1- Publications in Ship Structural Analysis and Design (1969-2002)

1- " Effect of Variation of Ship Section Parameters on Shear Flow Distribution, Maximum Shear Stresses and Shear Carrying Capacity Due to Longitudinal Vertical Shear Forces", European Shipbuilding, Vol. 18. (Norway-1969), Shama, M. A.,

2- "Effect of Ship Section Scantlings and Transverse Position of Longitudinal Bulkheads on Shear Stress Distribution and Shear Carrying Capacity of Main Hull Girder", Intern. Shipb. Progress, Vol. 16, No. 184, (Holland-1969), Shama, M. A.,

3- "On the Optimization of Shear Carrying Material of Large Tankers", SNAME, J.S.R, March. (USA-1971), Shama, M. A.,

4- " An Investigation into Ship Hull Girder Deflection", Bull. of the Faculty of Engineering, Alexandria University, Vol. XII., (Egypt-1972), Shama, M. A.,

5- "Effective breadth of Face Plates for Fabricated Sections", Shipp. World & Shipbuilders, August, (UK-1972), Shama, M. A.,

6- " Calculation of Sectorial Properties, Shear Centre and Warping Constant of Open Sections", Bull., Of the Faculty of Eng., Alexandria University, Vol. XIII, (Egypt-1974), Shama, M. A.

7- "A simplified Procedure for Calculating Torsion Stresses in Container Ships", J. Research and Consultation Centre, AMTA, (EGYPT-1975), Shama, M. A.

8- "Structural Capability of Bulk Carries under Shear Loading", Bull., Of the Faculty of Engineering, Alexandria University, Vol. XIII, (EGYPT-1975), Also, Shipbuilding Symposium, Rostock University, Sept. (Germany-1975), Shama, M. A.,

9- "Shear Stresses in Bulk Carriers Due to Shear Loading", J.S.R., SNAME, Sept. (USA-1975) Shama, M. A.,

10- "Analysis of Shear Stresses in Bulk Carriers", Computers and Structures, Vol.6. (USA-1976) Shama, M. A.,

11- "Stress Analysis and Design of Fabricated Asymmetrical Sections", Schiffstechnik, Sept., (Germany-1976), Shama, M. A.,

12- "Flexural Warping Stresses in Asymmetrical Sections" PRADS77, Oct., Tokyo, (Japan-1977), Intern. Conf/ on Practical Design in Shipbuilding, Shama, M. A.,

13- "Rationalization of Longitudinal Material of Bulk Carriers, Tehno-Ocean'88, (Jpan-1988), Tokyo, International Symposium, Vol. II, A. F. Omar and M. A. Shama,

14- "Wave Forces on Space Frame Structure", AEJ, April, (Egypt-1992), Sharaki, M., Shama, M. A., and Elwani. M.,

15- "Response of Space Frame Structures Due to Wave Forces", AEJ, Oct., (Egypt-1992). Sharaki, M., Shama, M. A., and Elwani. M. H.

16- "Ultimate Strength and Load carrying Capacity of a Telescopic Crane Boom", AEJ, Vol.41., (Egyopt-2002), Shama, M. A. and Abdel-Nasser, Y.

PRADS-International Symposium on Practical Design in Shipbuilding, Tokyo, Oct.1977

A - 14

FLEXURAL WARPING STRESSES IN ASYMMETRICAL SECTIONS

M. A. SHAMA

Basrah University

Iraq

ABSTRACT

The flexural warping stresses induced in uniform members having asymmetrical sections are examined. Various cases of support conditions are considered. The effect on warping stresses of support conditions and scantlings of section are investigated. A design criterion based on the provision of adequate strength and stability is suggested and an illustrative numerical example is given.

It is shown that the proposed method gives results in good agreement with the results of both finite element method and model tests

1. INTRODUCTION

Fabricated asymmetrical sections are widely used by shipbuilders for longitudinals, girders, etc. since they are generally more economical to produce than symmetrical sections. This economy of production could be further improved by using automatic welding [1].

Horizontal girders in oil tankers are made asymmetrical so as to reduce the amount of sludge accumulated over the top surface of the web plate. In bulk carriers, horizontal girders are also used for similar reasons.

Asymmetrical sections, however, are not structurally efficient [2,3,4] because of the additional flexural warping stresses induced by torsional loading. The latter results from the offset position of the shear centre associated with asymmetrical sections.

This paper is concerned with the calculation of the flexural warping stresses induced in uniform members having asymmetrical sections and the provision of a design criterion suitable for these sections.

2. FLEXURAL STRESSES IN UNIFORM MEMBERS

The total flexural stress, at any point, in a uniform longitudinal member having an asymmetrical section, under quasi-static conditions, is given by [5]:

$$\sigma_T = \sigma_H + \sigma_b + \sigma_w \qquad (1)$$

where: σ_T = total stress,

σ_H = hull girder stress,

σ_b = local flexural stress,

σ_w = flexural warping stress.

The design of these members is normally based on the condition that σ_T produces neither yielding nor instability. This could be achieved by the proper selection of scantlings so as to sustain the maximum value of σ_T without failure. Much work has been done by classification societies on the calculation of hull girder and local stresses. This paper, therefore, is devoted to the calculation of flexural warping stresses.

3. FLEXURAL WARPING STRESSES, σ_w

Flexural warping stresses induced in a uniform member having an open section can be calculated as follows [6]:

$$\sigma_w = -E.\phi''.w \qquad (2)$$

where: ϕ = angle of twist, $\phi'' = \frac{d^2\phi}{dx^2}$

E = modulus of elasticity

w = principal sectorial coordinate

Thus, for the outer (o) and inner (i) points of the face plate, σ_w is given by:

$$(\sigma_w)_r = -E.\phi''.w_r \quad , \quad r = o,i \qquad (3)$$

Since "w" varies linearly over each element of the member, σ_w will behave similarly, as shown in fig.(1). It is evident that σ_w depends on the principal sectorial coordinates of the section and ϕ''. The former may be calculated as given by Shama [7] and the latter could be determined from the solution of the general torsion equation [8]:

$$C.\phi' - C_1.\phi''' = T_x \qquad (4)$$

where: $C = GJ_t$ = torsional rigidity,

$C_1 = EJ_w$ = warping rigidity,

G = modulus of rigidity,

J_t = torsion constant of section,
J_w = warping constant of section,
T_x = torsional moment.

Torsional loading results from the presence of the shear centre C' on the opposite side of the face plate, see fig. (2). If the member is an integral part of a stiffened panel, C' should lie within the plating, as the latter cannot deform in its own plane.

Therefore, for uniform lateral loading, q, the torsional moment, T_x, is given by :

$$T_x = M_o + qex \qquad (5)$$

and the solution of equation (4) is given by :

$$\phi = A_o + A_1 \sinh kx + A_2 \cosh kx + M_o(kx - \sinh kx)/kC + qex^2/2C \qquad (6)$$

If the lateral loading is linearly distributed, T_x is given by :

$$T_x = M_o + qex^2/2L \qquad (7)$$

and the solution of equation (4) is given by :

$$\phi = B_o + B_1 \sinh kx + B_2 \cosh kx + (qe/LCk^2 + M_o/C)x + qex^3/6LC \qquad (8)$$

where: $k = \sqrt{C/C_1}$

A_i and B_i, (i=0,1,2) are arbitrary constants which depend on end conditions.

The solution of equation (6) and (8), for several cases of support conditions, are given in table (1).

4. PARAMETERS AFFECTING σ_w

The chief parameters affecting the magnitude of σ_w are the support conditions and scantlings of section. In order to examine the effects of these parameters on the magnitude of σ_w, a uniform member having the following particulars is considered : length (L) = 5200 mm, face plate ($b x t_f$) = 250x25 mm, web plate ($d x t_w$) = 950 x 20 mm, outer plate ($S x t_p$) = 1155x27.5 mm. For this asymmetrical section, the parameters examined are : b, t_f and t_w in addition to the support conditions.

4.1 Effect Of Scantlings On σ_w

The effects of variation of b, t_f and t_w are given in table (2). The total local stress, $\sigma_t = \sigma_b + \sigma_w$, is also given for the inner edge of the face plate.

It is evident from table (2) that increasing t_w has a significant effect on σ_w, increasing t_f has a much less effect and increasing b has a negligible effect.

4.2 Effect Of Support Conditions On σ_w

The influence of support conditions on the magnitude of σ_w is examined and the results for the particular case of uniform loading are given in table (3). The unconstrained warping condition is included in table (3) so as to extend th scope of comparison, as it is not common in practice. It is evident from table (3 that the magnitude of σ_w is influenced b the degree of constraint at both ends of member.

5. STRESS ANALYSIS USING FEM

The stresses and deformations of two structural models having asymmetrical sections subjected to uniform loading an fixed at both ends have been examined by Shama[5]. Structural model (I) is composed of one uniform member and model(II is composed of three uniform members. Th deficiency of face plate for the latter model is determined from the results of 2-D and 3-D stress analysis using FEM [2 as shown in fig.(3). In the 2-D stress analysis, the face plate is idealized by finite bar elements whose sectional are is varied from 10% to 100% of its original value. It is shown that the efficier cy of the asymmetrical face plate does not exceed 30%. The deformed shape of both models are shown in figs.(4,5). It is evident that increasing web thicknes reduces torsional effects.

6. STRES ANALYSIS USING MODEL TESTING

The results of a test model compose of five members having asymmetrical sec tions, uniformly loaded and fixed at bo ends [9] have been examined and analyse [5]. The total flexural stresses at the inner and outer edges of the face plate at the fixed ends, are given in table (

7. COMPARISON OF RESULTS

The results of the proposed method, FEM, model tests and the simple beam th ory are given in table (4). It is evide from these results that the simple beam theory cannot be used to predict the fl ural stresses in asymmetrical sections. The twist of the section clearly indica the effect of torsional loading induced uniform lateral pressure. These results indicate also that the proposed method be satisfactorily used to calculate the flexural warping stresses induced in as metrical sections. It is also evident t asymmetrical fabricated sections are de icient under lateral loading.

It should be realised that the defi iency of asymmetrical face plates could easily predicted by considering a long narrow plate loaded by shear forces alc one edge while the other edge is free, fig.(6). The normal and bending stresse induced in the plate section are given

$$\sigma_n = N/bt \quad , \quad \sigma_b = 3N/bt$$

where: $N = \int_0^l \tau . t . dx$

l = length of face plate.

Therefore, the normal stress at the loaded edge is given by :

$$(\sigma_t)_i = 4N/bt$$

and the normal stress at the free edge is given by :

$$(\sigma_t)_o = - 2N/bt = -(\sigma_t)_i/2$$

8. DESIGN CRITERIA

The design of a fabricated asymmetrical section could be based on the following conditions :

$$\sigma_T \leqslant \sigma_i \quad , (i = y,c) \qquad (9)$$

where: σ_y = yield stress,
σ_c = critical buckling stress [10]

For a fabricated longitudinal member, the flexural warping stress should satisfy the following conditions :

$$\sigma_w \leqslant (\sigma_i - \sigma_H - \sigma_b) \ , (i=y,c) \qquad (10)$$

Hull girder stress could be assumed 160 MN/sq.m and the yield stress 250 MN/sq.m. Therefore, conditions (10) become :

$$\sigma_w \leqslant (90 - \sigma_b) \quad MN/m^2 \qquad (11)$$

and $\sigma_w \leqslant (82.3 \text{ x } 10^3 (t_f/b)^2 - 160 - \sigma_b)$

$$MN/m^2 \qquad (12)$$

The magnitude of σ_b depends on the intensity of local loading, degree of constraints at both ends of member and the flexural properties of the section[5].

It should be noted that expression (12) is valid only when :

$$\sigma_c \leqslant \sigma_y/2 \qquad (13)$$

If condition (13) is not satisfied, a modified value of σ_c, given by [11], should be used :

$$(\sigma_c)_m = \sigma_y(1 - \sigma_y/\sigma_c) \qquad (14)$$

9. CONCLUDING REMARKS

The main conclusions drawn up from this investigation are :

i- Fabricated asymmetrical sections may be subjected to high flexural warping stresses in addition to the local and hull girder stresses.
ii- Flexural warping stresses are influenced by the degree of constraint at both ends of member and web thickness.
iii- The simple beam theory cannot be used to predict the flexural stresses induced in fabricated asymmetrical sections under lateral loading.
iv- Fabricated asymmetrical face plates are deficient under lateral loading. Their efficiency may not exceed 30%.

REFERENCES

1. ----:"Automatic Production of Tee-Beams", Shipping World and Shipbuilder, 3 December,(1964)
2. Shama,M.A.:"Effective Breadth of Face Plates For Fabricated Sections", Lloyds Register Of Shipping, October, (1971)
3. Terazawa,K. and others:"On the Elastic Bending Of Inverted Angle With Plating", Journal of Zosen Kiokai, SNAJ, Vol. 110, (1960)
4. Terazawa,K. and others:"On the Elastic Bending Of Parallel Angles With Plating", Journal of Zosen Kiokai, SNAJ, Vol. 112, (1963)
5. Shama,M.A.:"Stress Analysis and Design Of Fabricated Asymmetrical Sections", Schiffstechnik, 23, No. 113, Hamburg,(1976)
6. Oden,J.T.:"Mechanics of Elastic Structures", McGraw-Hill Co., (1967)
7. Shama,M.A.:"Calculation of Sectorial Properties, Shear Centre and Warping Constant of Open Sections", Bull. of the Faculty of Engineering, Alexandria University, (1974)
8. Timoshenko,S.:"Theory of Bending, Torsion and Buckling of Thin-Walled Members of Open Cross-Section", Journal of the Franklin Institute, Philadelphia, (1945)
9. ----:"Stress Distribution in Longitudinals With Offset Flanges", Lloyds Register of Shipping, (1971)
10. Mathewson,J.I. and Viner,A.C.:" Buckling AS a Mode Of Failure in Ship Structures", Lloyds Register of Shipping, (1970)
11. Ostenfeld,A.:"Exzentrische und zentrische knickfestigkeit", Zeitschrift des Vereines Deutscher Ingenieure, Vol.42 (1898)

Table (1) ; ϕ and $\overset{''}{\phi}$ For Different Support Conditions

case	support condition	ϕ and $\overset{''}{\phi}$ for uniform loading
1	at $x = o$ and $x = L$ $\phi = \overset{'}{\phi} = o$	$\phi = \frac{qeL}{kC}\left[\{\sinh kx/2.\sinh k(L-x)/2\}/\sinh kL/2 - kx\,(L-x)/2L\right]$ $\overset{''}{\phi} = \frac{qeL}{2C}\left[2/L - k.\cosh (kx - kL/2)/\sinh kL/2\right]$, $\overset{''}{\phi}_{max} = \overset{''}{\phi}_{x=o} \doteq \overset{''}{\phi}_{x=L}$
2	at $x = o$ and $x = L$ $\phi = \overset{''}{\phi} = o$	$\phi = \frac{qe}{C}\left[Z(\sinh kx - \sinh kL) - xL/2 + x^2\right]$, $Z=(\cosh kL - 1)/k^2\sinh kL$ $\overset{''}{\phi} = \frac{qe}{C}\left[k^2Z.\sinh kx - (\cosh kx - 1)\right]$, $\overset{''}{\phi}_{max} = \overset{''}{\phi}_{x=L/2}$
3	at $x = o$ $\phi = \overset{'}{\phi} = o$ and at $x = L$ $\phi = \overset{''}{\phi} = o$	$\phi = \frac{qe}{2C}\left[- 2G(\cosh kx - 1) - 2H(x^2 - \sinh kx)/x + x^2\right]$ $\overset{''}{\phi} = \frac{qe}{C}(- k^2G.\cosh kx + kH.\sinh kx + 1)$, $\overset{''}{\phi}_{max}=\overset{''}{\phi}_{x=x_m}, x_m= \frac{1}{k} \tanh^{-1}\frac{H}{kG}$ $\overset{''}{\phi}_{x=o}= - \frac{qekL}{C}\left[2(\cosh kL - 1) - kL.\sinh kL\right]/2(\cosh kL - \sinh kL)$ where: $H =\{(k^2L^2- 2).\sinh kL +2kL\}/2k^2(kL.\cosh kL - \sinh kL)$ $G =\{(k^2L^2- 2).\cosh kL + 2\}/2k(kL.\cosh kL - \sinh kL)$
		ϕ and $\overset{''}{\phi}$ for linear loading
4	at $x = o$ and $x = L$ $\phi = \overset{'}{\phi} = o$	$\phi = \frac{qe}{6C}\left[(3/\sinh kL - B.\tanh \frac{kL}{2})(1 - \cosh kx)+(kx - \sinh kx)B +kx^3/L^2\right]$ $\overset{''}{\phi} = - \frac{qeL}{6C}\left[(3/\sinh kL - B \tanh \frac{kL}{2}).k.\cosh kx + kB.\sinh kx - 6x/L^2\right]$ $\overset{''}{\phi}_{x=o} = - \frac{qekL}{6C}\left[B.\tanh kL/2 - 3/\sinh kL\right]$ $\overset{''}{\phi}_{x=L} = - \frac{qekL}{6C}\left[(B.\tanh kL/2 - 3/\sinh kL).\cosh kL - B.\sinh kL + 6/kL\right]$ $B = \{3(\cosh kL - 1) - kL.\sinh kL\}/\{kL.\sinh kL + 2(1 - \cosh kL)\}$
5	at $x = o$ and $x = L$ $\phi = \overset{''}{\phi} = o$	$\phi = - \frac{qe}{C}\left[\sinh kx/k^2.\sinh kL + (1/k^2L - L/6)x + x^3/6L\right]$ $\overset{''}{\phi} = - \frac{qe}{C}\left[(\sinh kx/\sinh kL - x/L)\right]$ $\overset{''}{\phi}_{max} = \overset{''}{\phi}_{x=x_m}$, $x_m = \frac{1}{k}.\cosh^{-1}(\sinh kL)/kL$
6	at $x = o$ $\phi = \overset{'}{\phi} = o$ and at $x = o$ $\phi = \overset{''}{\phi} = o$	$\phi = \left[qe/Ck^2.\cosh kL - (M_o/kC + qe/LCk^3).\tanh kL\right](1 - \cosh kx) -$ $(M_o/Ck + qe/LCk^3)(\sinh kx - kx) +qex^3/6CL$ $\overset{''}{\phi} = - k^2\left[qe/Ck^2.\cosh kL - (M_o/Ck + qe/LCk^3).\tanh kL\right]\cosh kx - k(M_o/C$ $+ qe/LCk^3).\sinh kx + qex/CL$ $\overset{''}{\phi}_{x=o} = - (kM_o/C + qe/kLC).\tanh kL + qe/C.\cosh kL$ $M_o = \frac{qe}{k}\{(kL - \sinh kL - \frac{k^3L^3}{6}.\cosh kL)\}/kL(kL - \tanh kL).\cosh kL$

Table (2) : Effect Of Scantlings Of Section On σ_w (dimensions in mm)

stress	$t_w = 20$			$t_w = 30$		
	$b = 250$		$b = 315$	$b = 250$		$b = 315$
	$t_f = 25$	$t_f = 30$	$t_f = 30$	$t_f = 25$	$t_f = 30$	$t_f = 30$
$(\sigma_w)_i/q$	1.082	1.125	1.120	0.608	0.650	0.683
$(\sigma_w)_o/q$	-3.615	-3.375	-3.305	-2.865	-2.720	-2.505
$(\sigma_b)/q$	2.085	1.893	1.842	1.740	1.608	1.437
$(\sigma_t)_i/q$	3.167	3.018	2.962	2.348	2.258	2.120

Table (3) : Effect of Support Conditions on σ_w

case	position	$(\sigma_w)_i/q$	$(\sigma_w)_o/q$
1	$x = 0$ or L	1.082	- 3.615
2	$x = L/2$	4.620	-15.460
3	$x = 0$	5.16	-17.250
	$x = x_m$	0.895	- 2.990

Table (4) : Correlation of Results

type of analysis	$(\sigma_t)_i$	$(\sigma_t)_o$	
Model I			
FEM	0.648	- 0.296	t/cm^2
Proposed method	0.595	- 0.283	t/cm^2
Simple beam theory	0.334	0.334	t/cm^2
Model II			
FEM	1.076	- 0.305	t/cm^2
Proposed method	0.952	- 0.310	t/cm^2
Simple beam theory	0.530	0.530	t/cm^2
Test Model			
Model results	476.0	- 244.0	lb/in^2
Proposed method	476.1	- 286.7	"
Simple beam theory	239.5	239.5	"

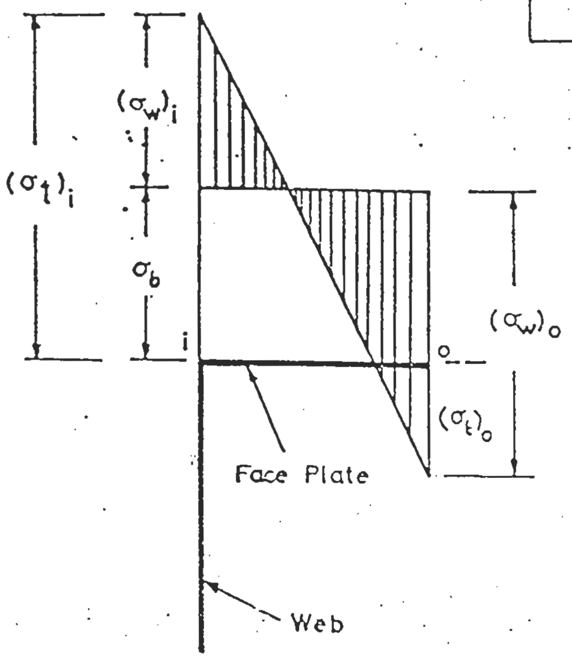

Fig.(1) Flexural Warping Stresses

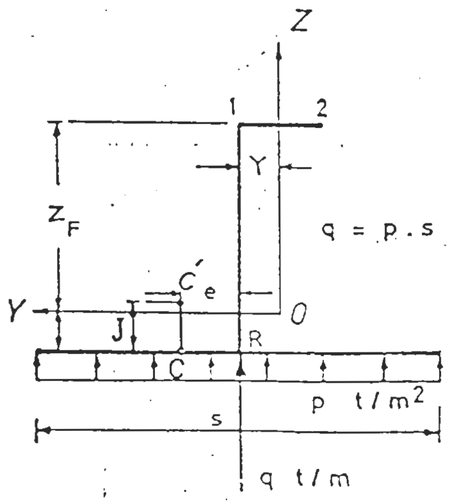

Fig.(2) Position Of Shear Centre

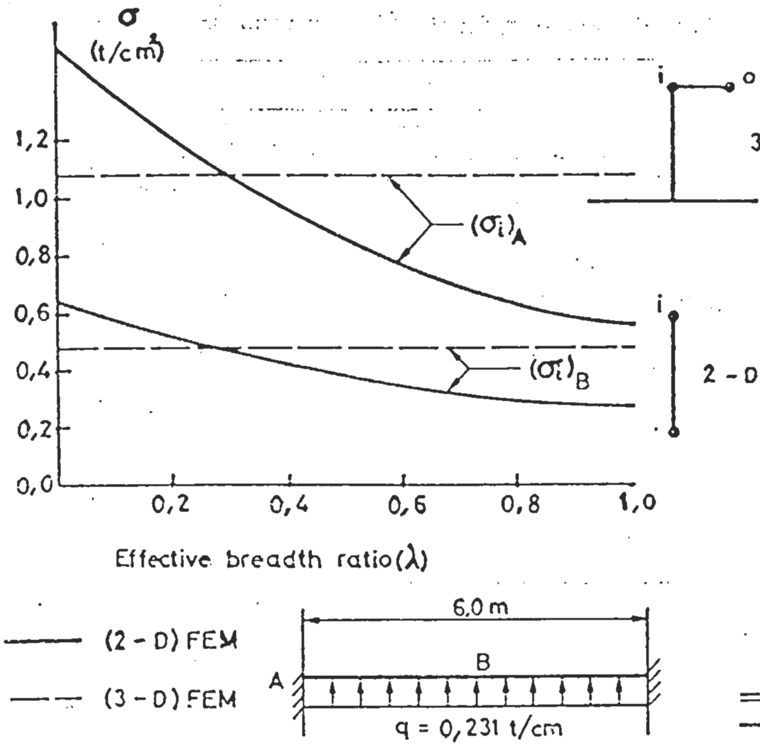

Fig.(3) Flexural Stresses in Face Plate

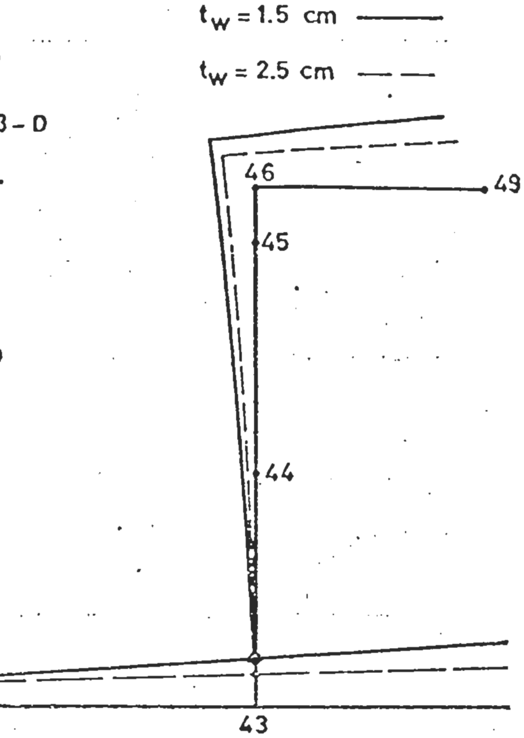

Fig.(4). Deformed Shape under Lateral Loading

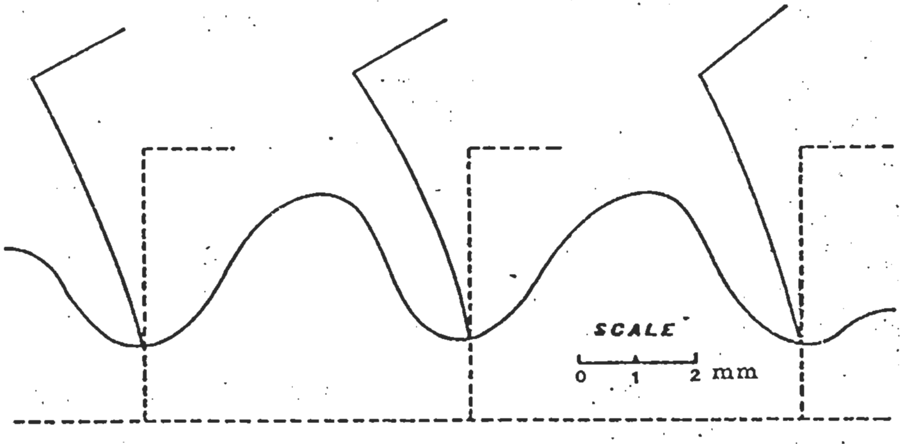

Fig.(5) Deformed Shape of Model (II)

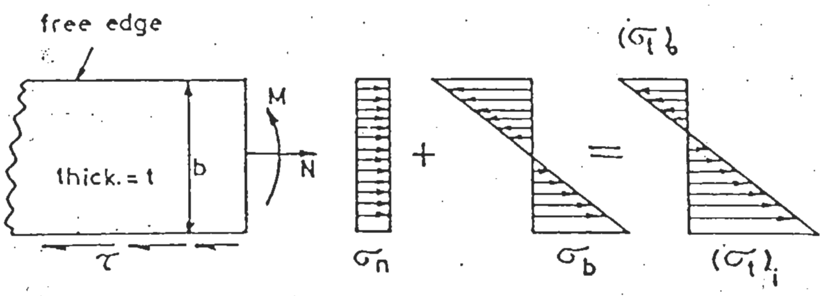

Fig.(6) Stresses due to Shear Loading

RATIONALIZATION OF LONGITUDINAL MATERIAL OF BULK CARRIERS

A.F. Omar
University of Florida
FL. U.S.A.

M.A. Shama
Alexandria University
Egypt

Summary

This paper presents a simplified structural analysis/design procedure for the rationalization of the material distribution along the midship region of bulk carriers, through the unification of the inherent safety factors. The method is based on the calculation of hull girder shear and bending stresses, due to the longitudinal vertical shearing forces and bending moments. The necessary conditions to safeguard against shear buckling of side shell and yielding of deck and bottom structures are specified.

The method is programmed for the Alexandria University, Faculty of Engineering, PDP-11/70 computer and is illustrated by a numerical example.

1. Introduction:

The use of the simplified formulae of the classification societies rules to obtain satisfactory scantlings, provide adequate strength and safety for least cost (or whatever other objective is chosen) are not really sufficient in the structural design process. This is because they have large inbuilt margins, of unknown magnitude. They therefore do not give a truly efficient design, the extra steel may represent a significant cost penalty in the life of the ship (1,2). For this reason, there must be a general trend toward "rationally based" structural design, which involves a thorough and accurate analysis of all the factors affecting the safety and the performance of the structure throughout its life (3). For large complex structures such as ships, the required accuracy can be achieved only by a thorough analysis of the full three-dimensional structure using some form of the finite element method, which is computationally very expensive. Therefore, a simplified structural analysis/design procedure capable of performing inexpensive structural analysis is required so as to reduce the large, highly constrained, non-linear structural analysis/design problem (when using a finite element technique) and consequently to achieve low computational cost.

In the author's estimation, the challenge posed by these tasks could be met only by developing a method for rationalization of material distribution along the ship length which makes the information required for optimization or using a finite element technique reasonable near to the required optimum solution. The procedure given here involves three main tasks:

1-Analysis: the calculation of the structural responses (hull girder shear and bending stresses)

2-Evaluation: the prediction of the critical or failure values of these responses (for example, ultimate strength of a stiffened panel)

3-Rationalization (or Redesign): the application of a systematic method for determining the design variables which rationalize a specified objective while satisfying the constraints (such as our objective of keeping a better distribution of steel along the ship length).

Bulk carriers typically have breadths equal to 1/7 to 1/5 of length with L/D ratios generally between 11.5 and 14 (4). The transverse shear stresses in beams with solid rectangular cross sections having such proportions would be relatively unimportant compared with the largest tensile and compressive stresses developed due to bending (5). However, in open thin-walled sections such as bulk carriers, it is well known that the transverse shear stresses in certain locations can be significant (5, 6,7). Thus, maximum shear stresses in the side shell may reach unfavourable values and consequently may cause shear instability, in an inadequate design (5,6). Adequate measures, therefore, should be taken to prevent instability and high stresses.

In this paper, the method given is based on the calculation of the induced hull girder shear and bending stresses over a typical section of bulk carrier, due to the longitudinal vertical shearing forces and bending moments. The longitudinal vertical forces and bending moments at any section, along a ship steaming in waves is the vectorial sum of the still-water component, wave-induced component and the dynamic component (6). A computer-aided method for the estimation of these components and their distributions along the length is given in reference (4). The ship section of a bulk carrier is idealized by a simplified configuration. The necessary conditions giving adequate strength with a unified safety factor (along the mid-ship region) against shear buckling and yielding, of side shell, deck and bottom structures, are examined and speci-

Vol. II.

Techno-Ocean '88
International symposium, Vol. II
Tokyo, Japan, 1988

fied. The method is programmed for Alexandria University, Faculty of Engineering, PDP-11/70 computer. The computer program is used to calculate the shear and bending stress distributions over three typical cross sections of a 38,500 DWT. bulk carrier along 0.4 L of the mid-ship region. The results of this study are analysed and discussed.

2. Shear Stress Distribution:

The method of calculation is based on the method given by Shama (6,7). It is assumed that the structure is not subjected to any torsional loading. The shear stress distribution is calculated by representing the actual structure by an idealized structure. Then a shear flow distribution around the idealized ship section is assumed. The resulting torsional deformations are then corrected by a set of correcting shear flows. The superposition of the assumed and correcting shear flows gives the correct shear flow distribution, from which the shear stress distribution could be easily determined. Fig(1) shows a typical cross section of a bulk carrier which is idealized by the section shown in Fig(2). The assumed shear flow distribution is as shown in Fig(3).

3. Bending Stress Distribution:

The primary stresses in the upright position, could be computed using the simple beam theory. Thus, the bending stress at any node "i" of member "r" is given by:

$$(\sigma_r) = \frac{BM^*}{I} \cdot Y_i \qquad (1)$$

where:

BM = total longitudinal vertical bending moment at the section under consideration.

Y_i = distance of node "i" of member "r" from the neutral axis of the ship section.

I = second moment of area of the ship section about its neutral axis.

4. Structural Design Criteria:

A successful ship structural design, i.e., the one where the elements fully suit their purposes, is a compromise between a wide range of conflicting factors stemming from the service conditions, the way the ship and her components have to resist the loads and shipyard practices. The problem is a manyfold one, and it is the naval architect's task to arrive at this compromise with a ship capable of fully meeting all the requirements at minimum cost and with economy in weight (8). The strength of the hull is of course the overriding quality. This means that an adequate amount of material has to be put into the structural elements in order to enable them to resist the loads attendant, to the most adverse service conditions, against the various expected modes of failure. Also a safety factor has to be introduced. It must be reasonably high so as to compensate for any irregularities, such as excessive working loads, impaired safe-load capacity of parts due to their corrosion, wear and tear, pitfalls in shipyard practices, etc. Conversely, unreasonably high safety factor may lead to what is designated over-design, in which the weight/strength ratio increases, which in turn lead to an adverse economical consequences (such as loss in deadweight carrying capacity, increase in fuel consumptions increase in building cost, etc.). Too low safety factor may lead to what is termed under design, which may lead in turn to the following consequences:

- Frequent failures of structural details which in turn leads to withdrawing the ship from the production line for the maintenance and repair work(9).
- Lost income for the stoppage of the ship which will significantly affect her profitability.
- Increasing the cost of repair work which would also affect the ship profitability.

In any case, structural elements should be of minimum weight compatible with the requirements for structural safety against the expected modes of failure. Economy in steel weight produces a less expensive ship, has a positive effect on the deadweight carrying capacity and consequently on the ship's profitability (9).

The simplest form of the design criterion may be a limiting stress, deflection, instability, ultimate load, etc. (10). In the following analysis, yielding of the deck and bottom structures and shearing of the side shell plating are selected to be the limiting stresses (possible modes of failure). The deck and bottom structures are subjected to high bending and shear stresses. The side shell plating is subjected to high shear stress, especially at the neutral axis (7).

In this study, the combined effects of shear and bending, in the deck and bottom structures, are taken into account by the equivalent stress formula. The permissible shear stress given by the rules of classification societies is taken as the design criterion for side shell plating. For a two dimensional member, Von Mises (10) equation could not be used to determine the equivalent stress at any point subjected to normal and shear stresses, i.e.,

$$\sigma_e = \sqrt{\sigma_X^2 + \sigma_Y^2 - \sigma_X\sigma_Y + 3\tau_{XY}^2} \qquad (2)$$

where:

σ_X = longitudinal stress in the X-direction.

σ_Y = transverse stress in the Y-direction.

τ_{XY} = shear stress at the point under consideration.

Since only longitudinal stresses are considered, the equivalent stress of Von Mises equation is then given by:

$$\sigma_e = \sqrt{\sigma_X^2 + 3\tau_{XY}^2} \leq \sigma_y \qquad (3)$$

Consequently the design criteria adopted are given by:

$$1\text{-}\ \sigma_e < \sigma_y \qquad (4)$$

$$2\text{-}\ \tau_{\max.\text{at side}} < \tau_{all} \qquad (5)$$

where:

σ_y = yield stress of material used (2.4 t/cm² for mild steel).

τ_{all} = permissible shear stress given by A.B.S. Rules (1.065 t/cm²).

Since the safety factor (γ) is of central importance in conventional desigh, the most frequently encountered definition of safety factor is used. It is defined by: the ratio of ultimate or yield strength in a component to the actual working stress. Thereupon, $\gamma_y = \sigma_y/\sigma_e, \gamma_s = \tau_{all}/\tau_{max}$. If the equivalent stress (σ_e) of the member exceeds the yield stress (σ_y), the scantling of this member should be increased and the design process is repeated until a satisfactory condition, of a unified [illegible] safety factor along the ship length, is reached. This safety factor should be unified along the ship length, as the variation in its value will lead to irrational distribution of steel which in turn lead to unnecessary increase in the hull steel weight.

5. The Comouter Program

The method of calculation is programmed in Basic for Alexandria University, Faculty of Engineering, PDP-11/70 computer. The computer flow chart is shown in Fig (4) and a copy of the program is given in reference [illegible]. The data and the results of this program are as follows:

i- Data:
- Main ship dimensions (L, B, T, D, C_B).
- Geometry and scantlings of ship sections according to the rules of any classification society.
- Position of neutral axis and the second moment of area of the ship section about its neutral axis (a subroutine given in reference [illegible] could be used for this purpose).
- Total longitudinal vertical shearing force and bending moment (it could be easily obtained using the computer program given in reference [illegible]).

ii- Results:
The following results are obtained at three ship-sections, (0.3 L, 0.5 L, and 0.7 L from after perpendicular (A.P.)):
- Shear stress distribution
- Bending stress distribution
- Equivalent stress distribution, at some critical points.

6. Case Studv:

A case study is worked out to demonstrate the capabilities of the developed computer program for estimating the shear and bending stresses over a three sections of a [illegible] DWT. bulk carrier and also for the rationalization of the material distribution over these sections and along the mid-ship region.

6.1 Data:

The total shearing force and bending moment at sections at 0.3 L, 0.5 L and 0.7 L measured from the A.P. are used as input data for the computer program. The stresses are calculated within the range subjected to maximum bending moments and high values of shearing forces which lies between 0.3 L and 0.7 L from A.P.

6.2 Results:

The results obtained are:

i- Shear stress distributions over the three selected ship sections.
ii- Bending stress distribution at some critical points of the three selected sections.
iii- The equivalent stress distribution at the same critical points.

The results are presented graphically in Figs (5), (6), (7), (8), (9) and (10) for the three ship sections (at 57 m., 95 m., and 133 m. measured from A.P. respectively). A copy of the output of such program is given in appendix (1).

7. Analvsis of Results:

1- Unfavourable stress conditions may be developed in the hopper and top wing tanks because of the high shear and bending stresses (see table I). Consequently, the scantlings of side shell plating, hopper and top wing tanks should be adequate enough to sustain yielding and shear buckling.

2- The inherent safety factors, along the midship region are as given in table ii. It is clear that the factors of safety for both the deck, bottom and side structures are far from uniform. This implies that the material distribution along the midshiop region is not rationally distributed. Therefore, it is necessary to adjust the deck, bottom and side shell plating thicknesses so as to achieve a more uniform distribution of the safety factor.

3- It is also clear that the safety factor of the bottom structure is higher than that for the deck structure. This may be necessary because the bottom structure is subjected to higher variabilities of local loading than the deck structure. The higher safety factor of the bottom structure is intended to cater for these local loadings. Therefore the limiting hull girder stresses in the bottom structure is expected to be less than that induced in the deck structure.

8. Conclusions:

The main conclusions that may be derived from this study are:

1- The hopper and top wing tanks may be subjected to unfavourable shear and bending stresses.

2- The formulae given by the rules of classification societies should be used only for preliminary design, as these formulae do not give a rational distribution of material along ship length. Therefore, it should be followed by a stress analysis/design procedure, taking into account the combined effects of both shear and bending stresses.

3- The given simplified method could be effectively used for the following cases:
i- In the absence of a finite element program.
ii- To reduce the computational cost of structural analysis or material optimization.

4- The method presented could be used effectively to indicate the lack of uniformity of the inherent safety factors in the ship section structural members and suggesting the possible adjustments in plating thicknesses so as to obtain a more uniform distribution of the safety factors which in turn lead to the rational distribution of material along the ship length.

References:

1- Owen, F.H., Mistree, F. and Zanic, V., "A Practical Method For the Rational Design of Ship Structures" J.S.R. Vol. 24 No 2 June 1980.
2- Shama, M.A., "The Cost of Irrationality in Ship Structural Design", Symposium on Practical Design in Shipbuilding, Tokyo, Japan, Oct. 1977.
3- Donald, L., Owen, H. and John, H., "Application of a Computer-Aided, Optimal Preliminary Ship Structural Design Method" SNAME Trans., Vol.

89,1981.

4- Omar, A.F., "Computer-Aided Design of Bulk Carriers", M.Sc. theses, Alexandria University, Faculty of Engineering, Alexandria, Egypt, 1986.

5- Evans, J.H., "Ship Structural Design Concepts", Second Cycle. Ship Structure Committee.

6- Shama, M.A., "Shear Stresses in Bulk Carriers Due to Shear Loading", Journal of Ship Research, Vol. 19, No. 3, Sept. 1975.

7- Shama, M.A., "Analysis of Shear Stresses in Bulk Carriers", Computers and Structures, Vol. 6, 1976.

8- Barabnov, N., "Structural Design of Sea-Going Ships", Peace Publishers, Mosco, 1963.

9- Shama, M.A., "Optimizing Hull Steel Weight for Overall Economic Transportation", Marine Week May 2, 1975.

10- Shama, M.A., "On the Rationalization of Ship Structural Design", Schiff Und Hafan, 1979.

Nomenclature:

L, B, D = Length, breadth and depth of ship respectively, m.
SF = Total longitudinal vertical shearing force at section under consideration, tonne.
DWT = Deadweight carrying capacity of the ship, tonne.
A, Z = Total area and section modulus of the ship section under consideration m^2, m^3 respectively.
l = Length of each element, m.
N = Number of longitudinal girders in bottom structure.
θ = Slope of each element, deg.
γ_{yi} γ_{si} = Yielding and shear buckling safety factors at section i, i=1, 2, 3.
γ_r = Required satisfactory level of safety factor.
$\delta\gamma_y = \gamma_{yi} - \gamma_{yi-1}$, $\delta\gamma_s = \gamma_{si} - \gamma_{si-1}$, i=3, 2.
ϵ = Very small quantity representing the acceptable deviation of the calculated safety factor from the required value.

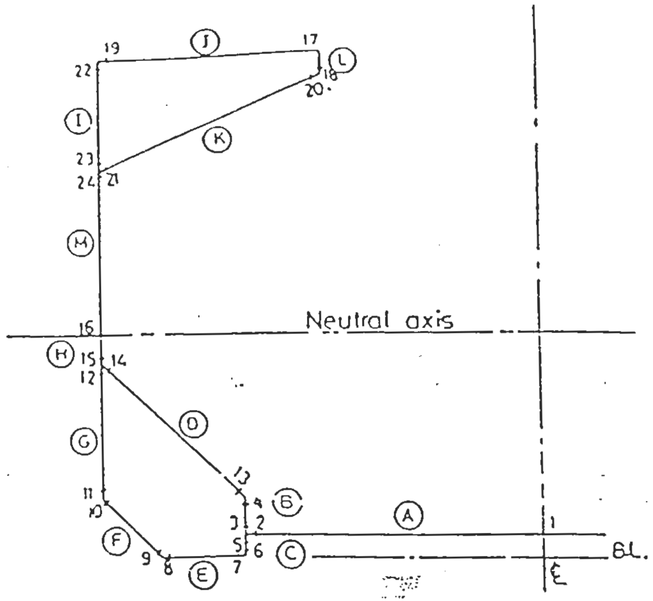

Fig.(2): Idealized structure

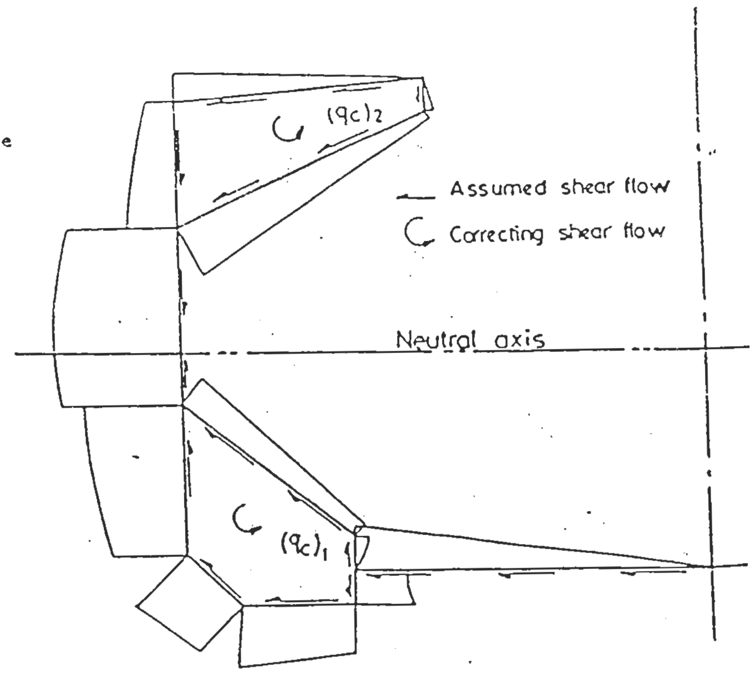

Fig.(3): Assumed shear flow distribution.

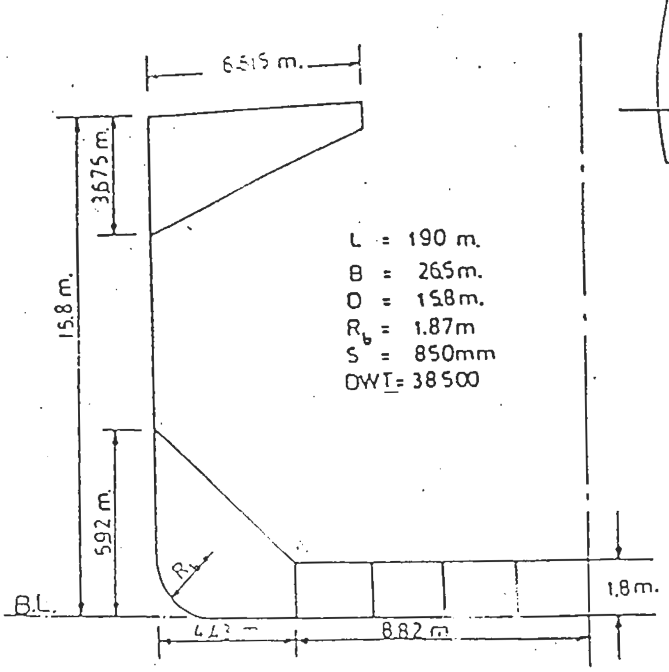

Fig.(1): Typical section of bulk carrier

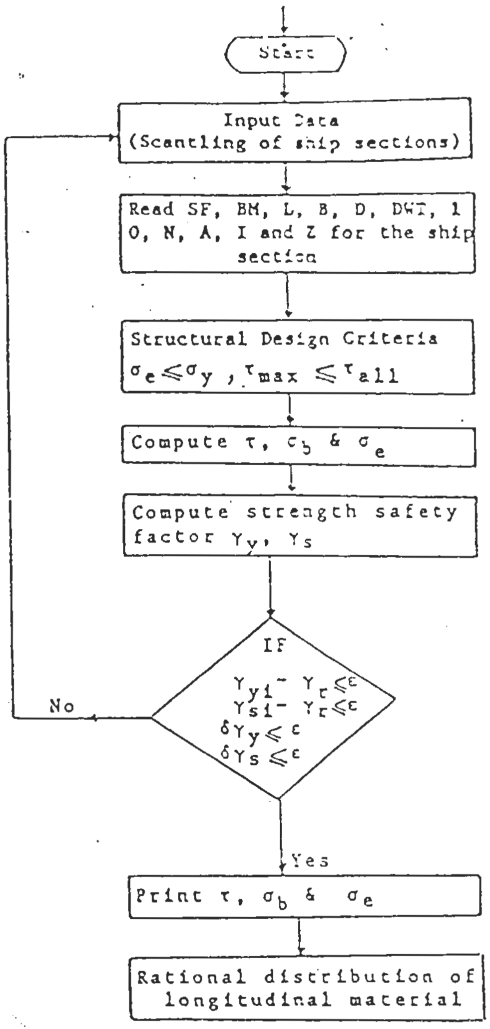

Fig. (4): Computer flow chart of design procedure

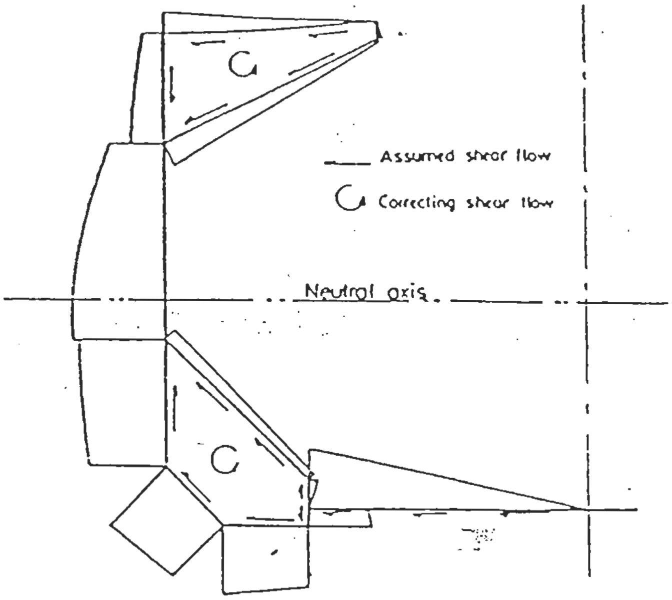

Fig.(5): Assumed shear flow distribution (at 75 m. from A.P.)

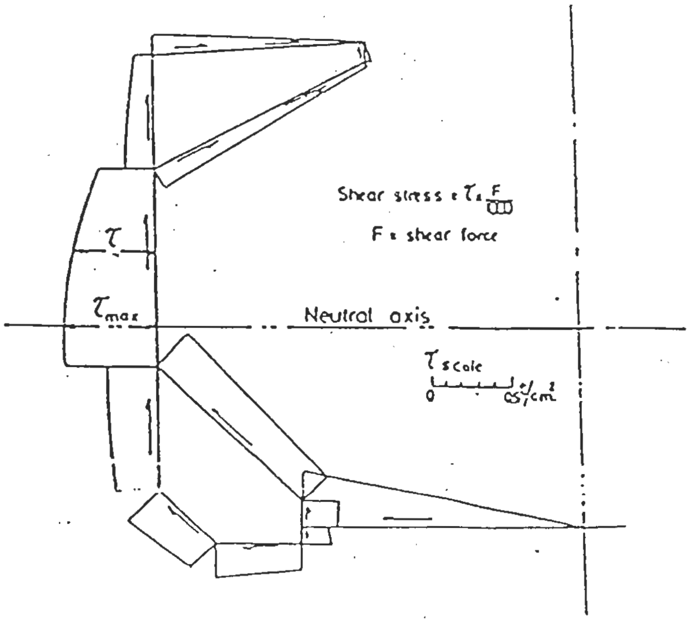

Fig.(6): Correct shear stress distribution (at 75 m. from A.P.

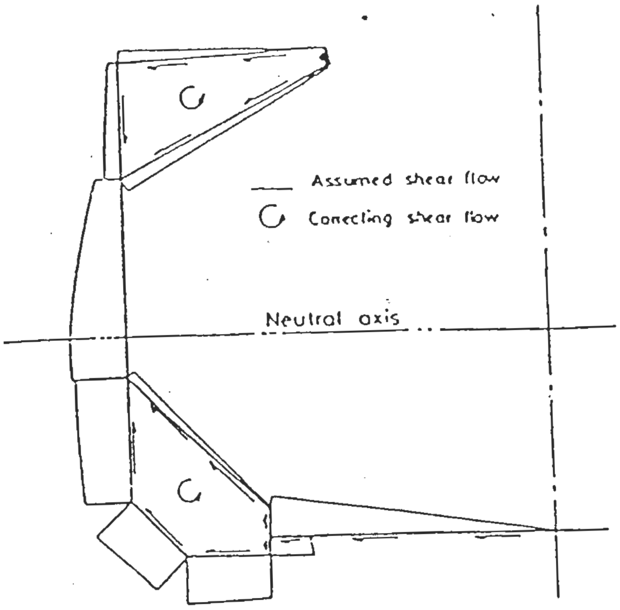

Fig.(7): Assumed shear flow distribution (at 95 m. from A.P.)

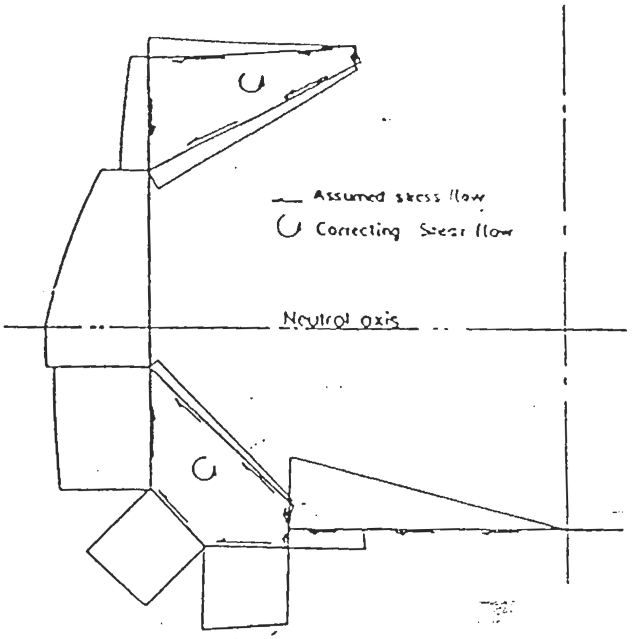

Fig.(9): Assumed shear flow distribution (at 133 m. from A.P.)

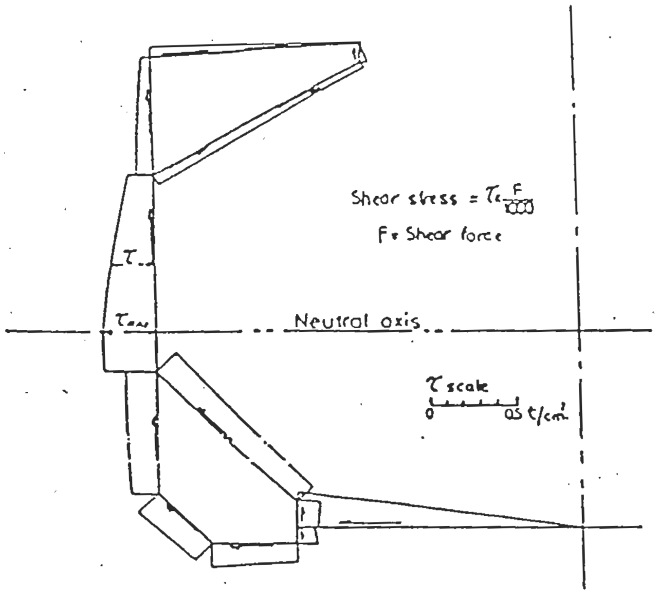

Fig.(8):Correct shear stress distribution (ship section at 95 m. from A.P)

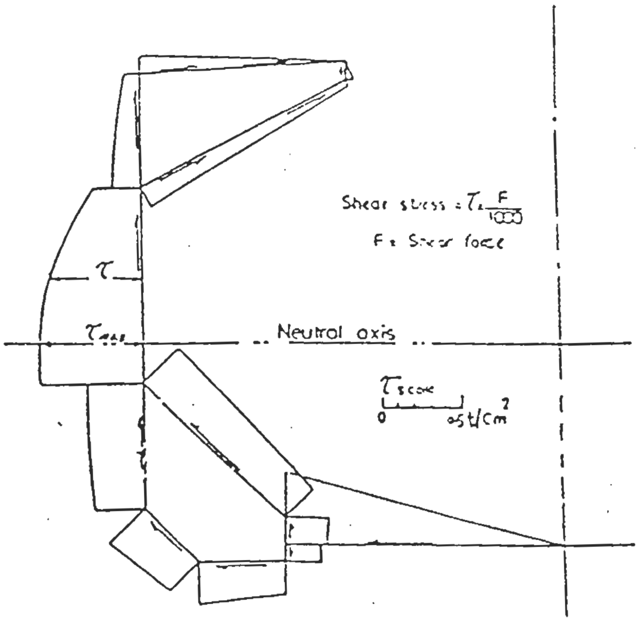

Fig.(10):Correct shear stress distribution (ship sec. at 133 m

Table I: Shear, Bending and Equivalent Stresses Over A Typical Ship Section of Bulk Carrier.

Point	Shear stress t/cm^2	Bending stress t/cm^2	Equivalent stress t/cm^2
4	0.2	0.92	0.9817
6	0.172	1.162	1.20
8	0.12	1.162	1.18
10	0.1386	0.8674	0.90
15	0.3374	0.193	0.6154
16	0.33817	0.0	0.586
17	0.001	1.50	1.50
19	0.026	1.423	1.424
22	0.045	1.193	1.425
24	0.155	0.822	0.865

Table II: Safety Factor Distribution Along the Mid-ship Region

Section position from AP	Calculated stresses/ strength safety factor		
	57m	95m	133m
at deck	$\frac{0.94662}{2.54}$	$\frac{1.424}{1.680}$	$\frac{1.0903}{2.2}$
at bottom	$\frac{0.83}{2.9}$	$\frac{1.1798}{2.04}$	$\frac{0.9672}{2.5}$
at side	$\frac{0.55702}{1.91}$	$\frac{0.3382}{3.15}$	$\frac{0.628634}{1.7}$

Appendix (1):

```
AT DISTANCE= 85 M.
******************

TOTAL SHEAR FORCE= 1407.8 T
TOTAL BENDING MOMENT= 288295 T.M

THE FOLLOWING RESULTS OF SHEAR & BENDING STRESSES CAN BE OBTAINED:

SHEAR COEFFICIENT OF THE SHIP= .288212E-3

THE CORRECT SHEAR FLOW DISTRIBUTION & SHEAR STRESS AT THE POINTS SHOWN IN FIG(  ) WILL BE AS FOLLOWS:-

*************************************************************************************************
POINT     ASSUMED SHEAR FLOW(T/CM)        CORRECT SHEAR FLOW(T/CM)        SHEAR STRESS(T/CM2)
*************************************************************************************************
 1          0                               0                               0
-------------------------------------------------------------------------------------------------
 2          .434361                         .434361                         .675415E-1
-------------------------------------------------------------------------------------------------
 3          0                               .232257                         .103548
-------------------------------------------------------------------------------------------------
 4          .888111E-2                      .241139                         .200949
-------------------------------------------------------------------------------------------------
 5          .434361                         .202103                         .168419
-------------------------------------------------------------------------------------------------
 6          .438537                         .246279                         .171099
-------------------------------------------------------------------------------------------------
 7          .438537                         .246279                         .962263E-1
-------------------------------------------------------------------------------------------------
 8          .443624                         .251367                         .119696
-------------------------------------------------------------------------------------------------
 9          .443624                         .251367                         .119698
-------------------------------------------------------------------------------------------------
 10         .523296                         .291034                         .13059
-------------------------------------------------------------------------------------------------
 11         .523296                         .291034                         .13229
-------------------------------------------------------------------------------------------------
 12         .557062                         .324805                         .147639
-------------------------------------------------------------------------------------------------
 13         .888111E-2                      .241139                         .159712
-------------------------------------------------------------------------------------------------
 14         .582026E-1                      .28246                          .176537
-------------------------------------------------------------------------------------------------
 15         .607265                         .607265                         .357369
-------------------------------------------------------------------------------------------------
 16         .608706                         .608706                         .33617
-------------------------------------------------------------------------------------------------
 17         0                               .573025E-2                      .941640E-3
-------------------------------------------------------------------------------------------------
 18         .183577E-3                      .022844                         .736265E-2
-------------------------------------------------------------------------------------------------
 19         .102675                         .949427E-1                      .248376E-1
-------------------------------------------------------------------------------------------------
 20         .183577E-1                      .022844                         .013805
-------------------------------------------------------------------------------------------------
 21         .112429                         .115759                         .723495E-1
-------------------------------------------------------------------------------------------------
 22         .102675                         .969427E-1                      .044974
-------------------------------------------------------------------------------------------------
 23         .166664                         .162737                         .739715E-1
-------------------------------------------------------------------------------------------------
 24         .274497                         .274497                         .15472
-------------------------------------------------------------------------------------------------

AND AT SOME CRITICAL POINTS OF FIG(  ) THE TOTAL EQUIVALENT STRESS WILL BE THE FOLLOWING:-

*****************************************
POINT     TOTAL EQUIVALENT STRESS(T/CM2)
*****************************************
 4          .951665
-----------------------------------------
 6          1.19953
-----------------------------------------
 8          1.17965
-----------------------------------------
 10         .899652
-----------------------------------------
 15         .615399
-----------------------------------------
 16         .585727
-----------------------------------------
 17         1.5441
-----------------------------------------
 19         1.42593
-----------------------------------------
 22         1.42555
-----------------------------------------
 24         .664449
```