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ON THE EFFECTIVENESS OF PANTING STRINGERS AND WEB FRAMES OF A SHIP

By Jiro SUHARA*

Introduction. A purpose of adopting panting stringers and web frames of a ship is to reduce unsupported spans of side frames, and another is to prevent lateral declination of frames from right-positions, which are subjected to external pressure. For the first purpose, if it is intended to prevent completely the deflections of side frames at the joining points of stringers and side frames loaded by external pressure, we must size the panting stringers and web frames in unpractically large scantlings. Therefore, in designing stages, it may be desired to estimate their favourable sizes and stiffness relative to side frames.

This paper presents a method of estimating the effectiveness of panting stringers and web frames relative to side frames and a designing method of these members with an example of application of this theory to a structure in a cargo ship.

Assumed Conditions. In ocean waves, the shell structure of ship in panting zone is subjected to heavy water pressure with very complicated distribution. This may be classified two kinds of pressure distribution, that is, the first is the dynamic pressure due to panting actions of ship which is indefinitely changing with time, and the second is statical pressure of surrounding water which is simply determined by the height of sea water level relative to ship hull. Therefore, exact estimation of maximum pressure distribution of resultant water pressure seemes to be very difficult. But fortunately we have results of damage analyses [1],[(1)] for the structure in panting zone of an ore carrier of 120.0 m in length, 16.4 m in breadth and 10.0 m in depth.

She encountered a storm of 980 millibar, and her shell plating between frames and framings with shell plating in panting zone were dented in by water pressure. Analyzing these damages, we knew that following assumptions for approximate pressure distribution may be valid. The position of the maximum of dynamic pressure is statistically at still water level as shown in Fig. 1(ii), and statical pressure linearly increase downward from still water level (Fig. 1 (i)). Then resultant pressure distribution at the moment of the severest loading condition is nearly uniform as shown in Fig. 1 (iii). Under this assumption, we obtained approximately 1 kg/cm^2

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(1) Numbers in parentheses [ ] refer to Bibliography at the end of the paper.

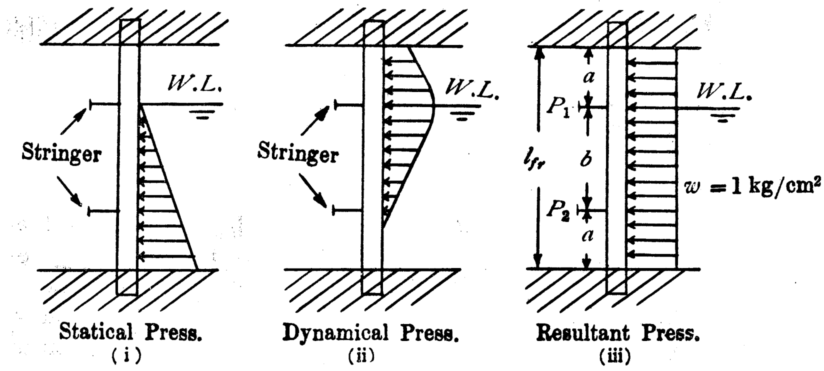

FIG. 1.

as maximum pressure per unit area of her shell plating in panting zone. Therefore we use same assumption for our problem.

The stress analyses of ship's structure are complex problems because the construction of a ship is statically indeterminate to high degree. However it may be possible to expect reasonable results for designing purpose, if we take suitable assumptions for boundary conditions to the structure as stated below. The scantlings and forms of side frames and shell platings will gradually vary along longitudinal direction, but they are assumed approximately uniform and symmetrical referred to the middle of frame spans for each portion of structure bounded between bulkheads or web frames. Moreover, in this paper, panting stringers are arranged symmetrically about midle section of frame span and have similar dimensions as usual designing practice.

The end conditions of side frames are determined exactly by relative stiffness between side frames and the adjacent members, but we assume for simplicity that both ends of side frames are clamped. By above mentioned assumptions, we may conclude that the deflections of both stringers are equal. But the results obtained under these assumptions should be corrected if necessary.

The side frames are arranged in close spacing, so we may assume that the interacting forces between side frames and panting stringers are continuously distributed over spans of stringers, this assumption was taken by W. Shilling [2] and the others.

Nomenclature. The following nomenclature is used in the paper:

a = distance from an end of a side frame to stringer (Fig. 1)
$\boldsymbol{a}$ = do. for web frame (Fig. 6)
b, $\boldsymbol{b}$ = spacing between panting stringers (Fig. 1 and Fig. 6)
α = interaction paramenter between stringers and side frames defined by Equations (3) and (4).
E = modulus of Elasticity

G = shear modulus

I_{fr}, I_{st}, I_{web} = moment of inertia of section of side frame, stringer and web frame respectively.

w = resultant of statical and dynamical pressure per unit area of shell plating.

GK_{web} = torsional rigidity of web frame.

l_{fr}, l_{st}, l_{st}', l_{web} = spans of side frames, stringers and web frames. (Fig. 1, Fig. 2 and Fig. 6)

s = spacing of side frames.

x = coordinate distance along axis of stringer (Fig. 2)

$\xi = x/l_{st}$

y = deflection of a stringer at any point.

y_m = deflection at the centre of span of the stringers when they are clamped at both ends.

η = deflection of side frame due to external water pressure at crossing points to stringers, when side frame is free from stringers.

M_{ik}, Q_{ik} = bending moment and supporting force at i end of stringer of ik span, respectively (Fig. 4).

M_{ik}, Q_{ik} = fixing moment and supporting force due to external pressure at i end of stringer ik, respectively when stinger ik is clamped at both ends i and k.

θ_i = angular rotation of stringer at i section (Fig. 4).

v_i = deflection of stringer at i section (Fig. 4).

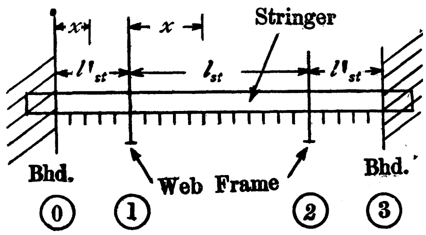

FIG. 2.

Equation of Flexure of Stringer For any span of stringer, for example ① ② span shown in Fig. 2, taking x axis along stringer from each end of span, the equation of flexure of a stringer [3] is

$$\lambda(d^4y/d\xi^4) + y = \eta \tag{1}$$

where
$$\xi = x/l_{st}, \quad \lambda = EI_{st}\mu s/l_{st}^4 \tag{2}$$

μ is the deflection of any side frame at the crossing points to the stringers (say P_1 and P_2), when frame is applied simultaneously unit concentrated loads at P_1 and P_2, but stiffening effects of stringers are ignored.

η is the deflection of a side frame at the points P_1 and P_2 by external pressure for the case being ignored the stiffening effects of stringer.

Then we use interaction criterion between stringers and side frames defined as follows:

$$\alpha = (4\lambda)^{-1/4} \tag{3}$$

For usual case, we may assume that side frames are straight in axes between a span of stringer, then we have

$$\left.\begin{aligned}&\lambda = I_{st}a^3s(4a^3+12a^2b+9ab^2+2b^3)/6I_{fr}l_{fr}^3l_{st}^4, \quad \eta = wsa^2(l_{fr}-a)^2/24EI_{fr}\\&\alpha = (4\lambda)^{-1/4} = \{3I_{fr}l^3{}_{fr}{}^3l_{st}^4/2I_{st}a^3s(4a^3+12a^2b+9ab^2+2b^3)\}^{1/4}\end{aligned}\right\} \tag{4}$$

Solution of Equation for Stringer with both Ends Clamped. If pressure is unchanged over the span of stringer, η is independent to x or ξ. Denoting $\xi' = 1/2 - \xi$, we have the solution of equation (1) for both ends fixed stringer as follows:

$$\begin{aligned}y = \eta[1 - (\sinh\alpha + \sin\alpha)^{-1}\cdot\{&\cosh\alpha\xi'\sin\alpha(1-\xi') + \cosh\alpha(1-\xi')\sin\alpha\xi'\\&+\sinh\alpha\xi'\cos\alpha(1-\xi) + \sinh\alpha(1-\xi')\cos\alpha(1-\xi')\}]\end{aligned} \tag{5}$$

Putting $\xi = 1/2$, above equation gives the deflection of stringer at the centre of the span

$$\begin{aligned}&y_m = \eta\{1 - 2f_1(\alpha)\},\\&f_1(\alpha) = \{\cosh(\alpha/2)\sin(\alpha/2) + \sinh(\alpha/2)\cos(\alpha/2)\}/(\sinh\alpha + \sin\alpha)\end{aligned} \tag{6}$$

From the equation (1), we can derive the equation of supporting force Q and bending moment M at fixed ends

$$\begin{aligned}Q &= \overline{Q}_{12} = \overline{Q}_{12} = -4\alpha^3f_2(\alpha)\cdot EI_{st}\eta\cdot l_{st}^{-3},\\ M &= \overline{M}_{12} = -\overline{M}_{12} = 2\alpha^2f_3(\alpha)\cdot EI_{st}\eta\cdot l_{st}^{-2},\end{aligned} \tag{7}$$

where their signs are determined positive when they are as shown in Fig. 4, and $f_2(\alpha)$ and $f_3(\alpha)$ are

$$f_2(\alpha) = \frac{\cosh\alpha - \cos\alpha}{\sinh\alpha + \sin\alpha},\qquad f_3(\alpha) = \frac{\sinh\alpha - \sin\alpha}{\sinh\alpha + \sin\alpha} \tag{8}$$

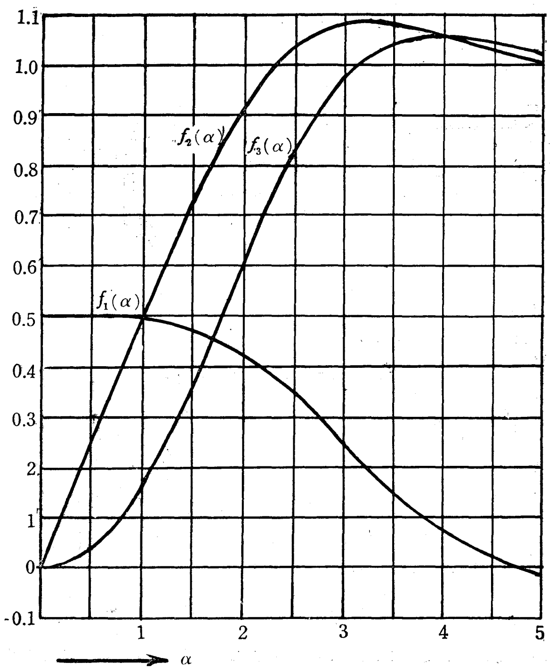

Fig. 3.

Plotted curves of $f_1(\alpha)$, $f_2(\alpha)$ and $f_3(\alpha)$ as functions of α are shown in Fig. 3.

It is to be noted that y_m becomes approximately equal to η when value of α increases larger than 4.75, then stringers are ineffective to stiffen the side frames near the centre of span of stringers for such value of α. Supporting force R_1 or R_2 acting from stringer to any side frame at the point P_1 or P_2 is given by

$$R_1 = R_2 = (\eta - y)/\mu \tag{9}$$

As designing practice, it is recommended to choose the value of α given by (3) with (2) or (4) less than 1.9, then the ratio of y_m/η becomes less than 1/10. It may be admissible for practical designing purpose. If the value of α is determined as mentioned above, the moment of inertia of section of stringer is given by following formula derived from (4).

$$I_{st} = 3l^3{}_{fr}\, l^4{}_{st}\, I_{fr}/2\alpha^4 s\,(4a^3 + 12a^2b + 9a^2b + 2b^3) \tag{10}$$

Slope Deflcction Equations for Stringer. Generally stringers are supported by web frames or bulkheads as shown in Fig. 2 as an example. For such cases, we obtain the relations between moments, supporting forces, angles of rotation and deflections at both ends of any span ik of the stringer from equation (5), these are so-called generalized slope deflection equations for stringer. Any span ik of a stringer subjected to distributed load over span is shown in Fig. 4, base line (i) (k) indicates its unloaded position and heavy S-curve ik shows its deformed state. Forces, moments, deflections and angular rotations at the ends of the span are defined positive when their directions are as indicated in the figure.

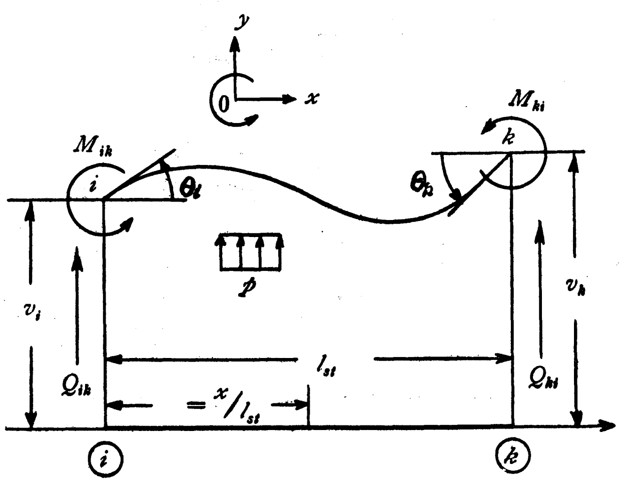

FIG. 4.

Then the generalized slope deflection equations become

$$\left.\begin{aligned}
M_{ik} &= (EI_{st}/l_{st})_{ik}\cdot[(A)_{ik}\theta_i + (B)_{ik}\theta_k + (C)_{ik}\cdot\{v_i/(l_{st})_{ik}\} \\
&\qquad - (D)_{ik}\{v_k/(l_{st})_{ik}\}] + \overline{M}_{ik} \\
M_{ki} &= (EI_{st}/l_{st})_{ik}\cdot[(B)_{ik}\theta_i + (A)_{ik}\theta_k + (D)_{ik}\cdot\{v_i/(l_{st})_{ik}\} \\
&\qquad - (C)_{ik}\{v_k/(l_{st})_{ik}\}] + \overline{M}_{ki} \\
Q_{ik} &= (EI_{st}/l^2{}_{st})_{ik}\cdot[(C)_{ik}\theta_i + (D)_{ik}\theta_k + (G)_{ik}\cdot\{v_i/(l_{st})_{ik}\} \\
&\qquad - (H)_{ik}\{v_k/(l_{st})_{ik}\}] + \overline{Q}_{ik} \\
Q_{ki} &= -(EI_{st}/l^2{}_{st})_{ik}\cdot[(D)_{ik}\theta_i + (C)_{ik}\theta_k + (H)_{ik}\cdot\{v_i/(l_{st})_{ik}\} \\
&\qquad - (G)_{ik}\{v_k/(l_{st})_{ik}\}] + \overline{Q}_{ki}
\end{aligned}\right\} \tag{11}$$

where the notation $(\quad)_{ik}$ means that the magnitudes indicated in brackets are referred to ik span of stringer also l_{st} and α are span length and interaction parameter defined by (3) with (2) or (4) referred to ik span of stringer. Then $(A)_{ik}$, $(B)_{ik}$, $(C)_{ik}$, $(D)_{ik}$, $(G)_{ik}$, and $(H)_{ik}$ are functions of $(\alpha)_{ik}$ defined as follows (the notation $(\quad)_{ik}$ is omitted in equation (12) and (13)):

$$\left.\begin{array}{ll} A=2\alpha V(\sinh 2\alpha-\sin 2\alpha), & B=4\alpha V(\sin\alpha\cosh\alpha-\cos\alpha\sinh\alpha) \\ C=2\alpha^2 V(\cosh 2\alpha-\cos 2\alpha), & D=8\alpha^2 V\sinh\alpha\sin\alpha \\ G=4\alpha^3 V(\sin 2\alpha+\sinh 2\alpha), & H=8\alpha^3 V(\sin\alpha\cosh\alpha+\cos\alpha\sinh\alpha) \\ \text{with} & \\ V=1/(\cosh 2\alpha+\cos 2\alpha-2) & \end{array}\right\} \quad (12)$$

If η is constant over span ik of stringer, and side frames are straight in their axes, we get

$$\left.\begin{array}{l} \overline{M}_{ik}=-\overline{M}_{ki}=-(2EI_{st}\eta\, l_{st}^{-2})\cdot\alpha^2(\sinh\alpha-\sin\alpha)/(\sinh\alpha+\sin\alpha) \\ \overline{Q}_{ik}=\overline{Q}_{ki}=-(4EI_{st}\eta\, l_{st}^{-3})\cdot\alpha^3(\cosh\alpha-\cos\alpha)/(\sinh\alpha+\sin\alpha) \end{array}\right\} \quad (13)$$

Putting $\alpha\to 0$, then we obtain $A\to 4$, $B\to 2$, $C\to 6$, $D\to 6$, $G\to 12$ and $H\to 12$. Equations (11) for this extreme case exactly coincide with the slope deflection equations based on simple beam theory which are used in ordinary rigid frame analyses.

Equations of Deformation for Stringer with Web Frame. Let us consider any two consecutive spans $(i-1, i)$ and $(i, i+1)$ of a stringer as shown in Fig. 5. On the junction i, let stringer be supported on a web frame with torsional stiffness GK_{Web} [5] and bending stiffness EI_{Web}, then equilibrium conditions of moments and forces on the junction i are

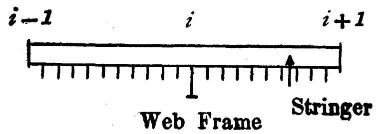

FIG. 5.

$$M_{i,i-1}+M_{i,i+1}=-(\kappa_{\text{Web}})_i\cdot\theta_i, \quad Q_{i,i-1}+Q_{i,i+1}=-(\mu_{\text{Web}})_i\cdot v_i \quad (14)$$

where $(\kappa_{\text{Web}})_i\cdot\theta_i$ and $(\mu_{\text{Wbe}})_i\cdot v_i$ are interacting couple and force between web frame and stringer at junction i respectively.

Let us assume that the axis of web frame is straight and its both ends are clamped (Fig. 6). then we have

$$\left.\begin{array}{l} (\kappa_{\text{Web}})_i=(GK_{\text{Web}}/\boldsymbol{a})_i \\ (\mu_{\text{Web}})_i=[6EI_{\text{Web}}\, l^3_{\text{Web}}/\{\boldsymbol{a}^3(4\boldsymbol{a}^3+12\boldsymbol{a}^2\boldsymbol{b} \\ \qquad\qquad +9\boldsymbol{a}\boldsymbol{b}^2+2\boldsymbol{b}^3)\}]_i \end{array}\right\} \quad (15)$$

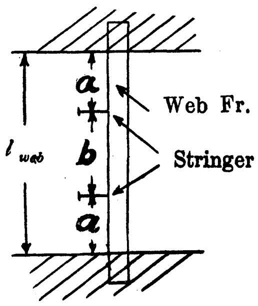

FIG. 6.

$\boldsymbol{a}$ and $\boldsymbol{b}$ are indicated in Fig. 6. Magnitudes shown in bracket with suffix i or $(i-1, i)$ etc. mean that they are referred to the values of i junction or $(i-1, i)$ span etc. of stringer respectively. Substituting the slope deflection equations applied to $(i-1, i)$ and $(i, i+1)$ spans respectively into equations (14), we get elastic equations of stringer for two consecutive spans:

$$\left.\begin{aligned}
&(EI_{st}B/l_{st})_{i-1,i}\cdot\theta_{i-1}+\{(EI_{st}A/l_{st})_{i-1,i}+(EI_{st}A/l_{st})_{i,i+1}+(\kappa_{\mathrm{Web}})_i\}\cdot\theta_i\\
&\quad+(EI_{st}B/l_{st})_{i,i+1}\cdot\theta_{i+1}+(EI_{st}D/l_{st}^2)_{i-1,i}\cdot v_{i-1}\\
&\quad-\{(EI_{st}C/l_{st}^2)_{i-1,i}-(EI_{st}C/l_{st}^2)_{i,i+1}\}v_i\\
&\quad-(EI_{st}D/l_{st}^2)_{i,i+1}\cdot v_{i+1}=-(\overline{M}_{i,i-1}+\overline{M}_{i,i+1})\\
&(EI_{st}D/l_{st}^2)_{i-1,i}\cdot\theta_{i-1}+\{(EI_{st}C/l_{st}^2)_{i-1,i}-(EI_{st}C/l_{st}^2)_{i,i+1}\}\cdot\theta_i\\
&\quad-(EI_{st}D/l_{st}^2)_{i,i+1}\cdot\theta_{i+1}+(EI_{st}H/l_{st}^3)_{i-1,i}\cdot v_{i-1}\\
&\quad-\{(EI_{st}G/l_{st}^3)_{i-1,i}+(EI_{st}G/l_{st}^3)_{i,i+1}+(\mu_{\mathrm{Web}})_i\}\cdot v_i\\
&\quad+(EI_{st}H/l_{st}^3)_{i,i+1}\cdot v_{i+1}=\overline{Q}_{i,i-1}+\overline{Q}_{i,i+1}
\end{aligned}\right\}\tag{16}$$

Applying above equations to every junction of stringers with boundary conditions, we obtain the simultaneous equations with respect to θ_i's and v_i's. Solving these equations, we obtain every value of θ_i's and v_i's. Then substituting these values into slope deflection equations (11) for each span of stringer and the formula of deflection of web frame by beam theory respectively, we obtain every value of bending moments and supporting forces at every end of the members.

Deflection at Any Point in a Span of Stringer. Using the deflections and angular rotations at both ends of any span ik of a stringer are given, deflection at any point in the span can be obtained from the solution of (1) with given boundary conditions as follows:

$$\begin{aligned}y=&v_ih_1(\xi,\alpha)+(l_{st})_{ik}\cdot\theta_ih_2(\xi,\alpha)+v_k\cdot h_3(\xi,\alpha)+(l_{st})_{ik}\cdot\theta_kh_4(\xi,\alpha)\\&+\eta\{1-h_1(\xi,\alpha)-h_2(\xi,\alpha)\}\end{aligned}\tag{17}$$

where x is coordinate distance from i end and $\xi=x/(l_{st})_{ik}$,

and

$$\left.\begin{aligned}
&h_1(\xi,\alpha)=h_3(1-\xi,\alpha),\quad h_2(\xi,\alpha)=-h_4(1-\xi,\alpha),\\
&V=1/(\cosh2\alpha+\cos2\alpha-2)\\
&h_3(\xi,\alpha)=2V\cdot\{2\sin\alpha\sinh\alpha\sin\alpha\xi\sinh\alpha\xi\\
&\qquad+(\sin\alpha\cosh\alpha+\cos\alpha\sinh\alpha)(\cos\alpha\xi\sinh\alpha\xi\\
&\qquad-\sin\alpha\xi\cosh\alpha\xi)\}\\
&h_4(\xi,\alpha)=2\alpha^{-1}\cdot V\cdot\{\sin\alpha\sinh\alpha(\sin\alpha\xi\cosh\alpha\xi-\cos\alpha\xi\sinh\alpha\xi)\\
&\qquad+(\cos\alpha\sinh\alpha-\sin\alpha\cosh\alpha)\sin\alpha\xi\sinh\alpha\xi\}
\end{aligned}\right\}\tag{18}$$

Bending Moments in Side Frame Supporting force R_1 or R_2 acting from stringer to any side frame at the point P_1 or P_2 is given by $R_1=R_2=(\eta-y)/\eta$, and specially for the case of the axis of side frame being straight, it becomes

$$\left.\begin{aligned}
&R_1=R_2=6EI_{fr}l_{fr}^3(\eta-y)/a^3(4a^3+12a^2b+9ab^2+2b^3)\\
\text{or}\quad&R_1=R_2=162EI_{fr}l_{fr}^{-3}(\eta-y),\quad\text{for}\quad a=b=l_{rf}/3
\end{aligned}\right\}\tag{19}$$

Then fixing moment in a side frame is

$$M_{fre}=(wsl_{fr}^2/12)-\{R_1a(l_{fr}-a)/l_{fr}\}\tag{20}$$

Bending moment in a side frame at midsection of span is

$$M_{fr0} = -(w\,s\,l_{fr}^2/24) + (R_1 a^2/l_{fr}) \tag{21}$$

Application to Shell Structure of a Cargo Ship This method of analysis has been applied to a shell and framing system at the fore hold of a cargo ship of 145.0 m in length 19.4 m in breadth and 12.3 m in deph.

Rough sketch of the arrangement of the structure is shown in Fig. 7. For reference we compared the various scantlings of the member required by various Rules of The Classification Societies in Table 1.

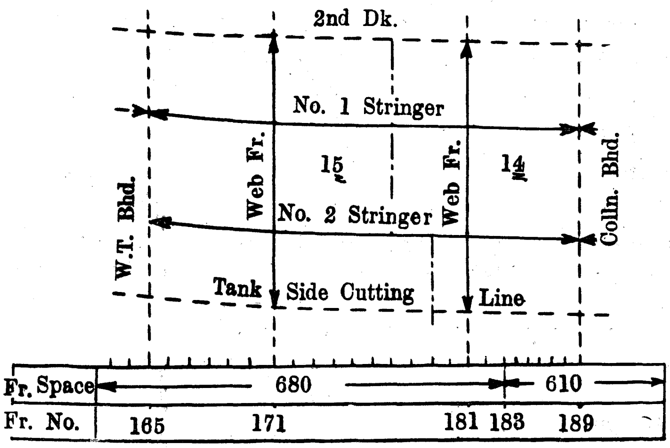

Fig .7.

Table 1. (Unit of dimensions in millimetres)

Name of Classification Society	Extent in Frame No.	165 ~ 173	174 ~ 189
	Distance from F. P.	Fr. No. 165 = 0.15 L (L: Principal Length)	Fr. No. 173 = 0.125 L (Do.)
N. K.	Frame with Web Frames	380 × 100 × 10.5/16 (⊏)	380 × 100 × 13/20 (⊏)
	Stringer with Web Frames	Face 300 × 15 F.B. or 250 × 90 × 12 (⊏), Intl Pl. 0.5 with Web Frame	
A. B.	Frame with Web Frames	380 × 100 × 13/20 (⊏)	380 × 100 × 13/20 (⊏)
	Stringer with Web Frames	Face 300 × 25 F.B. Intl Pl. 10 with Web Frame	
	Frame without Web Frame	380 × 100 × 13/20 (⊏)	380 × 100 × 13/20 (⊏), Rev. 75 × 75 × 12 ∟
	Stringer without Web Frame	Face 300 × 28 F.B. Intl Pl. 10 without Web Frame	
LLOYD	Frame without Web Frame	380 × 100 × 13/20 (⊏)	380 × 100 × 13/20 (⊏)
	Stringer without Web Frame	Face 300 × 10 F.B. Intl Pl. 10.5 or 200 × 90 × 10 ⊐	
	Frame without Web Frame and Stringer	380 × 100 × 13/20 (⊏) (Scanting of frame is unchanged, but shell platings are to be increased 25 % in thickness)	

Note, Frame spacing: 680 (Fr. No. 158 ~ 183 , 610 (Fr. No. 183 ~)
W. T. Bulkhead: Fr. No. 165, Collision Bulkhead: Fr No. 189
Web Frames: Fr. No. 171 and Fr. No. 181

By assumption described in preceeding paragraph we choose the scantlings of the structure of our problem as follows: Thickness of shell platings $= 14.5$ m/m, scantling of stringer $= 380 \times 10$ web with 300×25 flat bar, $I_{st} = 6.808 \times 10^4\ \mathrm{cm}^4$ (effective breadth* of shell plating is assumed to be equal to 40 times of thickness of shell plate).

Then, for simplicity, we consider the structure as its scantlings are symmetrical referred to the centre of span of the stringer. (Fig. 2)

Therefore, we may put $v_1 = v_2 = v$ and $\theta_1 = -\theta_2 = \theta$, that the equations of deformation (16) become

$$\left.\begin{aligned}&\{\rho A_{01} + (A_{12} - B_{12}) + \bar{\kappa}\}\theta - \{\rho^2 C_{01} - (C_{12} - D_{12})\}\varphi = X_1\\&\{\rho^2 C_{01} - (C_{12} - D_{12})\}\theta - \{\rho^3 G_{10} + (G_{12} - H_{12})\bar{\mu}\}\varphi = X_2\end{aligned}\right\}\quad(22)$$

where $(l_{st})_{12} = l_{st}$, $(l_{st})_{01} = (l_{st})_{23} = l_{st}'$, $(I_{st})_{10} = (I_{st})_{12} = (I_{st})_{23} = I_{st}$

$\rho = l_{st}/l_{st}'$, $\bar{\kappa} = GK_{\mathrm{Web}}\, l_{st}/EI_{st}\boldsymbol{a}$

$\bar{\eta} = 6EI_{\mathrm{Web}}\, l_{\mathrm{Web}}^3 l_{st}^3/EI_{st}\boldsymbol{a}^3(4\boldsymbol{a}^3 + 12\boldsymbol{a}^2\boldsymbol{b} + 9\boldsymbol{a}\boldsymbol{b}^2 + 2\boldsymbol{b}^3)$

$\varphi = v/l_{st}$, $X_1 = -(l_{st}/EI_{st})(\bar{M}_{10} + \bar{M}_{12})$, $X_2 = (l_{st}^2/EI_{st})(\bar{Q}_{10} + \bar{Q}_{12})$

Other numerical values inserted into above equations are summarized below:

1. External pressure: $w = 1\ \mathrm{kg/cm^2}$.
2. Constants for material $E = 2.1 \times 10^6\ \mathrm{kg/cm^2}$, $G = 0.81 \times 10^6\ \mathrm{kg/cm^2}$
3. Side frame: $I_{fr} = 3.442 \times 10^4\ \mathrm{cm}^4$. $s = 68.0$ cm, $l_{fr} = 650$ cm, $a = b = 216.7$ cm, $\eta = 0.3456$ cm, $(M_{f.e})_{R_1=0} = 2.39 \times 10^6$ kg cm, $(M_{fr0})_{R_1=0} = 1.19 \times 10^6$ kg cm
4. Stringer: $l_{st} = 680$ cm, $\rho = 1.453$, $I_{st} = 6.808 \times 10^4\ \mathrm{cm}^4$
5. Web frame: $l_{\mathrm{Web}} = 650$ cm, $\boldsymbol{a} = \boldsymbol{b} = 216.7$ cm, $I_{\mathrm{Web}} = 14.44 \times 10^4\ \mathrm{cm}^4$, $K_{\mathrm{Web}} = 0.01537 \times 10^4\ \mathrm{cm}^4$
6. Others:

TABLE 2.

Span of Stringer	α	A	B	C	D	G	H
01	2.693	5.493	0.9840	14.60	1.717	78.54	−4.938
12	3.912	7.832	0.6062	30.64	−1.707	300.15	−13.55

$\bar{\kappa} = 2.733 \times 10^{-3}$, $\bar{\mu} = 3.934 \times 10^2$

$\bar{M}_{10} = 2.907 \times 10^6$ kg cm, $\bar{M}_{12} = -3.323 \times 10^6$ kg cm,

$\bar{Q}_{10} = -4.024 \times 10^4$ kg, $\bar{Q}_{12} = -3.987 \times 10^4$ kg,

$X_1 = 1.976 \times 10^{-3}$, $X_2 = -0.259$,

$\theta = 1.027 \times 10^{-4}$, $\varphi = 2.732 \times 10^{-4}$, $v = 0.1858$ cm

Substituting the values of θ and v into (11), we have $M_{10} \fallingdotseq -M_{12} = 130.9 \times 10^4\ \mathrm{cm}^4$, this gives, $M_{10} + M_{12} \fallingdotseq 0$. Accordingly it can be

* Exactly, it should be determined by the method shown in C. H. A. Schade's paper [3], [4]. But we follow above-mentioned conventional method in this paper, because it leads us to safe side for our problem.

neglected the torsional stiffness of the web frame in practical calculations, then we have

$$Q_{10} = -2.087 \times 10^4 \text{ kg}, \quad Q_{12} = -1.23 \times 10^4 \text{ kg}$$

7. Deflection and fixing moment of a frame at mid-point of span (01) of stringer:

Substituting following conditions into equation (17), $v_i = 0$, $\theta_i = 0$ (stringer of (01) span is assumed to be clamped at the end of bulkheads), $(l_{st})_{ik} = l_{st}'$, $\xi = 0.5$, $\eta = 0.3456$ cm, $\alpha = 2.693$, we get the deflection of side frame at mid-point of span (01) as follows:

$$y_{(01)} = v\, h_3(\alpha, \xi) + l_{st}'\theta\, h_4(\alpha, \xi) + \eta\{1 - h_1(\alpha, \xi) - h_3(\alpha, \xi)\} = 0.1327 \text{ cm}$$

Reduction rate of deflection of this frame due to stringer relative to the value of the deflection for the case when the stiffening effect of stringer is ignored: $\{(\eta - y_{01})/\eta\} \times 100 = 61.6\,\%$

Supporting force is obtained by (19): $(R_1)_{01} = 9.079 \times 10^3$ kg

Fixing moment for this frame is obtained by (20):

$$M_{fre} = 1.08 \times 10^6 \text{ kg cm}$$

Reduction rate of fixing moment:

$$[\{(M_{fre})_{R1=0} - M_{fre}\}/(M_{fre})_{R1=0}] \times 100 = 54.8\,\%$$

8. Deflection and fixing moment of a frame at mid-point of span (12) of stringer:

substituting following conditions into equation (17),

$$v_i = v_k = v. \quad \theta_i = -\theta_k = \theta, \quad (l_{st})_{ik} = l_{st}, \quad \xi = 0.5,$$
$$\eta = 0.3456 \text{ cm}, \quad \alpha = 3.912$$

then we obtain the deflection of the frame at the mid-point of span (12) of stringer as follows:

$$y_{(12)} = 2v\, h_1(\xi, \alpha) + 2l_{st}\theta\, h_2(\xi, \alpha) + \eta\{1 - h_1(\xi, \alpha) - h_3(\xi, \alpha)\} = 0.3234 \text{ cm}$$

Reduction rate of deflection: $(\eta - y_{(12)})/\eta \times 100 = 6.42\,\%$

Supporting force obtained by (19): $(R_1)_{12} = 0.9466 \times 10^3$ kg

Fixing moment for this frame obtained by (20):

$$M_{fre} = 2.257 \times 10^6 \text{ kg cm}$$

Reduction rate of fixing moment:

$$[\{(M_{fre})_{R_1=0} - M_{fre}\}/(_{fre})_{R_1=0}] \times 100 = 5.75\,\%$$

Reduction rate of bending moment in this frame is very slight as shown above, that is, stringer is nearly ineffective for the frame near centre of the span of stringer.

Effective Scantlings of Stringer and Web Frame relative to Side Frames.

From (4), (19) and (20), we obtain the reduction rate of fixing moment of a frame:

$$\Omega = \{(M_{fre})_{R_1=0} - M_{fre}\}/(M_{fre})_{R_1=0}$$
$$= \{3(a+b)^3/(4a^3 + 12a^2b + 9ab^2 + 2b^3)\} \cdot (1-r)$$

where $r = y/\eta$, and y is the deflection of a frame at point P_1 or P_2 (Fig. 1). For our case $a = b = l_{fr}/3$, then we obtain $\Omega = (8/9) \cdot (1-r)$. Therefore if we put $r = 1/10$, we get $\Omega = 0.8$.

This value of Ω may be practically admissible. Let us assume that the web frames are sufficiently rigid, then we may regard that the both ends of span (12) of the stringers are approximately clamped. For this case, the deflection of y_m of a frame at near centre of span (12) is given by equation (6). If we put $y_m/\eta = 1/10$, then we obtain $\alpha \fallingdotseq 1.9$.

Substituting this value of α and other values of scantlings side frame into (10), we obtain $I_{st} = 1.223 \times 10^6\,\text{cm}^4$. Next, scantling of web frames of which stiffness is assumed as very large, may be practically determined as follows. Firstly, calculate the sum of supporting force of web frame at the junction 1 or 2, $R' \fallingdotseq -(\overline{Q}_{10} + \overline{Q}_{12})$, in which the value of $\overline{Q}_{12}$ is obtained by substituting $\alpha = 1.9$ for span (12) into equation (7) and the value of $\overline{Q}_{10}$ is obtained by substituting $\alpha = 1.9 \times (l_{st}'/l_{st}) = 1.3$ for span (01) into equation (7).(3)

Secondly, assume the value of deflection at point 1. In our case, we assume 1/10 th of the value of v obtained in last paragraph, namely we take $v_1 = (1/10) \cdot v = 0.01858\,\text{cm}$.

Lastly, determine the value of the moment of inertia of cross section of web frame by following formula

$$I_{\text{Web}} = R'\boldsymbol{a}^3(4\boldsymbol{a}^3 + 12\boldsymbol{a}^2\boldsymbol{b} + 9\boldsymbol{a}\boldsymbol{b}^2 + 2\boldsymbol{b}^3)/6El^3_{\text{Web}} \cdot v_1$$

then we get $I_{\text{Web}} = 4.984 \times 10^6\,\text{cm}^4$. This conventional method of determination of the scantling of stringers and web frames is valid when their scantlings are sufficiently stiff relative to side frames. (practically for the case $\alpha \leqq 1.9$). These results may be ascertained by application of the equation (22) to these members. Exact method gives $v_1 = 0.01812\,\text{cm}$, this value is satisfactoriiy approximate to presumed value. In this case, the reduction rates of deflection become 97.0 % at centre of (01) span and 89.6 % at centre of (12) span, and reduction rates of fixing moment become 86.2 % for centre of (01) span and 79.7 % for centre of (12) span.

These values shows that side frames are sufficiently supported by stringers and web frames.

But it seems to be practically difficult to realize the scantlings required from these values of I_{st} and I_{Web}. Therefore it is better way to increase the numbers of web frames without large changes in dimensions of stringers and web frames.

Conclusions. A method of analyzing the stiffness of panting stringers with web frames relative to side frames and rational designing method of the panel system have been proposed. By an application to the structure in an actual ship, it has been made clear that the stiffness of panting stringers with web frames required by the Rules of the Classification Societies is not necessarily sufficient relative to side frames. But the panting frames in recent ships have considerable strength to be safe for external pressure, even if the stiffening effects of stringers and web frames are ignored.

(2) Refer the equation (3), in this case we may put $(I_{st})_{01} = (I_{st})_{12} = I_{st}$

Accordingly it may be possibly decreased their dimensions by the application of the rational designing method presented in this paper.

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