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# RATIONALIZATION OF LONGITUDINAL MATERIAL OF BULK CARRIERS

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## 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-

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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:

$\sigma_X$ = longitudinal stress in the X-direction.
$\sigma_Y$ = transverse stress in the Y-direction.
$\tau_{XY}$ = 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- $\sigma_e < \sigma_y$ (4)

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

where:

$\sigma_y$ = yield stress of material used (2.4 t/cm² for mild steel).
$\tau_{all}$ = permissible shear stress given by A.B.S. Rules (1.065 t/cm²).

Since the safety factor ($\gamma$) 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 ($\sigma_e$) of the member exceeds the yield stress ($\sigma_y$), 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 (4). 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 (4) could be used for this purpose).
- Total longitudinal vertical shearing force and bending moment (it could be esily obtained using the computer program given in reference (4)).

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 33,500 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.

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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.

$\gamma_{yi}$ $\gamma_{si}$ = Yielding and shear buckling safety factors at section i, i=1, 2, 3.

$\gamma_r$ = 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.

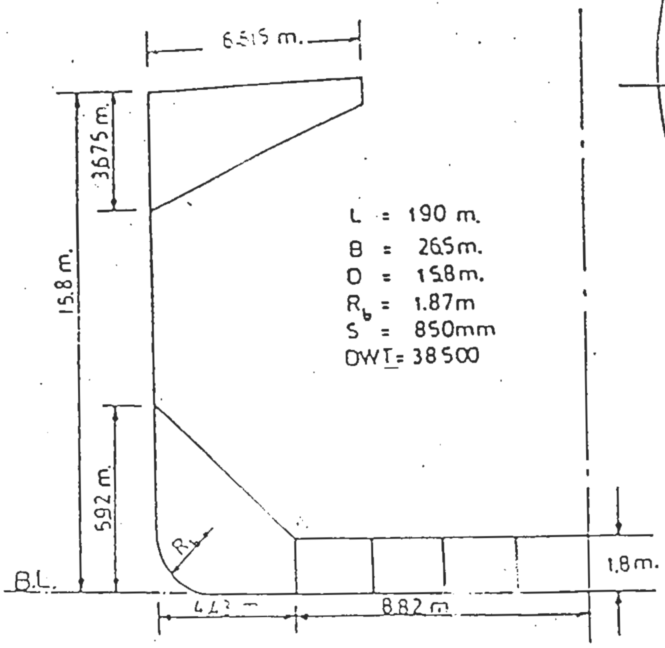

Fig.(1):Typical section of bulk carrier

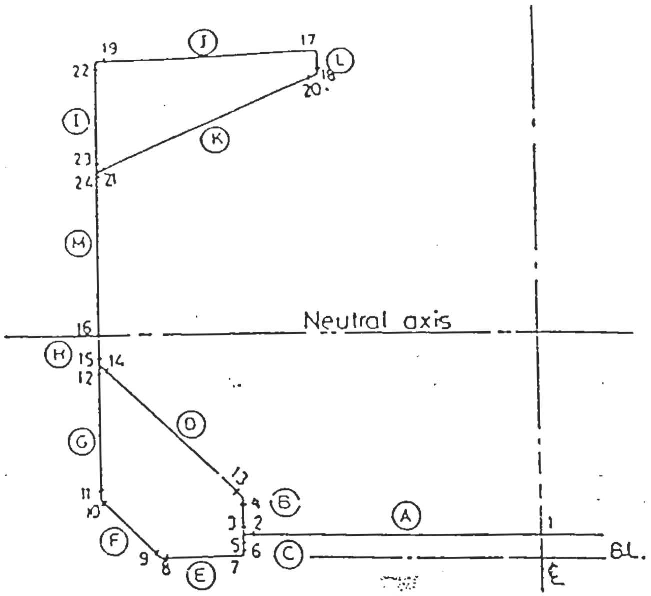

Fig.(2):Idealized structure

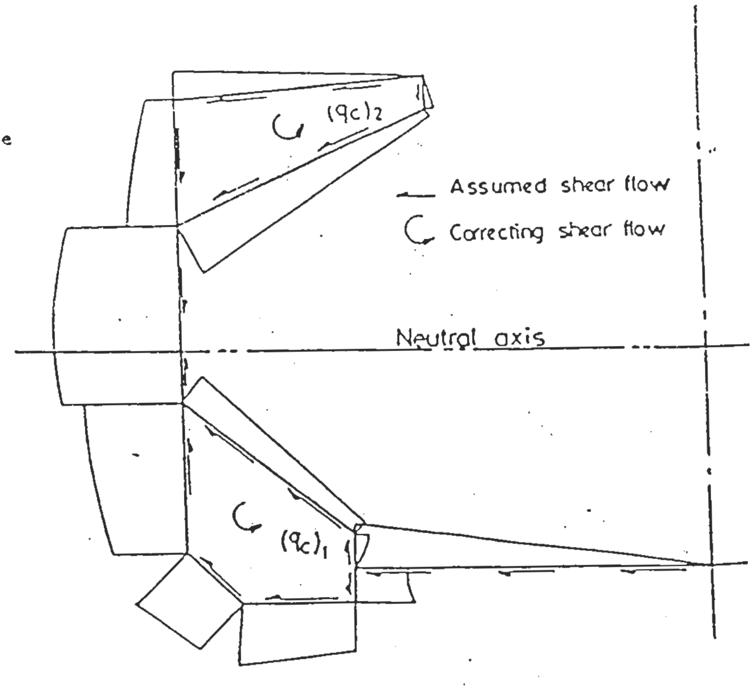

Fig.(3): Assumed shear flow distribution.

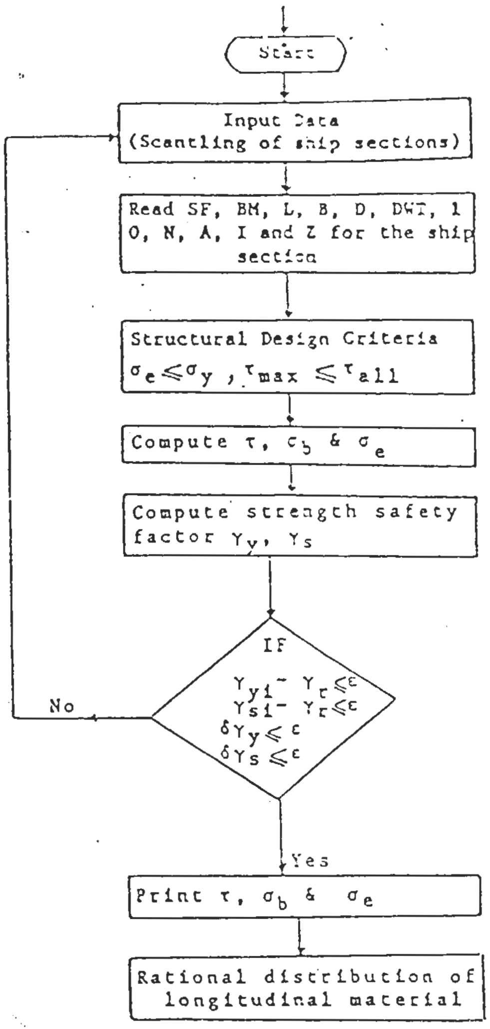

Fig. (4): Computer flow chart of design procedure

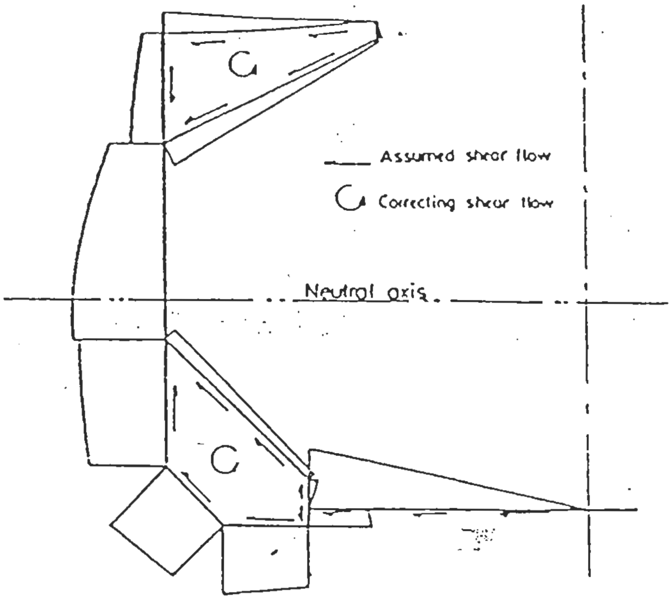

Fig.( 5 ): Assumed shear flow distribution (at 75 m. from A.P.)

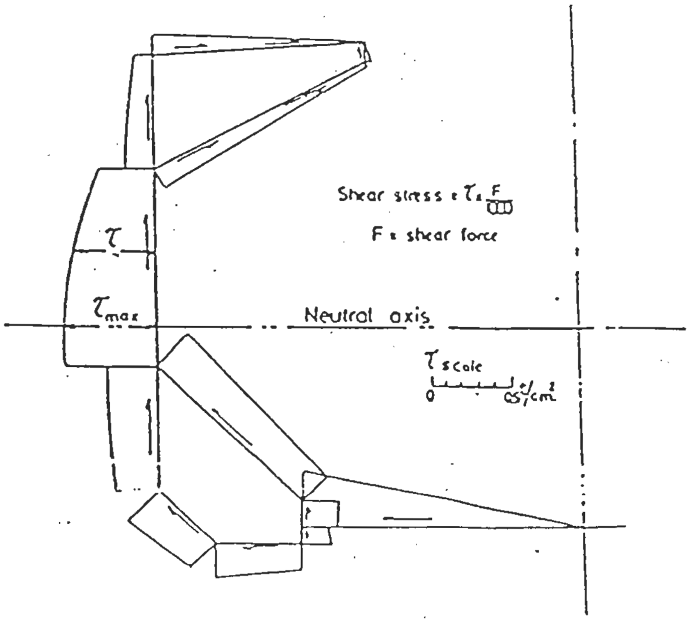

Fig.(6): Correct shear stress distribution (at 75 m. from A.P.

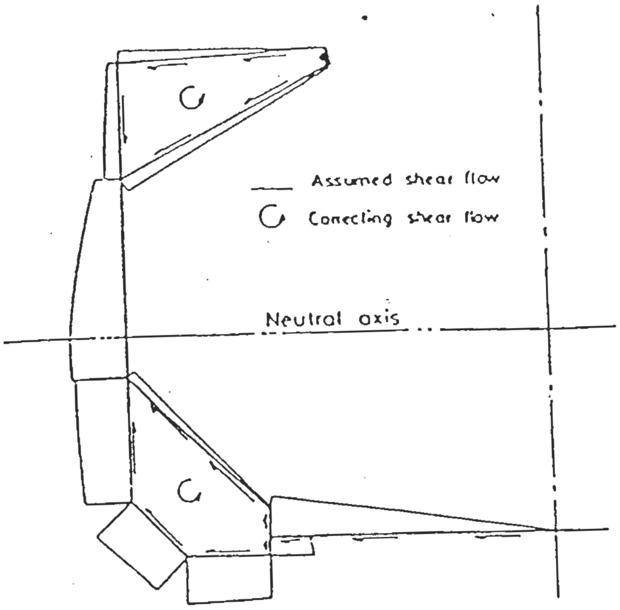

Fig.(7): Assumed shear flow distribution (at 95 m. from A.P.)

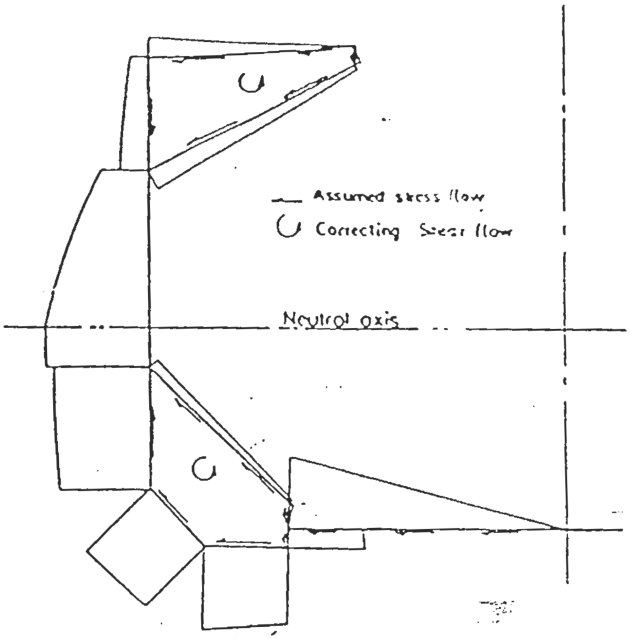

Fig.(9): Assumed shear flow distribution (at 133 m. from A.P.)

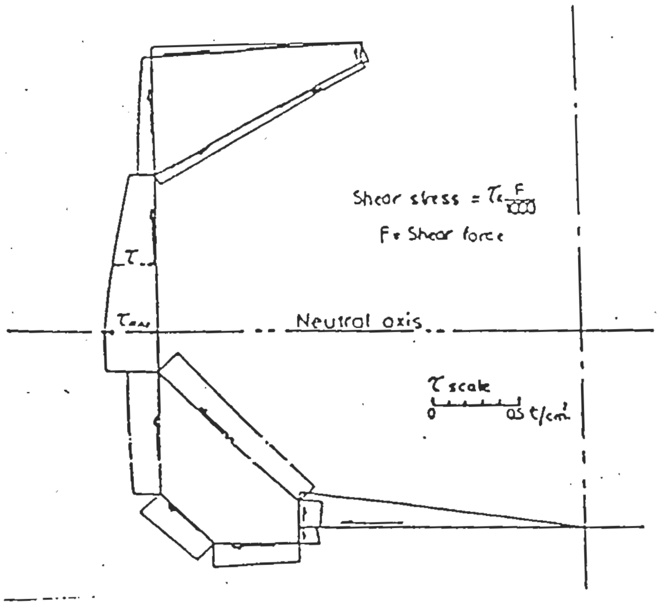

Fig.(8): Correct shear stress distribution (ship section at 95 m. from A.P.)

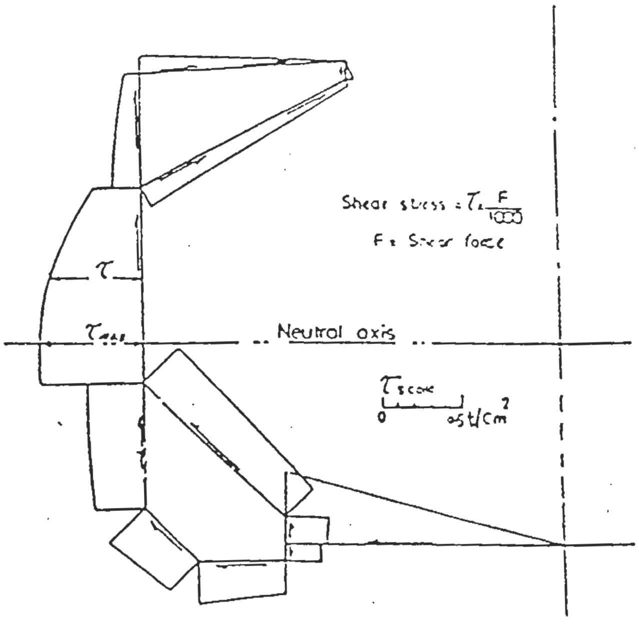

Fig.(10): Correct shear stress distribution (ship sec. at 133 m.)

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= 95 M.
******************

TOTAL SHEAR FORCE= 1407.8 T
TOTAL BENDING MOMENT= 200295 T.M


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


SHEAR COEFFICIET OF THE SHIP= .240212E-3


THE CORRECT SHEAR FLOW DISTRIBUTION & SHEAR STRSS 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                        .193548
-----------------------------------------------------------------------------------------
 4         .844111E-2                     .241139                        .200949
-----------------------------------------------------------------------------------------
 5         .434361                        .202103                        .168419
-----------------------------------------------------------------------------------------
 6         .436537                        .246279                        .171499
-----------------------------------------------------------------------------------------
 7         .438537                        .206279                        .962203E-1
-----------------------------------------------------------------------------------------
 8         .463624                        .251367                        .119696
-----------------------------------------------------------------------------------------
 9         .463624                        .251367                        .119698
-----------------------------------------------------------------------------------------
 10        .523296                        .291834                        .13059
-----------------------------------------------------------------------------------------
 11        .523296                        .291838                        .13229
-----------------------------------------------------------------------------------------
 12        .557462                        .324005                        .147639
-----------------------------------------------------------------------------------------
 13        .844111E-2                     .241139                        .159712
-----------------------------------------------------------------------------------------
 14        .582026E-1                     .28246                         .176537
-----------------------------------------------------------------------------------------
 15        .607265                        .607265                        .357369
-----------------------------------------------------------------------------------------
 16        .604706                        .604706                        .33617
-----------------------------------------------------------------------------------------
 17        0                              .573025E-2                     .941644E-3
-----------------------------------------------------------------------------------------
 18        .185577E-3                     .022444                        .736265E-2
-----------------------------------------------------------------------------------------
 19        .102675                        .949427E-1                     .260376E-1
-----------------------------------------------------------------------------------------
 20        .185577E-1                     .022444                        .013605
-----------------------------------------------------------------------------------------
 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          .931665
----------------------------------------
 6          1.19953
----------------------------------------
 8          1.17965
----------------------------------------
 10         .899652
----------------------------------------
 15         .615399
----------------------------------------
 16         .585727
----------------------------------------
 17         1.5441
----------------------------------------
 19         1.42593
----------------------------------------
 22         1.42555
----------------------------------------
 24         .664649
```