text{)} \end{aligned}$$

科員室ロンジに木芯材を挿入する。

$$(E_{w0}^\circ/E_{f0}^\circ)=(1,350/2,500)=0.54$$

Table 7. 主機室船底ロンジハット寸法

	a	l	m	i	i'
①~④ 92.33	92.33		1144.3	25578.8	
⑤ 20×18.4×0.54	198.72	18.0	3577.0	64385.3	6624.0
	291.05		Σ 4721.3	96588.1	
			16.22		

$$I_d=20016(\text{cm}^4), I_{\text{Req}}=11638(\text{cm}^4), Y_F=12.66(\text{cm}), \\ A_{ol}=277.5(\text{cm}^2), Z_d=1,580(\text{cm}^3), Z_{\text{Req}}=1,095(\text{cm}^3)$$

7.3 船底外板スプレーストリップ ($\sigma_H=0$)

$$P_1=2.03 \text{ (kgf/cm}^2\text{)}, S=114/4=28.5 \text{ (cm)},$$

$$l_0=600 \text{ (cm)}, L_d=k_d/2=0.0429,$$

$$\text{Tablec 25 より, } \overline{SF}_1=1.25, N_L=2.5L=57.5,$$

(87) 式より,

$$I_{\text{Req}}=(P_1 \cdot S \cdot l^3 \cdot N_L \cdot L_d) / (C_2 \cdot E_{f0}^\circ)=321 \text{ (cm}^4\text{)}$$

(89) 式より,

$$\begin{aligned} Z_{\text{Req}} &= (P_1 \cdot S \cdot l^2 \cdot \overline{SF}_1 \cdot L_d) / (C_1 \cdot \sigma_{fc0}^\circ) \\ &= 50.6 \text{ (cm}^3\text{)} \end{aligned}$$

$$t_w=0.539 \text{ (cm)}=H/8, f_0=3, n=8, \sigma_H=0$$

(95) 式より,

$$b_e=3\{1+(8 \times 8.1)/(4 \times 8.5)\}=8.7 \text{ (cm)}$$

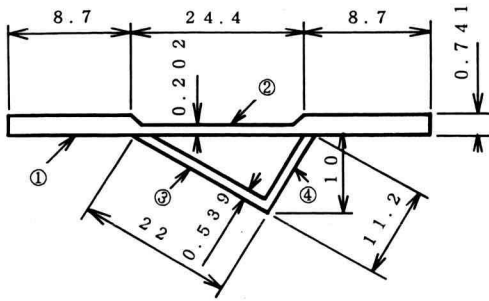


Fig. 1

Table 8. 船底外板スプレーストリップ寸法

	a	l	m	i	i'
①0.741×8.7×2	12.89	-0.3705	-4.8	1.8	
②0.202×24.4	4.93	-0.101	-0.5	0.1	
③22×0.539	11.86	5	59.3	296.5	98.8
④11.2×0.539	6.04	5	30.2	151.0	50.3
	35.72		Σ 84.2	598.5	
			2.35		

$I_d = 400(\text{cm}^4)$, $I_{\text{req}} = 320(\text{cm}^4)$, $Y_F = 7.64(\text{cm})$, $A_{ol} = 17.90(\text{cm}^2)$,
 $Z_d = 52.3(\text{cm}^3)$, $Z_{\text{req}} = 50.6(\text{cm}^3)$

No. 3 Panel の Spray strip の動的設計影響

$$\Delta_2 = [677 - (L \cdot V / W^{1/6})] / 15,000$$

$$= (677 - 389) / 15,000$$

$$= 0.0192 (\text{sec})$$

($m=1$ の防撓平板)

$$(16) \text{ 式より, } N_{WL} = 0.420, \Delta_2 N_W = 0.00807, L_{dL} = 3.55, \\ \Delta_2 N_W = 0.0286, L_{d\min} = 0.100,$$

5.3 項の船底サンドイッチ動荷重係数 L_{dL} 値は, Spray strip による値より大であるため, Spray strip 値は無視される。

7.4 船底ロンジハット Plate Theory 解析

7.4.1 ハットフランジ白化

$$t_w = 0.876 (\text{cm}), t_p = 0.202 (\text{cm}), t_d = 3.684 (\text{cm}),$$

$$5.3 \text{ 項より, } E_e = 0.148 \times 10^5 (\text{kgf/cm}^2),$$

$$P_d = P_1 \cdot L_{dL} = P_1 \times 0.1374 = 0.279 (\text{kgf/cm}^2),$$

$$T = 1.436 (\text{cm}), a = 114 (\text{cm}), K_0 = 87, \phi = 0.667,$$

(131) 式より,

$$\Psi = P_d (\lambda / E_e)_f (a / T)^4$$

$$= (0.279 \times 0.9865) (114 / 1.436)^4 / (0.148 \times 10^5)$$

$$= 7.39 \times 10^2$$

(134) 式より,

$$K_1 = E_e / (\lambda_f \cdot \Gamma \cdot \phi \cdot \sigma_{f0}) \\ = (0.148 \times 10^5) / (0.9865 \times 1.5 \times 0.667 \times 4,230) \\ = 3.54$$

(133) 式より,

$$\overline{SF}_w = [1 / (K_0 \cdot K_1)] (a / T)^2 [1 + (t_w / T)^2] \\ = [1 / (87 \times 3.54)] (114 / 1.436)^2 \times \\ [1 + (0.876 / 1.436)^2] \\ = 28.1 > 1.5 \text{ 白化せず。}$$

7.4.2 ハットクラウン座屈

$$L_d = K_d = 0.0857, \mu_{f\text{mean}} = \sqrt{0.150 \times 0.09} = 0.116$$

Table 36 より, $\overline{SF}_B = 1.5$, Table 37. より, $C_f = 12$,

$$k_f = 2 [\mu + (2\lambda G / E_0)_f] = 0.658, Z_L = 692 (\text{cm}^3),$$

$$t_f = 0.876 (\text{cm}),$$

$$b_f = 18 (\text{cm}), \sigma_{Hcd} = 69.4 (\text{kgf/cm}^2)$$

(137) 式より,

$$K_2 = \pi \sqrt{[1.1 C_f (3 + 2 K_f) / 12] (E_0 / \lambda)_f} = 3172$$

(136) 式より,

$$\overline{SF}_B = [Z_L / (P_1 \cdot L_d \cdot S \cdot l^2)] \times \\ [(K_2 \cdot t_f / b_f)^2 - (C_f \cdot \sigma_{Hcd})] \\ = 2.23 > 1.5 \text{ 座屈せず。}$$

7.4.3 ハットウェブ剪断座屈

(b-side warp direction)

$$E_1 = E_{b90} = 2.0 \times 10^5 (\text{kgf/cm}^2), C_\tau = 2, C_a = 10.2,$$

$$E_2 = E_{b0} = 2.5 \times 10^5 (\text{kgf/cm}^2),$$

$$\beta_a = (a / b) \sqrt{E_2 / E_1} = 0.0493,$$

$$\alpha = [E_{f0} \cdot \mu_f + 2(\lambda \cdot G)_f] / \sqrt{(E_1 \cdot E_2)} = 0.368,$$

(140) 式より,

$$K_3 = \sqrt[3]{2 C_a \cdot E_{b0} \cdot C_\tau / 3 \lambda_f} = 151$$

(139) 式より,

$$\overline{SF}_\tau = (t_w \cdot K_3)^3 / (P_1 \cdot L_d \cdot H_w \cdot S \cdot l_0) \\ = \frac{(0.876 \times 151)^3}{2.03 \times 6.0857 \times 28 \times 114 \times 600} \\ = 6.95 > 1.5 \text{ 座屈せず。}$$

8. 船側サンドイッチ外板設計

(b_T side warp direction)

8.1 サンドイッチ寸法

$$\begin{aligned}
 S &= a_L = b_T = 150 \text{ (cm)}, N_1 = 135, \\
 P_3 &= 0.524 \text{ (kgf/cm}^2\text{)}, \\
 E_{f90} &= 2 \times 10^5 \text{ (kgf/cm}^2\text{)}, \\
 \overline{SF}_1 &= 2.35/K_E = 2.53, \\
 \overline{SF}_3 &= 520 / (V/W^{1/6})^{1.72} = 4.0, \\
 \sigma_{HC1} &= \sigma_{fC90} / \overline{SF}_1 = 636 \text{ (kgf/cm}^2\text{)},
 \end{aligned}$$

(58) 式より,

$$\begin{aligned}
 t_F &= [C_6 \cdot P_n \cdot a \cdot E_{f90}] / [2C_1 \cdot N_1 \cdot (\sigma_{HC1})^2] \\
 &= \frac{32 \times 0.524 \times 150 \times 2 \times 10^5}{2 \times 12 \times 135 \times (636)^2} = 0.383 \text{ (cm)} \\
 t_{Fd} &= H5 = 0.337 \text{ (cm)}
 \end{aligned}$$

計画全厚 (59) 式より

$$\begin{aligned}
 t &= (C_1 \cdot a \cdot \sigma_{fC90} N_1) / (C_7 \cdot E_{f90} \overline{SF}_1) \\
 &= (12 \times 150 \times 1,610 \times 135) / (192 \times 2 \times 10^5 \times 2.53) \\
 &= 4.027 \text{ (cm)}
 \end{aligned}$$

計画芯材厚 (60) 式より,

$$t_c = (t - 2t_{Fd}) = 4.027 - (2 \times 0.337) = 3.35 \text{ (cm)}$$

設計芯材厚

$$\begin{aligned}
 t_{cd} &= (\text{Balsa} + \text{M600} + \text{Balsa}) = (1.58 + 0.12 + 1.58) \\
 &= 3.28 \text{ (cm)}
 \end{aligned}$$

設計全厚 (61) 式より,

$$t_d = (t_{cd} + 2t_{Fd}) = 3.28 + (2 \times 0.337) = 3.954 \text{ (cm)}$$

8.2 サンドイッチ縦座屈安全率

(62) 式より,

$$\begin{aligned}
 e_{1d} &= (1/2)(t_{cd} + t_{Fd}) \\
 &= (1/2)(3.28 + 0.337) = 1.809 \text{ (cm)}
 \end{aligned}$$

(63) 式より,

$$\begin{aligned}
 D_s &= (E_{f90} t_{Fd} / 6\lambda_f)(t_{Fd}^2 + 3e_{1d}^2) \\
 &= [(2 \times 10^5 \times 0.337) / (6 \times 0.9865)] \times \\
 &\quad [0.337^2 + (3 \times 1.809^2)] \\
 &= 1.13 \times 10^5 \text{ (kgf} \cdot \text{cm)}
 \end{aligned}$$

(64) 式より,

$$\begin{aligned}
 V_s &= [D_s / (t_{cd} \cdot G_c)] (\pi / b_T)^2 \\
 &= [(1.13 \times 10^5) / (3.28 \times 562)] (\pi / 150)^2 \\
 &= 0.0269
 \end{aligned}$$

圧縮座屈係数 $K_c = 3.84$ ($b/a = 1$)

座屈安全率 (65) 式より,

$$\begin{aligned}
 \overline{SF}_2 &= [(K_c \cdot D_s) / (2t_{Fd} \cdot \sigma_{HCd})] (\pi / b_T)^2 \\
 &= \frac{3.84 \times 1.13 \times 10^5}{0.766 \times 94.5} \times (\pi / 150)^2 \\
 &= 2.93 > 2 \quad \text{座屈せず。}
 \end{aligned}$$

8.3 サンドイッチ応力安全率

(67) 式より,

$$\begin{aligned}
 E_e &= 12\lambda \cdot D_s / (t_d)^3 \\
 &= 12 \times 0.9865 \times 1.13 \times 10^5 / (3.954)^3 \\
 &= 0.216 \times 10^5 \text{ (kgf/cm}^2\text{)}
 \end{aligned}$$

(68) 式より,

$$T = t_d \sqrt[3]{E_e / E_{f90}} = 3.954 \sqrt[3]{0.216 / 2} = 1.883 \text{ (cm)}$$

(69) 式より,

$$\begin{aligned}
 \rho_e &= (2t_{Fd} \cdot \rho_f + t_{cd} \cdot \rho_c) / T \\
 &= \frac{[(2 \times 0.337 \times 1.57) + (3.28 \times 0.15)] \times 10^{-3}}{1.883} \\
 &= 0.823 \times 10^{-3} \text{ (kgf/cm}^3\text{)}
 \end{aligned}$$

$$J_1 = [(1/150^2) + (1/150^2)] \times 10^4 = 0.889 \text{ (cm}^{-2} \times 10^4\text{)}$$

Table 11 より, ($b/a = 1$, $\alpha_r = 2$)(71) 式より, $N_{WP} = 3.63$, $L \cdot V / W^{1/6} = 349$,

Table 9 より,

$$\Delta_2 = [677 - (L \cdot V / W^{1/6})] / 15,000 = 0.0219 \text{ (sec)}$$

$$\Delta_2 N_{WP} = 0.0794, (0.14 > N_w \geq 0.06)$$

Table 7 より, $L_{dP} = 0.274$

$$P_{3d} = 0.524 L_{dP} = 0.144 \text{ (kgf/cm}^2\text{)}$$

$$\sigma_{HCd} = 94.5 \text{ (kgf/cm}^2\text{)}$$

応力安全率 (72) 式より,

$$\begin{aligned}
 \overline{SF}_3 &= \frac{\sigma_{fC90}}{[(P_{2d} \cdot a_L^2) / (C_1 \cdot t_{Fd} \cdot t_d)] + \sigma_{HCd}} \\
 &= \frac{1,610}{[(0.144 \times 150^2) / (12 \times 0.337 \times 3.954)] + 94.5} \\
 &= 5.42 > 4
 \end{aligned}$$

8.4 撓み指数 (73) 式より,

$$N_1 = \frac{C_7 \cdot E_{f90} \cdot G_C \cdot t_{Fd} \cdot t_d^2}{P_{3d} \cdot S[(C_8 \cdot E_{f90} \cdot t_{Fd} \cdot t_d) + (G_C \cdot S^2)]}$$

$$N_1 = 192 \times 2 \times 10^5 \times 562 \times 0.337 \times (3.954)^2 / \{0.144 \times 150[(24 \times 2 \times 10^5 \times 0.337 \times 3.954) + (562 \times 150^2)]\}$$

$$= 276 > 135$$

8.5 船側サンドイッチ外板面内剪断座屈安全率

$$A = (a/b)^2 = 1, V_s = 0.0269,$$

$$D_s = 1.13 \times 10^5 \text{ (kgf} \cdot \text{cm)}$$

$$H_s = 150 \text{ (cm)}, 1/(1+A) = 0.5 > V_s = 0.0269 > 0$$

(77) 式より, $K_s = 4(4+3A)/[3+(13+9A)V_s]$

$$= 7.796$$

4.5 項より, 最大剪断力 $F_H = 5.87 \text{ (Ton)}$

剪断座屈安全率 (80) 式より,

$$\overline{SF} = [(2K_s \cdot D_s \cdot H_s) / (F_H \times 10^3)] (\pi/S)^2$$

$$= [(2 \times 7.796 \times 1.13 \times 10^5 \times 150) \div (5.87 \times 10^3)] \times (\pi/150)^2$$

$$= 19.7 > 6$$

8.6 船側外板座屈発生安全率

8.6.1 近似座屈発生式による値

(81) 式より,

$$(\sigma_{cr})_w = 0.43 \sqrt[3]{E_{f90} \cdot E_{CT} \cdot G_C}$$

$$= 0.43 \sqrt[3]{2 \times 10^5 \times 1,500 \times 562}$$

$$= 2,375 \text{ (kgf/cm}^2\text{)}$$

(82) 式より,

$$\sigma_{\max} = [(C_7 \cdot E_{f90} \cdot t_d) / (C_1 \cdot a_L \cdot N_1)] + \sigma_{HC}$$

$$= [192 \times 2 \times 10^5 \times 3.954 / (12 \times 150 \times 135)] + 94.5$$

$$= 719 \text{ (kgf/cm}^2\text{)}$$

(83) 式より,

$$\overline{SF}_{w1} = (\sigma_{cr})_w / \sigma_{\max} = (2,375 / 719) = 3.30 > 3$$

座屈発生せず。

8.6.2 表面材の初期撓みに基づく値

($\sigma_{fT90} > \sigma_{fC90}$ よって, σ_{fC90} を採用)

(84) 式より,

$$Q = \sigma_{fC90} \sqrt[3]{\lambda_f / (E_{f90} \cdot E_{CT} \cdot G_C)}$$

$$= 1,610 \sqrt[3]{0.9865 / (2 \times 10^5 \times 1,500 \times 562)} = 0.290$$

(85) 式より,

$$q = (t_{Cd} \cdot G_C \cdot Q) / (t_{Fd} \cdot \sigma_{fC90})$$

$$= (3.28 \times 562 \times 0.29) / (0.337 \times 1,610) = 0.985$$

$$K = 0.87, \sigma_{Pe} = 25 \text{ (kgf/cm}^2\text{)}, \alpha_w = 0.05$$

$$E_{CT} = 1,500 \text{ (kgf/cm}^2\text{)}$$

(86) 式より,

$$\overline{SF}_{w2} = (\sigma_{Pe} \cdot t_{Cd} \cdot K) / (\alpha_w \cdot t_{Fd} \cdot E_{CT})$$

$$= (25 \times 3.28 \times 0.87) / (0.05 \times 0.337 \times 1,500)$$

$$= 2.82 > 1.5 \text{ 座屈発生せず。}$$

8.7 船側サンドイッチ外板寸法

$$t_d = (t_{Fd} + t_{Cd} + t_{Fd}) = 3.37 + 32.80 + 3.37$$

$$= 39.54 \text{ (mm)}$$

$$t_{Cd} = (\text{Balsa} + \text{M600} + \text{Balsa}) = 15.8 + 1.2 + 15.8$$

$$= 32.8 \text{ (mm)}$$

サンドイッチ表皮合計板厚

$$T_F = 2t_{Fd} = 0.674 \text{ (cm)}$$

9. 船側横肋骨

(変断面, ガンネル肘板, チャインスニップ)

9.1 肋骨要求値

$$P_3 = 0.524 \text{ (kgf/cm}^2\text{)}, C_1 = 8, C_2 = 184.6,$$

$$l = 150 \text{ (cm)}$$

(122) 式より, $F_a = 1.5 + (X/l), (l/S) = 1 < 4$

$$\overline{SF}_T = 1.25 F_a = (225 + X) / 120,$$

$$k_2 = 0.12[1 - (V - 22/28)] = 0.0857$$

$$N_T = 65L^{0.15} F_a = 65 \times 23^{0.15} \times [1.5 + (X/150)]$$

$$= 0.694(225 + X)$$

$$L_a = k_2[2.95k_2 / (l/S)^{0.776}] = 0.2529$$

(123) 式より,

$$I_{\text{Req}} = (P_3 \cdot S \cdot l^3 \cdot L_a \cdot N_T) / (C_2 \cdot E_{f0})$$

$$= \frac{0.524 \times 150 \times 150^3 \times 0.2529 \times 0.694(225 + X)}{184.6 \times 2.5 \times 10^5}$$

$$= (225 + X) \text{ (cm}^4\text{)}$$

(125) 式より,

$$Z_{\text{Req}} = (P_3 \cdot S \cdot l^2 \cdot L_a \cdot \overline{SF}_T) / (C_1 \cdot \sigma_{fC0})$$

$$= [0.524 \times 150 \times 150^2 \times 0.2529 \times (225 + X)] \div [8 \times 1,840 \times 120]$$

$$= (225 + X) / 3.95 \text{ (cm}^3\text{)}$$

Chine 部 $X=0$ (cm) $I_{Req}=225$ (cm⁴)

$Z_{Req}=57$ (cm³)

Gannel 部 $X=150$ (cm) $I_{Req}=375$ (cm⁴)

$Z_{Req}=95$ (cm³)

9.2 Chine 部側肋骨

$I_{Req}=225$ (cm⁴) $Z_{Req}=57$ (cm³)

H_w (cm) 11 = 11

t_f (cm) 0.22 < 0.51 $b_2=b_f=8$ (cm)

A_f (cm²) 1.1 < 2.55

(93) 式より,

$$t_{fc} = [0.51 + 12(2.55/11)] / [1 + 12(8/11)] \\ = 0.338 \text{ (cm)}$$

$$t_{fd} = H/6 = 0.404 \text{ (cm)} = t_{wd}$$

(95) 式より,

$$b_e = 3[1 + (6 \times 6.1) / (4 \times 6.5)] = 7.2 \text{ (cm)}$$

$$b_P = (40 \times 0.337) + 8 = 21.5 \text{ (cm)}$$

Table 9. チャイン部寸法

	a	l	m	i	i'
①0.337×21.5	7.25	-0.1685	-1.2	0.2	
②0.404×7.2×2	5.82	0.202	1.2	0.2	
③11×0.404×2	8.89	5.5	48.9	268.9	89.6
④0.404×8	3.23	11.202	36.2	405.3	
	25.19		Σ 85.1	764.2	
			3.38		

$I_d=476$ (cm⁴), $I_{Req}=225$ (cm⁴), $Y_f=8.02$ (cm), $A_{or}=17.94$ (cm²),
 $Z_d=59$ (cm³), $Z_{Req}=57$ (cm³),
 $H_w \times (b_f/b_2) \times (t_f/t_w) = 110 \times (80/80) \times (4.04/4.04)$ (mm)

9.3 Gannel 部側肋骨

$I_{Req}=375$ (cm⁴) $Z_{Req}=95$ (cm³)

H_w (cm) 16 = 16

t_f (cm) 0.8 < 0.88 $b_2=b_f=8$ (cm)

A_f (cm²) 1.0 < 2.7

(93) 式より,

$$t_{fc} = [0.88 + 12(2.7/16)] / [1 + 12(8/16)] \\ = 0.415 \text{ (cm)}$$

$$t_{fd} = H/6 = 0.404 \text{ (cm)} = t_{wd}, b_P = 21.5 \text{ (cm)},$$

$$b_e = 7.2 \text{ (cm)}$$

Table 10. ガンネル部寸法

	a	l	m	i	i'
①0.337×21.5	7.25	-0.1685	-1.2	0.2	
②0.404×7.2×2	5.82	0.202	1.2	0.2	
③16×0.404×2	12.93	8	103.4	827.5	275.8
④0.404×8	3.23	16.202	52.3	847.9	
	29.23		Σ 155.7	1951.6	
			5.33		

$I_d=1,121$ (cm⁴), $I_{Req}=375$ (cm⁴), $Y_f=11.07$ (cm),
 $A_{or}=21.98$ (cm²), $Z_d=101$ (cm³), $Z_{Req}=95$ (cm³)

9.4 側横肋骨変断面寸法

Table 11. 船側横肋骨変断面寸法

	$H_w \times (b_f/b_2) \times (t_f/t_w)$ (mm)	A_b (cm ²)	A_{bmax} (cm ²)
チャイン部	$110 \times (80/80) \times (4.04/4.04)$	17.94	19.96
ガンネル部	$160 \times (80/80) \times (4.04/4.04)$	21.98	

10. 船側肋骨ガンネル肘板設計

$$P_3 = 0.524 \text{ (kgf/cm}^2\text{)}, k_d = 0.2529, \overline{SF} = 12,$$

$$S = 150 \text{ (cm)}$$

$$h = 976 P_3 \cdot k_d = 976 \times 0.524 \times 0.2529 = 129 \text{ (cm)}$$

$$l = 150 \text{ (cm)} > h = 129 \text{ (cm)}, i = (l - h) = 21 \text{ (cm)}$$

$$\omega = h \cdot S / 976 = 129 \times 150 / 976 = 19.8 \text{ (kgf/cm)}$$

$$R_1 = [\omega / (l^2 \cdot h)] \{ [(l^5 - i^5) / 40l] -$$

$$[(l^4 - i^4) / 8] + (3l^3 h / 8) \}$$

$$= [19.8 / (150^2 \times 129)] \{ [(150^5 - 21^5) / (40 \times 150)]$$

$$- [(150^4 - 21^4) / 8] + (3 \times 150^3 \times 21 / 8) \}$$

$$= (86.33 - 431.52 + 181.31) = |164| \text{ (kgf)}$$

$$M_1 = (\omega \cdot h / 6)(2l + i) - (R_1 \cdot l)$$

$$= (19.8 \times 129 / 6)[(2 \times 150) + 21] - (164 \times 150)$$

$$= 112,050 \text{ (kgf} \cdot \text{cm)}$$

$$M_{T1} = P_2 \cdot S_T \cdot l_{T1}^2 / 12 = 0.032 \times 150 \times 150^2 / 12$$

$$= 9,000 \text{ (kgf} \cdot \text{cm)}$$

$$M_N = M_1 = 112,050 \text{ (kgf} \cdot \text{cm)} > M_{T1}$$

$$\overline{SF} = 12, t_f = 2t_w, b_f = 8.5 \text{ (cm)},$$

Table 12. f_n 値

H (層数)	10	11	12	13
$t_w = 0.0674 H$ (cm)	0.674	0.741	0.809	0.876
f_n (cm)	48	41	36	32

(149) 式より,

$$\begin{aligned} f_n &= (1.414 M_N \cdot \overline{SF}) / [\sigma_{fc90} (30 t_w^2 + t_f \cdot b_f)] \\ &= (1.414 \times 112,050 \times 12) / [1,610 (30 t_w + 17) t_w] \\ &= 69.5 / [t_w (1.765 t_w + 1)] \text{ (cm)} \end{aligned}$$

(146) 式より,

$$\begin{aligned} A_n &= (t_f \cdot b_f + 30 t_w^2) \\ &= (2 \times 0.809 \times 8.5) + (30 \times 0.809^2) = 33.4 \text{ (cm}^2\text{)} \end{aligned}$$

(148) 式より, $f_n = 36 \text{ (cm)}$ として,

$$\begin{aligned} \overline{SF}_n &= 0.707 \sigma_{fc90} \cdot A_n \cdot f_n / M_N \\ &= 0.707 \times 1,610 \times 33.4 \times 36 / 112,050 = 12.21 > 12 \end{aligned}$$

設計寸法

$$\begin{aligned} f_1 \times f_1 \times b_f \times t_f / t_w \\ &= 360 \times 360 \times 85 \times 16.18 / 8.09 \text{ (mm)} \\ \overline{SF}_d &= 12.21 \end{aligned}$$

11. 強力甲板サンドイッチパネル設計

11.1 サンドイッチ寸法 (a -Side warp direction)

$$\begin{aligned} S &= a_L = b_T = 150 \text{ (cm)}, P_d = 2P_2 = 0.064 \text{ (kgf/cm}^2\text{)} \\ V/W^{1/6} &= 16.93, \overline{SF}_1 = (16/k_E) = 16, \overline{SF}_2 = 2, \\ \overline{SF}_3 &= 4, N_1 = 600, k_E = 1, C_1 = 12, C_6 = 32, \\ C_7 &= 192, C_8 = 24 \end{aligned}$$

(56) 式より,

$$\sigma_{HC1} = \sigma_{fc0} / \overline{SF}_1 = 1,840 / 16 = 115 \text{ (kgf/cm}^2\text{)}$$

甲板外板板厚 (58) 式より,

$$\begin{aligned} t_F &= C_6 \cdot P_d \cdot a \cdot E_{f0} / [2C_1 \cdot N_1 (\sigma_{HC1})^2] \\ &= \frac{32 \times 0.064 \times 150 \times 2.5 \times 10^5}{2 \times 12 \times 600 \times 115^2} = 0.403 \text{ (cm)} \\ t_{Fd} &= H6 = 0.404 \text{ (cm)} \end{aligned}$$

計画全厚 (59) 式より,

$$\begin{aligned} *t &= (C_1 \cdot a \cdot \sigma_{fc0} \cdot N_1) / (C_7 \cdot E_{f0} \overline{SF}_1) \\ &= (12 \times 150 \times 1,840 \times 600) / (192 \times 2.5 \times 10^5 \times 16) \\ &= 2.588 \text{ (cm)} \end{aligned}$$

計画芯材厚 (60) 式より,

$$t_c = t - 2t_{Fd} = 2.588 - (2 \times 0.404) = 1.78 \text{ (cm)}$$

* $t_{cd} = (\text{Balsa} + \text{M600} + \text{Balsa})$

$$\begin{aligned} &= (1.27 + 0.12 + 1.27) \\ &= 2.66 \text{ (cm)} \end{aligned}$$

* $t_{cd} = 1.90 \text{ (cm)}$, \overline{SF}_2 をクリアするため t_{cd} を増大

する。

(61) 式より,

$$t_d = t_{cd0} + 2t_{Fd} = 2.66 + (2 \times 0.404) = 3.468 \text{ (cm)}$$

(62) 式より,

$$\begin{aligned} e_{1d} &= (1/2)(t_{cd0} + t_{Fd}) = (1/2)(2.66 + 0.404) \\ &= 1.532 \text{ (cm)} \end{aligned}$$

曲げ剛性 (63) 式より,

$$\begin{aligned} D_s &= (E_{f0} t_{Fd} / 6\lambda_f)(t_{Fd}^2 + 3e_{1d}^2) \\ &= [(2.5 \times 10^5 \times 0.404) / (6 \times 0.9865)] \times \\ &\quad (0.404^2 + 3 \times 1.532^2) \\ &= 1.23 \times 10^5 \text{ (kgf} \cdot \text{cm)} \end{aligned}$$

(64) 式より,

$$\begin{aligned} V_s &= (D_s / t_{cd0} \cdot G_c)(\pi / b_T)^2 \\ &= [(1.23 \times 10^5) / (2.66 \times 562)](\pi / 150)^2 \\ &= 0.036 \\ K_c &= 3.80, (b_T / a_L) = 1 \end{aligned}$$

11.2 縦座屈安全率 (Trans System)

(65) 式より,

$$\begin{aligned} \overline{SF}_2 &= [(K_c \cdot D_s) / (2t_{Fd} \cdot \sigma_{HCd})](\pi / b_T)^2 \\ &= [(3.8 \times 1.23 \times 10^5) / (2 \times 0.404 \times 126)] \times \\ &\quad (\pi / 150)^2 \\ &= 2.02 > 2 \end{aligned}$$

11.3 応力安全率

($\sigma_{fT0} > \sigma_{fc0}$, よって σ_{fc0} と σ_{HCd} を採用する。)

(72) 式より,

$$\begin{aligned} \overline{SF}_3 &= \sigma_{fc0} / [(P_d \cdot a_L^2) / (C_1 \cdot t_{Fd} \cdot t_d) + \sigma_{HCd}] \\ &= \frac{1,840}{(0.064 \times 150^2) / (12 \times 0.404 \times 3.468) + 126} \\ &= 8.69 > 4 \end{aligned}$$

11.4 水圧撓み指数

(73) 式より,

$$\begin{aligned} N_1 &= \frac{C_7 \cdot E_{f0} G_c \cdot t_{Fd} \cdot t_d^2}{P_d \cdot a [(C_8 \cdot E_{f0} t_{Fd} \cdot t_d) + (G_c \cdot a^2)]} \\ &= 192 \times 2.5 \times 10^5 \times 562 \times 0.404 \times 3.468^2 / \\ &\quad \{0.064 \times 150 [(24 \times 2.5 \times 10^5 \times 0.404 \times 3.468) \\ &\quad + (562 \times 150^2)]\} \\ &= 649 > 600 \end{aligned}$$

11.5 強力甲板サンドイッチパネル寸法

甲板全厚: t_d

$$\begin{aligned} t_d &= t_{Fd} + t_{Cd} + t_{Fd} \\ &= H6 + \text{芯材} + H6 = 4.04 + 26.60 + 4.04 \\ &= 34.68 \text{ (mm)} \end{aligned}$$

芯材設計値: t_{Cd}

$$\begin{aligned} t_{Cd} &= \text{Balsa} + \text{M600} + \text{Balsa} = 12.7 + 1.2 + 12.7 \\ &= 26.60 \text{ (mm)} \\ T_F &= 2 \times 0.404 = 0.808 \text{ (cm)} \end{aligned}$$

11.6 強力甲板座屈発生安全率

11.6.1 近似座屈発生応力による値

(81) 式より,

$$\begin{aligned} \sigma_{Crw} &= 0.43 \sqrt[3]{E_{f0} \cdot E_{CT} \cdot G_c} \\ &= 0.43 \sqrt[3]{2.5 \times 10^5 \times 1,500 \times 562} \\ &= 2,559 \text{ (kgf/cm}^2\text{)} \end{aligned}$$

(82) 式より,

$$\begin{aligned} \sigma_{\max} &= (C_7 \cdot E_{f0} \cdot t_d) / (C_1 \cdot a_L \cdot N_1) + \sigma_{HCD} \\ &= \frac{192 \times 2.5 \times 10^5 \times 3.468}{12 \times 150 \times 600} + 126 \\ &= 154 + 126 = 280 \text{ (kgf/cm}^2\text{)} \end{aligned}$$

(83) 式より,

$$\overline{SF}_{w1} = \sigma_{Crw} / \sigma_{\max} = 2,559 / 280 = 9.14 > 3 \text{ 安全である。}$$

11.6.2 表皮材の初期撓みに基づく値

$$\begin{aligned} \sigma_{fT0} &> \sigma_{fC0} = 1,840 \text{ (kgf/cm}^2\text{)} \\ \sigma_{Pe} &= 25 \text{ (kgf/cm}^2\text{)}, \alpha_w = 0.05 = 1/20 \end{aligned}$$

(84) 式より,

$$\begin{aligned} Q &= \sigma_{fC0} \sqrt[3]{\lambda_f / (E_{f0} \cdot E_{CT} \cdot G_c)} \\ &= 1840 \sqrt[3]{0.9865 / (2.5 \times 10^5 \times 1,500 \times 562)} = 0.308 \end{aligned}$$

(85) 式より,

$$\begin{aligned} q &= (t_{Cd} \cdot G_c \cdot Q) / (t_{Fd} \cdot \sigma_{fC0}) \\ &= (2.66 \times 562 \times 0.308) / (0.404 \times 1,840) = 0.619 \\ \text{パラメータ値 } K &= 1.545 \end{aligned}$$

(86) 式より,

$$\begin{aligned} \overline{SF}_{w2} &= (\sigma_{Pe} \cdot t_{Cd} \cdot K) / (\alpha_w \cdot t_{Fd} \cdot E_{CT}) \\ &= (2.5 \times 2.66 \times 1.545) / (0.05 \times 0.404 \times 1,500) \\ &= 3.39 > 1.5 \text{ 安全である。} \end{aligned}$$

12. 非強力甲板サンドイッチパネル設計

(甲板開口側線内四辺支持扱い)

$$\begin{aligned} S &= a_L = 150 \text{ (cm)}, b_T = 250 \text{ (cm)}, P_d = 2P_2 = 0.064 \\ &\text{(kgf/cm}^2\text{)}, \text{Table 23. より, } \overline{SF}_1 = 6.86 \\ \sigma_{fT0} &= 4,230 > \sigma_{fC0} = 1,840 \text{ (kgf/cm}^2\text{)}, C_1 = 8, \\ C_6 &= 9.6, C_7 = 38.4, C_8 = 4.8, N_1 = 100 \\ \sigma_{HC1} &= \sigma_{fC0} / \overline{SF}_1 = 1,840 / 6.86 = 268 \text{ (kgf/cm}^2\text{)} \end{aligned}$$

(58) 式より,

$$\begin{aligned} t_F &= (C_6 \cdot P_d \cdot a \cdot E_{f0}) / (2C_1 \cdot N_1 \cdot \sigma_{HC1}^2) \\ &= \frac{9.6 \times 0.064 \times 150 \times 2.5 \times 10^5}{2 \times 8 \times 100 \times 268^2} = 0.200 \text{ (cm)} \end{aligned}$$

$$t_{Fd} = H4 = 0.270 \text{ (cm)},$$

(設計値 N_1 をクリヤするため増厚する。)

計画全厚値 (59) 式より,

$$\begin{aligned} t &= (C_1 \cdot a \cdot \sigma_{fC0} \cdot N_1) / (C_7 \cdot E_{f0} \cdot \overline{SF}_1) \\ &= (8 \times 150 \times 1,840 \times 100) / (38.4 \times 2.5 \times 10^5 \times 6.86) \\ &= 3.353 \text{ (cm)} \end{aligned}$$

芯材設計厚 (60) 式より,

$$\begin{aligned} t_c &= 3.353 - (2 \times 0.270) = 2.813 \text{ (cm)} \\ t_{Cd} &= (\text{Balsa} + \text{M} + \text{Balsa}) = 1.27 + 0.12 + 1.27 \\ &= 2.66 \text{ (cm)} \end{aligned}$$

(強力甲板と同一にする。)

設計全厚 (61) 式より,

$$t_d = t_{Cd} + 2t_{Fd} = 2.66 + (2 \times 0.270) = 3.20 \text{ (cm)}$$

応力安全率 (76) 式より,

$$\begin{aligned} \overline{SF}_3 &= (C_1 \cdot \sigma_{fC0} \cdot t_{Fd} \cdot t_d) / (P_d \cdot a^2) \\ &= (8 \times 1,840 \times 0.270 \times 3.20) / (0.064 \times 150^2) \\ &= 8.83 > 4 \end{aligned}$$

撓み指数 (73) 式より,

$$\begin{aligned} N_1 &= \frac{C_7 \cdot E_{f0} \cdot G_c \cdot t_{Fd} \cdot t_d^2}{P_d \cdot a [(C_8 \cdot E_{f0} \cdot t_{Fd} \cdot t_d) + (G_c \cdot a^2)]} \\ &= 38.4 \times 2.5 \times 10^5 \times 562 \times 0.270 \times 320^2 \div \\ &\quad \{0.064 \times 150 [(4.8 \times 2.5 \times 10^5 \times 0.270 \times 3.20) + \\ &\quad (562 \times 150^2)]\} \\ &= 114 > 100 \text{ 設計値は } N_1 = 114 \text{ となる。} \end{aligned}$$

非強力甲板サンドイッチ寸法

$$\begin{aligned} t_d &= t_{Fd} + t_{Cd} + t_{Fd} = H4 + \text{Coa} + H4 \\ &= 2.7 + 26.6 + 2.7 = 32.0 \text{ (mm)} \end{aligned}$$

$$t_{cd} = \text{Balsa} + \text{M600} + \text{Balsa} = 12.7 + 1.2 + 12.7 \\ = 26.6 \text{ (mm)}$$

非強力甲板サンドイッチ合計有効板厚

$$T_F = 2t_{Fd} = 2 \times 0.27 = 0.540 \text{ (cm)}$$

13. 甲板ビーム

$$P_2 = 0.032 \text{ (kgf/cm}^2\text{)}, S = 150 \text{ (cm)}, \\ l = 50B = 275 \text{ (cm)}, \text{ Table 33. より, } \overline{SF}_T = 4, \\ N_T = 195L^{0.15} = 312, \\ \sigma_f = \sigma_{fco} = 1,840 \text{ (kgf/cm}^2\text{)}$$

(123) 式より,

$$I_{Req} = (P_2 \cdot S \cdot l^3 \cdot N_T) / (C_2 \cdot E_{f0}^\circ) \\ = (0.032 \times 150 \times 275^3 \times 312) / (384 \times 2.5 \times 10^5) \\ = 325 \text{ (cm}^4\text{)}$$

(125) 式より,

$$Z_{Req} = (P_2 \cdot S \cdot l^2 \cdot \overline{SF}_T) / (C_1 \cdot \sigma_{fco}^\circ) \\ = (0.032 \times 150 \times 275^2 \times 4) / (12 \times 1,840) \\ = 65.8 \text{ (cm}^3\text{)}$$

$$I_{Req} = 325 \text{ (cm}^4\text{)} \quad Z_{Req} = 65.8 \text{ (cm}^3\text{)}$$

$$\begin{array}{llll} H_w \text{ (cm)} & 12 & = & 12 \\ t_f \text{ (cm)} & 0.274 & < & 0.60 \quad b_2 = b_f = 8 \text{ (cm)} \\ A_f \text{ (cm}^2\text{)} & 1.36 & < & 3.00 \end{array}$$

(93) 式より,

$$t_{fc} = [0.6 + 12(3/12)] / [1 + 12(8/12)] = 0.400 \text{ (cm)} \\ t_{fd} = H6 = 0.404 \text{ (cm)} = t_{wd}, \quad (H = n = 6)$$

(95) 式より,

$$b_e = 3[1 + (6 \times 6.1) / (4 \times 6.5)] = 7.22 \text{ (cm)}$$

(96) 式より, $b_P = (40 \times 0.404) + 8 = 24.2 \text{ (cm)}$

Table 13. 甲板ビーム部寸法

	a	l	m	i	i'
①0.404×24.2	9.78	-0.202	-2.0	0.4	
②0.404×7.2×2	5.83	0.202	1.2	0.2	
③12×0.404×2	9.70	6	58.2	349.2	116.4
④0.404×8	3.23	12.202	39.4	480.9	
	28.54		Σ 96.8	947.1	
			3.39		

$I_d = 619 \text{ (cm}^4\text{)}, I_{Req} = 325 \text{ (cm}^4\text{)}, Y_F = 9.01 \text{ (cm)}, A_{oT} = 19.06 \text{ (cm}^2\text{)}, \\ Z_d = 68.7 \text{ (cm}^3\text{)}, Z_{Req} = 65.8 \text{ (cm}^3\text{)}, h_T = 13 \text{ (cm)}: \text{ (甲板ガーダ貫通高さ)} H_w \times (b_f/b_2) \times (t_f/t_w) = 120 \times (80/80) \times (4.04/4.04) \text{ (mm)}$

$$h_T = 13 \text{ (cm)}: \text{ 甲板ガーダ貫通高さ} \\ H_w \times (b_f/b_2) \times (t_f/t_w) \\ = 120 \times (80/80) \times (4.04/4.04) \text{ (mm)}$$

14. 甲板ガーダ (サンドイッチ甲板ガーダ)

$$S = 200 \text{ (cm)}, h_T = 13 \text{ (cm)}, l_{max} = 400 \text{ (cm)}, \\ P_2 = 0.032 \text{ (kgf/cm}^2\text{)}, l_T = 50B = 275 \text{ (cm)}, \\ \text{Table 30 より, } N_L = 8L^{1.56} = 1065, \overline{SF}_L = 5, \\ \overline{SF}_{2L} = 2, \overline{SF}_{4L} = 7, L_d = 1, V/W^{1/6} = 16.93,$$

14.1 推定甲板縦曲げ応力

(4) 式より, $\beta_i = 12.92^\circ, A_F = 6 \text{ (g)}$

$$M_S = [W \cdot L(A_F + 1)/60][(39 - \beta_T)/(29 - \beta_T)] \\ = [31 \times 23(6 + 1)/60][(39 - 12.92)/(29 - 12.92)] \\ = 134.9 \text{ (Ton} \cdot \text{m)}$$

(200) 式より,

$$t_m = [(6.74 \times 0.15) + (4.04 \times 0.88) + (6.74 \times 1.5)] \\ \times (1/2.5) \\ = 5.87 \text{ (mm)}$$

(7) 式より,

$$e = 1.25[1 - (B_H/B)] = 1.25[1 - (250/550)] = 0.682$$

(8) 式より,

$$\sigma_{DK} = \frac{M_S^{1.34}(E_{f0}^\circ \times 10^{-5})^{0.35} e \times 10^3}{L^{0.9} t_m^{1.1} D^{3.44} (V/W^{1/6})^{0.21}} \\ = \frac{134.9^{1.34} \times 2.5^{0.35} \times 0.682 \times 10^3}{23^{0.9} \times 5.87^{1.1} \times 2.5^{3.44} \times 16.93^{0.21}} \\ = 135 \text{ (kgf/cm}^2\text{)}$$

14.2 甲板ガーダ要求値

(縦強度計算の甲板ガーダを算定する甲板応力を(8)式により, 推算して使用する。)

(109) 式より,

$$I_{Req} = (P_2 \cdot S \cdot l^3 \cdot N_L) / (C_2 \cdot E_{f0}^\circ) \\ = \frac{(0.032 \times 200 \times 400^3 \times 1,065)}{(384 \times 2.5 \times 10^5)} = 4,544 \text{ (cm}^4\text{)}$$

(111) 式より,

$$Z_{Req} = (P_2 \cdot S \cdot l^2) / \{C_1[(\sigma_{fco}^\circ / \overline{SF}_L) - \sigma_{Hcd}]\} \\ = \frac{0.032 \times 200 \times 400^2}{12[(1,840/5) - \sigma_{DK}]} = 85,333/242 \\ = 353 \text{ (cm}^3\text{)}$$

(118) 式より, $C=1$

$$A_w \tau = P_2 \cdot S_0 \cdot \overline{I} S F_{4L} \cdot L_d / \tau_{EW90}^\circ$$

$$= 0.032 \times 200 \times 400 \times 7 \times 1 / 1,400 = 12.8 \text{ (cm}^2\text{)}$$

14.3 甲板ガーダ寸法

$$I_{Req} = 4,544 \text{ (cm}^4\text{)} \quad Z_{Req} = 353 \text{ (cm}^3\text{)}$$

$$H_w \text{ (cm)} \quad 22 = 22$$

$$t_f \text{ (cm)} \quad 1.20 < 1.313 \quad b_2 = b_f = 15 \text{ (cm)}$$

$$A_f \text{ (cm}^2\text{)} \quad 8.75 < 11.25$$

(93) 式より,

$$t_{fc} = [1.313 + 12(11.25/22)] / [1 + 12(15/22)]$$

$$= 0.811 \text{ (cm)}$$

$$t_{fc} = 0.811 \text{ (cm)}, b_f = b_2 = 15 \text{ (cm)}, t_P = 0.404 \text{ (cm)}$$

$$h_T = 13 \text{ (cm)}, h_w = 9 \text{ (cm)}, H_w = 22 \text{ (cm)},$$

$$A_w \tau = 12.8 \text{ (cm}^2\text{)}$$

残存ハットウェブ板厚 (94) 式より,

$$t_{wc} = t_{fc} [H_w / (H_w - h_T)^{0.77}] = 0.811 (22/9)^{0.77}$$

$$= 1.61 \text{ (cm)} \leq 2t_{fc}$$

$$t_{wdmax} = 2t_{fc} = H/24 = 1.62 \text{ (cm)}$$

(96) 式より, $b_P = 40_{tP} + b_2 = (40 \times 0.404) + 15$
 $= 31.2 \text{ (cm)}$

Table 14. 甲板ガーダ部寸法

	a	l	m	i	i'
①0.404×31.2	12.60	-0.202	-2.5	0.5	
②9×1.62×2	29.16	17.5	510.3	8930.3	196.6
③1.62×15	24.30	22.81	554.3	12643.2	
	66.06		Σ 1062.1	21770.8	
			16.08		

$$I_c = 4,690 \text{ (cm}^4\text{)}, I_{Req} = 4,544 \text{ (cm}^4\text{)}, Y_P = 16.48 \text{ (cm)},$$

$$Z_c = 285 \text{ (cm}^3\text{)}, Z_{Req} = 366 \text{ (cm}^3\text{)}$$

(97) 式より,

$$H_{wd} = 22 \sqrt{353/285} = 24.5 \text{ (cm)} \rightarrow 25 \text{ (cm)}$$

(高さ修正)

$$h_w = H_{wd} - h_T = 25 - 13 = 12 \text{ (cm)}$$

Table 15. 甲板ガーダ部寸法

	a	l	m	i	i'
①0.404×31.2	12.60	-0.202	-2.5	0.5	
②12×1.62×2	38.88	19.0	738.7	14035.7	466.6
③1.62×15	24.30	25.81	627.2	16187.6	
	75.78		Σ 1363.4	30690.4	
			17.99		

$$I_c = 6,165 \text{ (cm}^4\text{)}, I_{Req} = 4,544 \text{ (cm}^4\text{)}, Y_P = 18.39 \text{ (cm)},$$

$$Z_c = 335 \text{ (cm}^3\text{)}, Z_{Req} = 366 \text{ (cm}^3\text{)}$$

(98) 式より,

$$b_{fd} = b_f (Z_{Req}/Z_c)^2 = 15(366/335)^2 = 17.9 \rightarrow 18 \text{ (cm)}$$

(高さを制限し, 幅を変化させる)

(96) 式より, $b_{Pd} = (40 \times 0.404) + 18 = 34.2 \text{ (cm)}$

$$b_{fd} = b_{2d} = 18 \text{ (cm)}, H_{wd} = 25 \text{ (cm)},$$

$$h_w = 25 - 13 = 12 \text{ (cm)}, b_{Pd} = 34.2 \text{ (cm)}$$

Table 16. 甲板ガーダ部寸法

	a	l	m	i	i'
①0.404×34.2	13.82	-0.202	-2.8	0.6	
②12×1.62×2	38.88	19.0	738.7	14035.7	466.6
③1.62×18	29.16	25.81	752.6	19425.1	
	81.86		Σ 1488.5	33928.0	
			18.18		

$$I_d = 6,872 \text{ (cm}^4\text{)}, I_{Req} = 4,544 \text{ (cm}^4\text{)}, Y_P = 18.58 \text{ (cm)},$$

$$Z_d = 370 \text{ (cm}^3\text{)}, Z_{Req} = 366 \text{ (cm}^3\text{)}$$

甲板ガーダ寸法

$$H_w \times (b_f/b_2) \times (t_f/t_w)$$

$$= 250 \times (180/180) \times (16.2/16.2) \text{ (mm)}$$

$$a_0 = 68.04 \text{ (cm}^2\text{)}, m_0 = 1,491.3 \text{ (cm}^3\text{)},$$

$$t_{dDK} = 3.468 \text{ (cm)}$$

$$e_0 = (m_0/a_0) + t_{dDK} = 21.92 + 3.47 = 25.4 \text{ (cm)}$$

$$= 0.254 \text{ (m)}$$

14.4 甲板ガーダ縦座屈安全率

$$A = 81.86 \text{ (cm}^2\text{)}, A_w = 38.88 \text{ (cm}^2\text{)}, l_0 = 600 \text{ (cm)},$$

$$I_d = 6,872 \text{ (cm}^4\text{)}, \sigma_{DK} = 135 \text{ (kgf/cm}^2\text{)},$$

$$\sigma_{Hcd} = 126 \text{ (kgf/cm}^2\text{)},$$

(113)式より,

$$\overline{SF}_{2L} = \frac{(E_{f0} I_d / (A \cdot \sigma_{HC})) (\pi / l_0)^2}{(E_0 / G) (I_d / A_w) (\pi / l_0)^2 + 1}$$

$$= \frac{2.5 \times 10^5 \times 6872 / (81.86 \times \sigma_{HC})}{(2.5 / 0.27) (6872 / 38.88) + 1} = 551 / \sigma_{HC} \geq 2$$

Table 17. 縦座屈安全率

	σ_{BK}	σ_{HCL}
σ_{HC} (kgf/cm ²)	135	126
$\overline{SF}_{2L} \geq 2$	4.08	4.37

14.5 甲板ガーダ設計係数解析

(110)式より,

$$N_L = (C_2 \cdot E_{f0} \cdot I_L) / (P_2 \cdot S \cdot l^3)$$

$$= (384 \times 2.5 \times 10^5 \times 6,872) / (0.032 \times 200 \times 400)$$

$$= 1,611 > 18L^{1.56} = 1,065$$

(112)式より,

$$\overline{SF}_L = C_1 \cdot \sigma_{fco} \cdot Z_L / (P_2 \cdot S \cdot l^2 + C_1 \cdot Z_L \cdot \sigma_{HCL})$$

$$= 12 \times 1,840 \times 370 / [(0.032 \times 200 \times 400^2)$$

$$+ (12 \times 370 \times 126)]$$

$$= 5.16 > 5$$

14.6 甲板ガーダハットクラウン曲げ座屈安全率

(137)式より,

$$K_2 = \pi \sqrt{[1.1 C_f (3 + 2 K_f) / 12] (E_0 / \lambda)_f}$$

$$= \pi \sqrt{[1.1 \times 12 (3 + 2 \times 0.329 / 12)]$$

$$\times \sqrt{2.5 \times 10^5 / 0.9865}} = 3172$$

$$K_f = [\mu + (2 \lambda \cdot G / E_0)]_f = 0.329,$$

Table 37 より $C_f = 12$, $L_d = K_2 = 1.0$

(136)式より,

$$\overline{SF}_B = [Z_L / (P_2 \cdot S \cdot l^2 \cdot L_d)] \times$$

$$[(K_2 \cdot t_f / b_f)^2 - (C_f \cdot \sigma_{HCL})]$$

$$= [370 / (0.032 \times 200 \times 400^2 \times 1)] \times$$

$$[(3,172 \times 1.62 / 18)^2 - (12 \times 126)]$$

$$= 28.90 > 1.5 \text{ 座屈なし。}$$

$$Z = 370 \text{ (cm}^3\text{)}, \sigma_{HCL} = 126 \text{ (kgf/cm}^2\text{)}, L_d = 1$$

14.7 甲板ガーダハットウェブ剪断座屈安全率

$$C_a \approx 10, L_d = 1, H_{wd} = 25 \text{ (cm)}, \overline{SF}_\tau = 1.5, C\tau = 2,$$

$$l = 400 \text{ (cm)}, S = 200 \text{ (cm)}, t_w = 1.62 \text{ (cm)}$$

(140)式より,

$$K_3 = \sqrt[3]{2 C_a \cdot E_{f0} \cdot C_\tau / 3 \lambda_f}$$

$$= \sqrt[3]{2 \times 10 \times 2.5 \times 10^5 \times 2 / (3 \times 0.9865)} = 150$$

(139)式より,

$$\overline{SF}_\tau = (t_w \cdot K_3)^3 / (P_2 \cdot L_d \cdot H_{wd} \cdot S \cdot l)$$

$$= (1.62 \times 150)^3 / (0.032 \times 1 \times 25 \times 200 \times 400)$$

$$= 224 > 1.5$$

15. 支柱〔圧力配管用炭素鋼管 (STPG-38)〕

$$W_P = P_2 \cdot a_P \cdot b_P = 0.032 \times 300 \times 200 = 1,920 \text{ (kgf)}$$

$$l = 130 \text{ (cm)}, \overline{SF} = 2, 40 t_m > d_0$$

15.1 弾性域座屈設計

$$t_3 > W_P / 72 l = 1,920 / (72 \times 130) = 0.205 \text{ (cm)}$$

$$(d_0 - t_3) < l / 38.36 = 130 / 38.36 = 3.39 \text{ (cm)}$$

$$\overline{SF}_3 = \{2.1 \times 10^6 \cdot t_3 [\pi (d_0 - t_3)]^3\} / (8 W_P \cdot l^2)$$

$$= \{t_3 (d_0 - t_3)^3 / 3.99\} > 2$$

$$\sigma_{cr} = (2.1 \times 10^6 / 8) [\pi (d_0 - t_3) / l]^2$$

$$= 153 (d_0 - t_3)^2 < 1,760 \text{ (kgf/cm}^2\text{)}$$

$d_0 < (3.39 + t_3) < 3.595 \text{ (cm)}$ 適当な Pipe が存在しない。

15.2 塑性域座屈設計

$$(d_0 - t_4) > l / 38.36 = 130 / 38.36 = 3.39 \text{ (cm)}$$

$$\overline{SF}_4 = (7,288 t_4 / W_P) \{[(d_0 - t_4) - [l^2 / 6,098 (d_0 - t_4)]]\}$$

$$= 3.796 t_4 \{(d_0 - t_4) - [2.77 / (d_0 - t_4)]\} \geq 2$$

$$\sigma_{cr} = \frac{W_P \cdot \overline{SF}_4}{[\pi \cdot t_4 (d_0 - t_4)]} = \frac{1,920 \times \overline{SF}_4}{[\pi \cdot t_4 (d_0 - t_4)]}$$

$$\geq 1,760 \text{ (kgf/cm}^2\text{)}$$

Table 18. 塑性域座屈設計

	Schedule	40
d_a	3.40	4.27
t_a	0.34	0.36
$(d_a - t_a) > 3.39$	\times 3.06	\bigcirc 3.91
$\overline{SF}_4 > 2$		\bigcirc 4.38
$\sigma_{cr} > 1,760$		\bigcirc 1,901
$40 t_a > d_a$		\bigcirc 14.4

STPG (32A×3.6t) #40 Pipe. $\overline{SF}_3 = 4.38 > 2$

16. 中央部縦強度計算

(A, N, A_x を B, L , 上 1,000 とする。)

Table 19. 中央部縦強度計算

	a	l	m	i	h	i'
Keel Plate 0.674×52.5	35.39	0.945	33.4	31.6		
BTM Plate 0.404×228	192.11	0.488	44.9	21.9	0.870	5.8
No.1 BTM L 86.66	86.66	0.757	65.6	49.7		
No.2 BTM L 86.66	86.66	0.327	28.3	9.3		
Chine Reinforce 0.337×30	10.11	0.105	1.1	0.1		
	310.93		173.3	112.6		5.8
Side Shell 0.674×150	101.10	0.715	72.3	51.7	1.500	19.0
Side Chine Reinforce 0.337×40	13.48	0.115	1.6	0.2	0.400	0.2
Sheer Reinforce 0.337×40	13.48	1.305	17.6	23.0	0.400	0.2
Gunnel angle 1.011×12×2	24.26	1.500	36.4	54.6		
DK Girder 38.02	68.04	1.297	88.2	114.5		
DK Plate 0.808×160	129.28	1.500	193.9	290.9		
Stringer Reinforce 0.270×40	10.80	1.572	16.4	25.0		
	360.44 +310.93 671.37		426.4 -173.3 253.1 0.377	559.9 +112.6 672.5 +25.2 697.7		19.4 +5.8 25.2

Table 20. Bottom and Deck値

Bottom	Deck
$Y_B = 1.377$ (m)	$Y_{DK} = 1.123$ (m)
$Z_B = 874.8$ (cm ² ·m)	$Z_{DK} = 1072.6$ (cm ² ·m)
$\sigma_{BS} = +154$ (kgf/cm ²)	$\sigma_{DKS} = -126$ (kgf/cm ²)
$\sigma_{BH} = -69.4$ (kgf/cm ²)	$\sigma_{DKH} = +56.6$ (kgf/cm ²)

$I_B = 1204.56$ (cm⁴·m²)、 $M_B = 134.9$ (Ton·m)、
 $M_H = 60.7$ (Ton·m)、 $F_H = 5.87$ (Ton)

17. 主機室前方横隔壁

$E_{f90^\circ} = 2 \times 10^5$ (kgf/cm²)、 $\sigma_{B90^\circ} = 2,980$ (kgf/cm²)、
 $K_E(E_{f90^\circ} \times 10^{-5}/2.5)^{1/3} = 0.928$ 、 $N_B = 40K_E = 37$

$$N_T = 35K_E = 32,$$

$$D_* = 2.5 \text{ (m)} > 2d_* = 2 \times 0.85 = 1.7 \text{ (m)} = d_1$$

$$\text{下端: } P_B = 1.025d_1/10 = 1.025 \times 1.7/10 \\ = 0.174 \text{ (kgf/cm}^2\text{)},$$

$$\text{上中段: } P_T = 3 \cdot P_B/4 = 0.131 \text{ (kgf/cm}^2\text{)},$$

17.1 隔壁板厚設計

Table 21. 隔壁板厚設計

	船底部	上中段部
P (kgf/cm ²)	0.174	0.131
a (cm)	125	140
\overline{SF}_1	2.5	
$\theta = (P \cdot E_{f90^\circ} / \lambda) (\overline{SF}_1 / \sigma_{BS} \cdot \Gamma)^2$	1.103×10^{-2}	8.307×10^{-3}
$\Omega = (a/t) \sqrt{\lambda \cdot \Gamma \cdot \sigma_{BS} / E_{f90^\circ} \cdot \overline{SF}_1}$	42.0	56.0
(a/t)	447	596
t_c (cm)	0.279	0.235
$H = t_c / 0.0674$	5	4
t_s (cm)	0.337	0.270
$\Psi = P (\lambda / E_{f90^\circ}) \cdot (a/t)^4$	1.62×10^4	4.67×10^4
$\Lambda = (\sigma_{BS} \cdot \lambda \cdot \Gamma / E_{f90^\circ}) (a/t)^2$	1.07×10^3	2.15×10^3
$\overline{SF}_2 = (\lambda \cdot \Gamma \cdot \sigma_{BS} / \Lambda \cdot E_{f90^\circ}) (a/t)^2$	$2.83 > 2.5$	$2.76 > 2.5$
(W/t)	8.65	12.60
N	$42.9 > 37$	$41.2 > 32$
$W = 10 \times a/N$ (mm)	29.1	34.0

17.2 船体中心線防撓材 (両端支持)

$$b = 125 \text{ (cm)}, l = 250 \text{ (cm)}, P_B = 0.174 \text{ (kgf/cm}^2\text{)},$$

$$N = 75, \overline{SF} = 3, C_4 = 9/\sqrt{3}, C_5 = 153,$$

$$\sigma_{fT0^\circ} > \sigma_{fC0^\circ} = 1,840 \text{ (kgf/cm}^2\text{)} = \sigma_{f0^\circ}$$

(163) 式より,

$$I = (P_B \cdot b \cdot l^3 \cdot N) / (C_5 \cdot E_{f0^\circ}) \\ = \frac{0.174 \times 125 \times 250^3 \times 75}{153 \times 2.5 \times 10^5} = 666 \text{ (cm}^4\text{)}$$

(164) 式より,

$$Z = (P_B \cdot b \cdot l^2 \cdot \overline{SF}) / (C_4 \cdot \sigma_{fC0^\circ}) \\ = \frac{0.174 \times 125 \times 250^2 \times 3}{(9/\sqrt{3}) \times 1840} = 142 \text{ (cm}^3\text{)}$$

$$I_{\text{Req}} = 666 \text{ (cm}^4\text{)} \quad Z_{\text{Req}} = 142 \text{ (cm}^3\text{)}$$

$$H_w \text{ (cm)} \quad 15 \quad = \quad 15$$

$$t_f \text{ (cm)} \quad 0.80 \quad < \quad 1.25 \quad b_2 = b_f = 8 \text{ (cm)}$$

$$A_f \text{ (cm}^2\text{)} \quad 1 \quad < \quad 6$$

(93) 式より,

$$t_{fC} = [t_f + 12(A_f/H_w)] / [1 + 12(b_f/H_w)]$$

Table 22. Balsa Coa K/G Hybrid FRP Sandwich Panel.

	$t_f + t_c + t_r$	t_s	Balsa+M600+Balsa
内張キール	3.37+40.4+3.37	47.14	19+2M+19
船底外板	2.02+32.8+2.02	36.84	15.8+M+15.8
船側外板	3.37+32.8+3.37	39.54	15.8+M+15.8
強力甲板	4.04+26.6+4.04	34.68	12.7+M+12.7
非強力甲板	2.70+26.6+2.70	32.00	12.7+M+12.7

主構造部目
 L B D = 23.00(m) × 5.50(m) × 2.50(m) × 0.85(m)
 W V A = 31.00(m) × 30.00(m) × 6(m)
 重量容積 6.000(m)
 船底心積 1.500(m)
 Kevlar/Glass Hybrid Cloth 使用
 H=0.674(m)

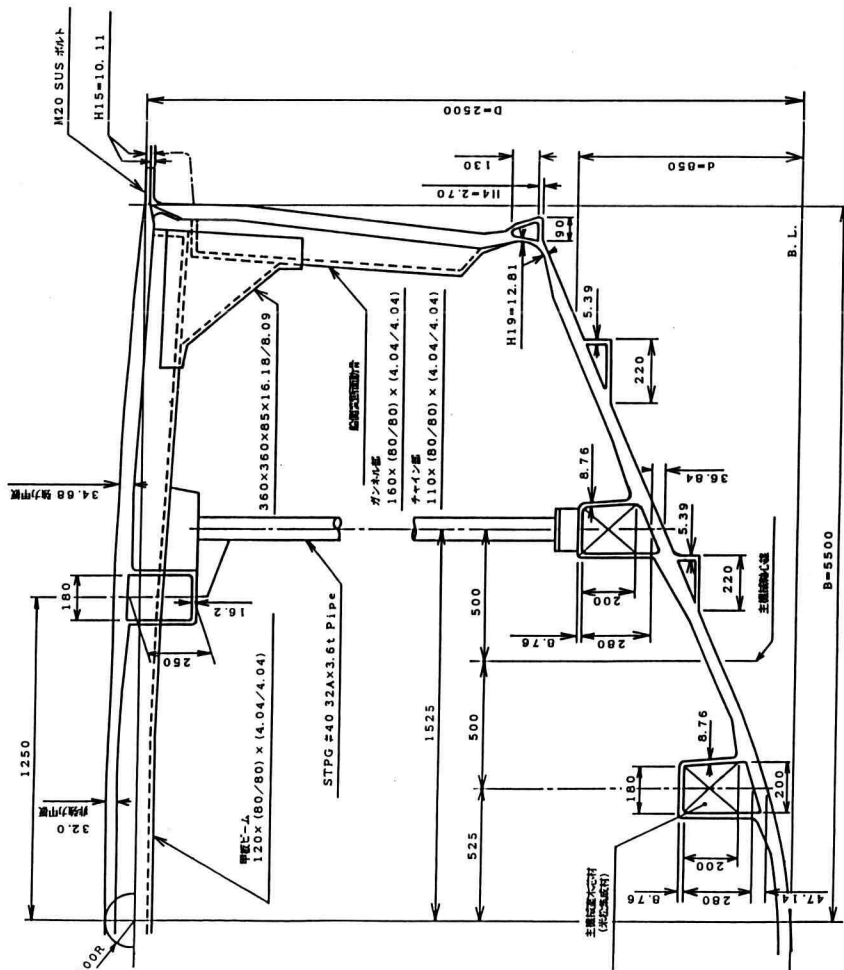


Fig. 2 主機室前端横隔壁

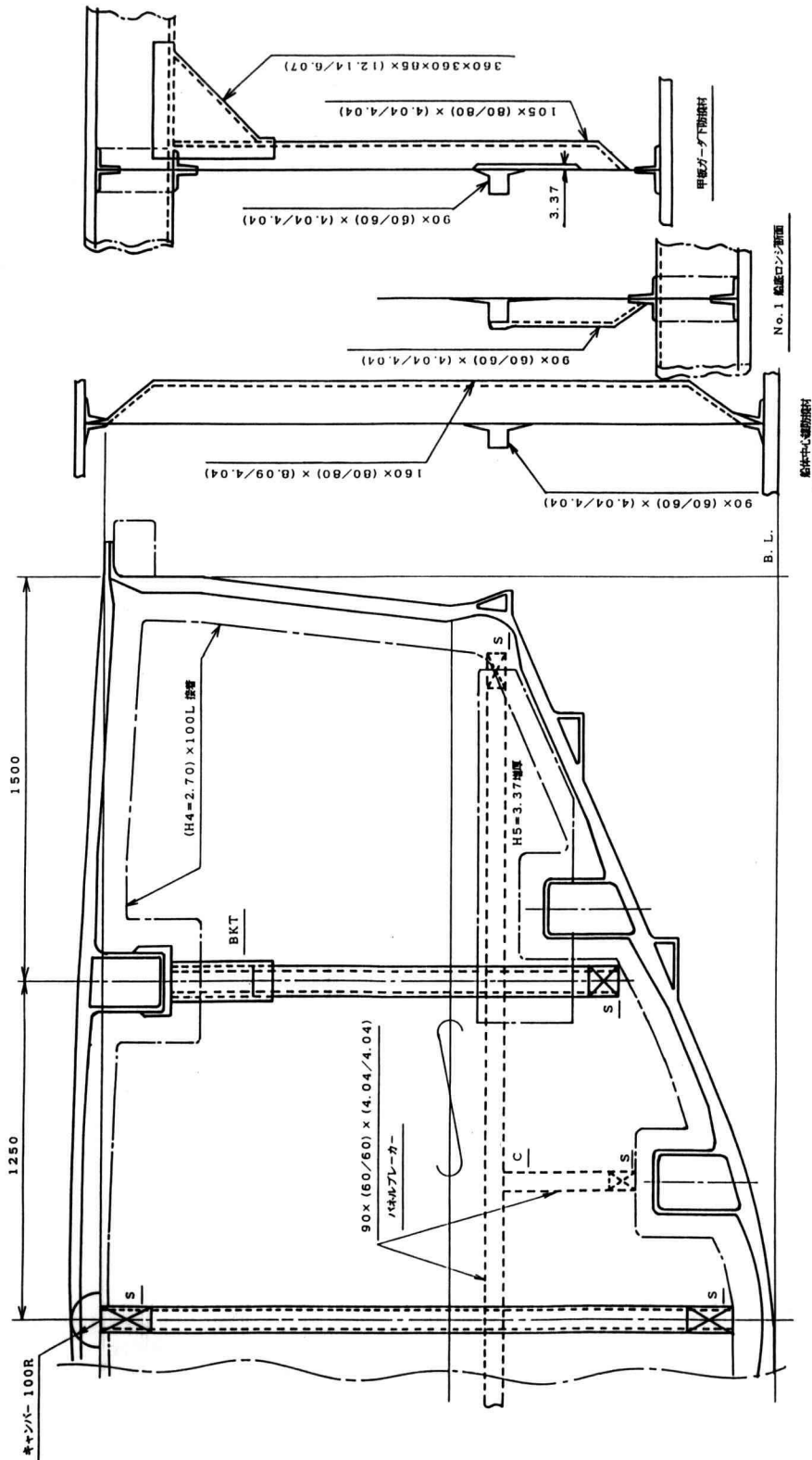


Fig. 3

$$= [1.25 + 12(6/15)] / [1 + 12(8/15)] = 0.818 \text{ (cm)}$$

$$t_{fd} = H12 = 0.809 \text{ (cm)},$$

$$t_{wd} = H6 = 0.404 \text{ (cm)}, (H = n = 6)$$

(95) 式より,

$$b_e = 3\{1 + [(6/4)(6+0.1)/(6+0.5)]\} = 7.22 \text{ (cm)}$$

(96) 式より, $b_P = (40 \times 0.337) + 8 = 21.5 \text{ (cm)}$

Table 23. 船体中心線防撓材寸法

	a	l	m	i	i'
①0.337×21.5	7.25	-0.1685	-1.2	0.2	
②0.404×7×2	5.66	0.202	1.1	0.2	
③15×0.404×2	12.12	7.5	90.9	681.8	227.3
④0.809×8	6.47	15.405	99.7	1535.2	
	31.50		Σ 190.5	2444.7	
			6.05		

$$I_d = 1,292(\text{cm}^4), I_{req} = 833(\text{cm}^4), Y_f = 9.76(\text{cm}),$$

$$Z_d = 132(\text{cm}^3), Z_{req} = 142(\text{cm}^3)$$

船体中心線防撓材修正計算 (97) 式より,

$$H_{wd} = H_w \sqrt{Z_{req}/Z_c} = 15\sqrt{142/132} = 16 \text{ (cm)}$$

Table 24. 船体中心線防撓材修正計算寸法

	a	l	m	i	i'
①0.337×21.5	7.25	-0.1685	-1.2	0.2	
②0.404×7×2	5.66	0.202	1.1	0.2	
③16×0.404×2	12.93	8.0	103.4	827.5	275.8
④0.809×8	6.47	16.405	106.1	1741.0	
	32.31		Σ 209.40	2844.7	
			6.48		

$$I_d = 1,488(\text{cm}^4), I_{req} = 666(\text{cm}^4), Y_f = 10.33(\text{cm}),$$

$$Z_d = 144(\text{cm}^3), Z_{req} = 142(\text{cm}^3)$$

中心線防撓材寸法

$$H_w \times (b_f/b_2) \times (t_f/t_w) = 160 \times (80/80) \times (8.09/4.04) (\text{mm})$$

17.3 甲板ガーダ直下防撓材 (上端固定下端支持)

$$C_4 = (120/7), C_5 = 327, P_B = 0.174 \text{ (kgf/cm}^2\text{)},$$

$$\overline{SF}_0 = 2 \sim 4, L_d = 1$$

$$\sigma_{f0} = \sigma_{fc0} = 1,840 \text{ (kgf/cm}^2\text{)} < \sigma_{fT0}$$

設定断面係数 (167) 式より,

$$Z_0 = (P_B \cdot b \cdot l^2 \cdot \overline{SF}_0) / (C_4 \cdot \sigma_{fc0})$$

$$= \frac{0.174 \times 138 \times 165^2 \times \overline{SF}_0}{(120/7) \times 1,840} = 20.73 \overline{SF}_0 \text{ (cm}^3\text{)}$$

防撓材断面積 (168) 式より,

$$A = [A_f + 2t_w(H_w + b_e) + (t_P \cdot b_P)] \text{ (cm}^2\text{)}$$

計算断面係数 (169) 式より,

$$Z_c = \frac{P_B \cdot b \cdot l^2}{C_4[(\sigma_{fc0}/2.5) - (P_2 \cdot b_0 \cdot l_0 \cdot L_d/2A)]}$$

$$= 0.174 \times 138 \times 165^2 / \{ (120/7)[(1840/2.5) - (0.032 \times 200 \times 600 \times 1/2A)] \}$$

$$= 51.8 / [1 - (2.6/A)] \text{ (cm}^3\text{)}$$

断面 2 次モーメント (170) 式より,

$$I_c = (P_B \cdot b \cdot l^3 \cdot N) / (C_5 \cdot E_{f0})$$

$$= (0.174 \times 138 \times 165^3 \times 90) / (327 \times 2.5 \times 10^5)$$

$$= 119 \text{ (cm}^4\text{)}$$

応力安全率 (171) 式より,

$$\overline{SF}_1 = \frac{\sigma_{fc0}}{[P_B \cdot b \cdot l^2 / (C_4 \cdot Z)] + (P_2 \cdot b_0 \cdot l_0 \cdot L_d/2A)}$$

$$= 1,840 / \{ [0.174 \times 138 \times 165^2 / (120Z/7)] + (0.032 \times 200 \times 600 \times 1/2A) \}$$

$$= 0.958 / [(19.86/Z) + (1/A)]$$

縦座屈安全率 (172) 式より,

$$\overline{SF}_2 = \frac{[2E_{f0} \cdot I / (P_2 \cdot b_0 \cdot l_0 \cdot L_d)](\pi/l)^2}{[I \cdot E_{f0} / (A_w \cdot G_f)](\pi/l)^2 + 1}$$

$$= [(2 \times 2.5 \times 10^5 \times I) / (0.032 \times 200 \times 600 \times 1)] \times (\pi/165)^2 / \{ [I \times 2.5 / A_w \times 0.27] (\pi/165)^2 + 1 \}$$

$$= 0.047I / [(1/298)(I/A_w) + 1]$$

撓み指数 (173) 式より,

$$N = (C_5 \cdot E_{f0} \cdot I) / (P_B \cdot b \cdot l^3)$$

$$= (327 \times 2.5 \times 10^5 \times I) / (0.174 \times 138 \times 165^3)$$

$$= I / 1.32$$

ハット頂板厚さ (93) 式より,

$$t_{fc} = [t_f + 12(A_f/H_w)] / [1 + 12(b_2/H_w)]$$

$$= 0.9[(H_w + 40) / (H_w + 96)] \text{ (cm)}$$

フランジ有効幅 (95) 式より, $n = H$ として,

$$b_e = 3\{1 + (H/4)(H+0.1)/(H+0.5)\} \text{ (cm)}$$

(168) 式より,

$$(t_P \cdot b_P) = t_P(40t_P + b_2) = [(40 \times 0.337) + 8] \times 0.337$$

$$= 7.24 \text{ (cm}^2\text{)}$$

Table 25. \overline{SF}_0

\overline{SF}_0	2	3	4
Z_0 (cm ³)	41.5 (a) ₀	62.2 (b) ₀	82.9
H_w (cm)	8	10.5	13
t_f (cm)	0.8		
A_f (cm ²)	3.0		
t_{fc} (cm)	0.415	0.427	0.438
$H=t_{fc}/0.0674$	7	7	7
$t_{fd}=t_{wd}$ (cm)	0.472	0.472	0.472
b_e (cm)	7.97	7.97	7.97
A (cm ²)	25.3	27.7	30.0
Z_c (cm ³)	57.7 (a) _c	57.2 (b) _c	56.7

比例常数 (174) 式より,

$$C_X = (Z_{ac} - Z_{a0}) / [(Z_b - Z_a)_0 + (Z_a - Z_b)_c] \\ = (57.1 - 41.5) / [(62.2 - 41.5) + (57.7 - 57.2)] \\ = 0.764$$

設計防撓材

$$\text{ウェブ高さ } H_w = (10.5 - 8)C_X + 8 = 9.91 \text{ (cm)}$$

$$\text{断面係数 } Z_0 = (62.2 - 41.5)C_X + 41.5 \\ = 57.3 \text{ (cm}^3\text{)}$$

$$\text{断面積 } A = (27.7 - 25.3)C_X + 25.3 = 27.1 \text{ (cm}^2\text{)}$$

応力安全率 (171) 式より,

$$\overline{SF}_1 = 0.958 / [(1/A) + (19.86/Z)] = 2.50 > 2$$

防撓材設計寸法

$$I_{\text{Req}} = 119 \text{ (cm}^4\text{)} \quad Z_{\text{Req}} = 57.3 \text{ (cm}^3\text{)}$$

$$H_w \text{ (cm)} \quad 11 \quad = \quad 11$$

$$t_f \text{ (cm)} \quad 0.10 \quad < \quad 0.53 \quad b_2 = b_f = 8 \text{ (cm)}$$

$$A_a \text{ (cm}^2\text{)} \quad 0.50 \quad < \quad 2.65$$

(93) 式より,

$$t_{fc} = [0.53 + 12(2.65/11)] / [1 + 12(8/11)] \\ = 0.352 \text{ (cm)},$$

$$H_6 = 0.404 \text{ (cm)} = t_{fd} = t_{wd}$$

(95) 式より,

$$b_e = 3[1 + (6 \times 6.1) / (4 \times 6.5)] = 7.22 \text{ (cm)}$$

応力安全率 (171) 式より,

$$\overline{SF}_1 = 0.958 / [(1/A) + (19.86/Z_a)] \\ = 0.958 / [(1/25.2) + (19.86/59.4)] = 2.56 > 2$$

縦座屈安全率 (172) 式より,

Table 26. 甲板ガーダ防撓材設計寸法

	a	l	m	i	i'
①0.337×21.5	7.25	-0.1685	-1.2	0.2	
②0.404×7.22×2	5.83	0.202	1.2	0.2	
③11×0.404×2	8.89	5.5	48.9	268.9	89.6
④0.404×8	3.23	11.202	36.2	405.3	
	25.20		Σ 85.1	764.2	
			3.38		

$$I_d = 476 \text{ (cm}^4\text{)}, I_{\text{Req}} = 119 \text{ (cm}^4\text{)}, Y_f = 8.02 \text{ (cm)}, \\ Z_d = 59.4 \text{ (cm}^3\text{)}, Z_{\text{Req}} = 57.3 \text{ (cm}^3\text{)}, A = 25.2 \text{ (cm}^2\text{)}, \\ A_w = 8.89 \text{ (cm}^2\text{)}$$

$$\overline{SF}_2 = 0.047 \cdot I_d / [1 + (1/298)(I_d/A_w)] \\ = 0.047 \times 476 / [1 + (1/298)(476/8.89)] \\ = 18.96 > 2$$

撓み指数 (173) 式より,

$$N = (C_5 \cdot E_{f0} \cdot I_d) / (P_B \cdot b \cdot l^3) = I / 1.32 \\ = 476 / 1.32 = 361 > > 90$$

甲板ガーダを受ける隔壁防撓材寸法

$$H_w \times (b_f/b_2) \times (t_f/t_w)$$

$$= 110 \times (80/80) \times (4.04/4.04) \text{ (mm)}$$

17.4 甲板ガーダを支持する隔壁防撓材肘板の設計

$$d_1 = 2d = 170 \text{ (cm)}, j = 42 \text{ (cm)},$$

$$h = 170 - 42 = 128 \text{ (cm)},$$

$$l = 165 \text{ (cm)}, S = 138 \text{ (cm)}, i = 37 \text{ (cm)},$$

$$b_f = 8.5 \text{ (cm)}, \overline{SF} = 10,$$

$$\omega = 1.025h \cdot S / 1,000 = 128 \times 138 / 976$$

$$= 18.1 \text{ (kgf/cm)}$$

$$R_2 = [\omega / (8l^2 \cdot h)] [l^5 - i^5 / 5l] - (l^4 - i^4) + 3l^3 \cdot h \\ = 736 \text{ (kgf)}$$

$$M_1 = (\omega \cdot h / 6)(2h + 3i) - (R_2 \cdot l)$$

$$= (18.1 \times 128 / 6)[(2 \times 128) + (3 \times 37)]$$

$$- (736 \times 165)$$

$$= 20,271 \text{ (kgf} \cdot \text{cm)}$$

$$M_L = P_2 \cdot S_L \cdot l^2 / 12 = 0.032 \times 200 \times 400^2 / 12$$

$$= 85,333 \text{ (kgf} \cdot \text{cm)}$$

$$M_N = M_L = 85,333 \text{ (kgf} \cdot \text{cm)} > M_1 = 20,271 \text{ (kgf} \cdot \text{cm)}$$

肘板ハット寸法 (146) 式より,

$$A_n = (t_f \cdot b_f + 30t_w^2) = (17t_w + 30t_w^2) \text{ (cm}^2\text{)}$$

$$b_f = 8.5 \text{ (cm)}, t_f = 2t_w \text{ (cm)}$$

(147) 式より,

$$A_n = (1.414 M_N \cdot \overline{SF}) / (\sigma_{fc90^\circ} \cdot f_n) \\ = (1.414 \times 85,333 \times 10) / (1,610 f_n) = 749 / f_n \text{ (cm}^2\text{)}$$

(146) (147) 式より,

$$t_w^2 + 2t_w(17/60) - (25/f_n) = 0 \\ t_w = -(17/60) + \sqrt{(17/60)^2 + (25/f_n)} \\ = (1/3.53) \{ \sqrt{1 + (311/f_n)} - 1 \} \\ f_n = 311 / [(3.55 t_w + 1)^2 - 1]$$

Table 27. f_n 値

H (層数)	8	9	10
$t_w = 0.0674H$ (cm)	0.539	0.607	0.674
f_n (cm)	42	36	30

肘板ハット有効断面積 (146) 式より,

$$A_n = (t_f \cdot b_f + 30 t_w^2) \\ = (2 \times 0.607 \times 8.5) + 30 \times (0.607)^2 = 21.4 \text{ (cm}^2\text{)}$$

肘板ハット応力安全率 (148) 式より,

$$\overline{SF}_n = 0.707 \sigma_{fc90^\circ} \cdot A_n \cdot f_n / M_N \\ = 0.707 \times 1,610 \times 21.4 \times 36 / 85,333 = 10.28 > 10$$

甲板ガーダ, 隔壁防撓材の肘板寸法

$$f_1 \times f_1 \times b_f \times (t_f / t_w) \\ = 360 \times 360 \times 85 \times (12.14 / 6.07) \text{ (mm)}$$

17.5 船底ロンジを支持する隔壁板補強設計
(水平防撓材を付して補強する方式)17.5.1 水平防撓材 ($\sigma_H = 0$, $L_d = 1$)

$$\sigma_{f0^\circ} = \sigma_{fc0^\circ} = 1,840 \text{ (kgf/cm}^2\text{)} < \sigma_{fT0^\circ} \\ P_B = 0.174 \text{ (kgf/cm}^2\text{)}, b = 75 \text{ (cm)}, \overline{SF}_T = 4, \\ l = 125 \text{ (cm)}, N_T = 200$$

(105) 式より,

$$I_{Req} = (P_B \cdot S \cdot l^3 \cdot N_T) / (C_2 \cdot E_{f0^\circ}) \\ = (0.174 \times 75 \times 125^3 \times 200) / (384 \times 2.5 \times 10^5) \\ = 53 \text{ (cm}^4\text{)}$$

(107) 式より,

$$Z_{Req} = (P_B \cdot S \cdot l^2 \cdot \overline{SF}_T) / (C_1 \cdot \sigma_{fc0^\circ}) \\ = (0.174 \times 75 \times 125^2 \times 4) / (12 \times 1,840) \\ = 37 \text{ (cm}^3\text{)} \\ I_{Req} = 53 \text{ (cm}^4\text{)} \quad Z_{Req} = 37 \text{ (cm}^3\text{)}$$

$$H_w \text{ (cm)} \quad 9 \quad = \quad 9 \\ t_f \text{ (cm)} \quad 0.1 \quad < \quad 0.45 \quad b_2 = b_f = 6 \text{ (cm)} \\ A_f \text{ (cm}^2\text{)} \quad 0.5 \quad < \quad 2.25$$

(94) 式より,

$$t_{fc} = [0.45 + 12(2.25/9)] / [1 + 12(6/9)] = 0.383 \text{ (cm)} \\ H6 = 0.404 \text{ (cm)} = t_{fa} = t_{wa}$$

(95) 式より,

$$b_e = 3[1 + (6 \times 6.1) / (4 \times 6.5)] = 7.2 \text{ (cm)}$$

(96) 式より, $b_p = 40 t_p + b_2 = (40 \times 0.337) + 6$
 $= 31.2 \text{ (cm)}$

Table 28. 水平防撓材設計寸法

	a	l	m	i	i'
①0.337×19.5	6.57	-0.1685	-1.1	0.2	
②0.404×7.2×2	5.82	0.202	1.2	0.2	
③9×0.404×2	7.27	4.5	32.7	147.2	49.1
④0.404×6	2.42	9.202	22.3	204.9	
	22.08		Σ 55.1	401.5	
			2.50		

$$I_d = 264 \text{ (cm}^4\text{)}, I_{Req} = 53 \text{ (cm}^4\text{)}, Y_f = 6.90 \text{ (cm}^3\text{)}, Z_d = 38 \text{ (cm}^3\text{)}$$

$$Z_{Req} = 37 \text{ (cm}^3\text{)}, A = 22.03 \text{ (cm}^2\text{)}, A_w = 7.27 \text{ (cm}^2\text{)}$$

$$H_w \times (b_f / b_2) \times (t_f / t_w) = 90 \times (60 / 60) \times (4.04 / 4.04) \text{ (mm)}$$

17.5.2 No. 1 Panel の垂直支持材
(水平防撓材寸法と同じ)

$$P_B = 0.174 \text{ (kgf/cm}^2\text{)}, b = 62.5 \text{ (cm)}, \\ l = 58 \text{ (cm)}, L_d = k_d = 0.0857$$

応力安全率 (171) 式より,

$$\overline{SF}_1 = \frac{\sigma_{fc0^\circ}}{[(P_B \cdot b \cdot l^2) / (C_4 \cdot Z)] + (P_{10} \cdot b_0 \cdot l_0 \cdot L_d / 2A)} \\ = 1,840 / \{ [0.174 \times 62.5 \times 58^2 / (120 \times 38 / 7)] \\ + [2.03 \times 125 \times 600 \times 0.0857 / (2 \times 22.08)] \} \\ = 5.23 > 4$$

座屈安全率 (172) 式より,

$$\overline{SF}_2 = \frac{[2E_{f0^\circ} \cdot I / (P_{10} \cdot b_0 \cdot l_0 \cdot L_d)] (\pi/l)^2}{[(I \cdot E_{f0^\circ}) / (A_w \cdot G_f)] (\pi/l)^2 + 1} \\ = [(2 \times 2.5 \times 10^5 \times 264) / (2.03 \times 125 \times 600 \\ \times 0.0857)] / [(264 \times 2.5) / (7.27 \times 0.27) + 1] \\ = 14.94 > 2$$

撓み指数 (173) 式より,

$$\begin{aligned}
 N &= (C_s \cdot E_{f0} \cdot I) / (P_B \cdot b \cdot l^3) \\
 &= (153 \times 2.5 \times 10^5 \times 264) / (0.174 \times 62.5 \times 58^3) \\
 &= 4,759 > 200
 \end{aligned}$$

17.5.3 No.2 Panel 増厚補強

$$\begin{aligned}
 \gamma_0 &= (a_f/b) = (15/95) = 0.158, \quad \overline{SF}_2 = 1.5, \\
 \sqrt{n(n+1)} &> \gamma_0 > \sqrt{n(n-1)}, \quad n=1, \\
 2K_f &= 2[0.116 + (2 \times 0.9865 \times 0.27/2.5)] = 0.658 \\
 H_c &= (\pi^2/12)[(\gamma_0/n)^2 + (n/\gamma_0)^2 + 2K_f] \\
 &= (\pi^2/12)[(0.158/1)^2 + (1/0.158)^2 + 0.658] \\
 &= 33.51
 \end{aligned}$$

(179) 式より,

$$\begin{aligned}
 \omega_0 &= P_{10} \cdot S_0 \cdot l_0 \cdot L_a / 4b_f \\
 &= (2.03 \times 125 \times 600 \times 0.0857) / (4 \times 18) \\
 &= 181 \text{ (kgf/cm)}
 \end{aligned}$$

(180) 式より,

$$\begin{aligned}
 t_2 &= \sqrt[3]{(\omega_0 \cdot \lambda \cdot b^2 \cdot \overline{SF}_2) / (H_c \cdot E_{f0})} \\
 &= \sqrt[3]{\frac{181 \times 0.9865 \times 95^2 \times 1.5}{33.55 \times 2.5 \times 10^5}} = 0.661 \text{ (cm)}
 \end{aligned}$$

$$t_0 = t_2 - t_B = 0.661 - 0.337 = 0.324 \text{ (cm)}$$

水平防撓材下方を, $H \times 5 = 0.337 \text{ (mm)}$ 増厚する。

Table 29. 構造部材寸法長

サンドイッチ外板、甲板寸法			
	$t_d = t_{fd} + t_{ed} + t_{sd} \text{ (mm)}$	$t_{ce} = \text{Balsa} + \text{M} + \text{Balsa}$	
円弧キールプレート	47.14=3.37+40.40+3.37	40.40=19.0+2.4+19.0	
船底外板	36.84=2.02+32.80+2.02	32.80=15.8+1.2+15.8	
船側外板	39.54=3.37+32.80+3.37	32.80=15.8+1.2+15.8	
強力甲板	34.68=4.04+26.60+4.04	26.60=12.7+1.2+12.7	
非強力甲板	32.00=2.70+26.60+2.70	26.60=12.7+1.2+12.7	

防撓ハット材寸法			
	$H_u \times (b_1/b_2) \times (t_1/t_u)$	$a_g \text{ (cm}^2\text{)}$	$e_g \text{ (m)}$
一般船底ロンジ (科員室)	280×(180/200)×(8.76/8.76)	86.66	0.166
主機室船底ロンジ	一般ロンジ+(200×184)木芯材	—	—
船側肋骨チェーン部	110×(80/80)×(4.04/4.04)	17.94	—
船側肋骨ガンネル部	160×(80/80)×(4.04/4.04)	21.98	—
甲板ビーム	120×(80/80)×(4.04/4.04)	19.06	—
甲板ガーダ	250×(180/180)×(16.20/16.20)	68.04	0.253

横隔壁構造部材寸法			
	$H_u \times (b_1/b_2) \times (t_1/t_u)$	$t_g \text{ (mm)}$	$t_r \text{ (mm)}$
甲板ガーダ直下防撓材	110×(80/80)×(4.04/4.04)	3.37	2.70
船体中心線防撓材	160×(80/80)×(8.09/4.04)		
水平防撓材	90×(60/60)×(4.04/4.04)		

主船殻構造材板寸法		
	$f_1 \times f_1 \times b_r \times (t_1/t_u) \text{ (mm)}$	
甲板ガーダ隔壁防撓材材板	360×360×85×(12.14/6.07)	
船側肋骨ガンネル材板	360×360×85×(16.18/8.09)	