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SFLOW – SHEAR FLOW COMPUTER PROGRAM FOR VERY LARGE CARGO CARRIERS

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ABSTRACT

The existence of shear stress, as of the primary forces, in a ship's structure is overlooked due to the more emphasised analysis of the longitudinal bending stress. Realising the importance of shear flow distribution calculation in analysing the shear stress of a ship's structure, a component program, SFLOW, is developed to calculate shear flow distribution in a ship's structure of thee Very Large Cargo Carrier (VLCC). This is rightly so as the hull structure of VLCCs is typical, and facilitate the basis for further development to calculate shear flow distribution of other vessel types. The computer program SFLOW can display results in both numeric and graphical display. User-friendliness and flexibility characteristics are added to the program to improve the usability and enhanced the prospect of future development and application.

1.0 INTRODUCTION

A ship under longitudinal bending during operation will cause bending stress to occur on its structure. This stress will further generate the more significant shear stress, which is of important consideration in analysing the structural strength of a ship.

In a ship, the position of maximum shearing forces occurs at about the ends of the half-length amidships when the ship is at sea-wave conditions. The vertical component of ship's structure is provided by the shell plating, girders and by longitudinal bulkheads. In these structural elements, the shear stress will be maximum and limitation of its effect will be a considering factor that determines the thickness of these elements.

The existence of shear stress in a ship's structure has two effects. Firstly, the shear distorts the sections; thus, the conditions upon which the bending moment theory is based are no longer fulfilled, since it altered the distribution of bending stress across the section. The solution of this problem is complex and involves detailed mathematical concepts. As far as the ship structure is concerned, the general effect will be the increase of bending stress at the corners of the section, that is the deck edges and the bilge, and to reduce the stress at the centre of the deck and the bottom. This effect is appreciable only when the ratio of length of the structure is small.

Secondly, the overall deflection of the structure will increase when the shear stress in present. However, this effect is relatively insignificant except in the analysis of ship vibration, where the calculation of neutral frequency may be affected. A lower frequency may result from the added shear stress together with the bending stress.

This paper will discuss in depth the theoretical analysis of shear flow calculation and as well as the development of SFLOW, which is a computer program to calculate the effect of shear force on open and multicell ships.

2.0 SHEAR FLOW ANALYSIS

2.1 Shear Flow In Open Sections

A ship's hull girder, like any beam loaded by transverse vertical forces, will experience a vertical shear force Q acting on the cross section. In a thin-walled section, for example box girder on an I-beam, the calculation of the total shear force, Q exerted and distributed across the section is of significant importance, hence to determine the appropriate wall thickness of the structure. Therefore, it becomes necessary to analyse the shear stress τ distribution across the overall section.

An example of a this-walled symmetric box girder being exerted a vertical shear force Q, is presented in Figure 1. Elementary beam theory shows that over a differential segment of length dx, Q will cause difference in bending moment as

$$dm = Qdx$$

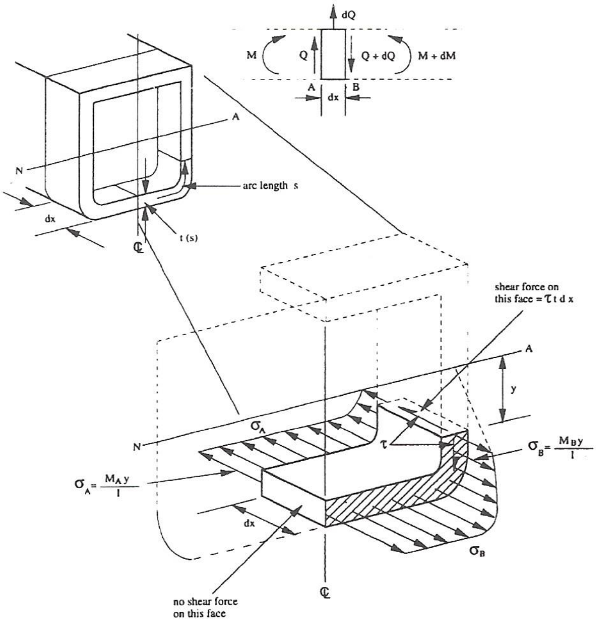


Fig. 1 Free Body Diagram of Transverse Shear

This change in bending moment will result in unequal bending stress σ_A and σ_B acting on the two faces of the differential segment. By making two cuts, one at the center-line and the other at an arc length s from center-line; an isolated portion of the differential segment is obtained. The imbalance in the longitudinal normal stress must be counter-balanced by longitudinal shear stress forces the cut sections.

However, due to symmetry, no shear stress is allowed in the center-plane and therefore the balancing must come entirely from the shear stress τ at the other cut. Longitudinal equilibrium shows that:

$$\tau\, dx = \int_0^s \sigma_B t\, ds - \int_0^s \sigma_A t ds \tag{1}$$

substituting $\sigma = \frac{M_y}{I}$ and $dM = dx$ gives

$$\tau t = \frac{Q}{I} \int_0^s yt\, ds \tag{2}$$

The integral function on the right side is a function of geometry of the section and of position s around the section. For convenience this quantity is assigned the symbol *m*.

$$m = \int_0^s yt\, ds \tag{3}$$

It is noted that *m* is the first moment about the neutral axis of the cumulative section area starting from the open end (shear-stress free end) of the section. Substituting for *m* in Eqn.(2) and solving for τ .

$$\tau = \frac{Qm}{tI} \tag{4}$$

The product τt is of special significance in the torsion of thin-walled sections, and has some analogies as compared to the flow of an ideal fluid within a closed pipe. It is therefore referred to as the 'shear flow' an is given the symbol *q*.

$$q = \tau t \tag{5}$$

In the present case, the shear flow is also a useful quantity, in which the shear stress is due to transverse load. Referring to Eqn. (4), it is noted that the shear flow is given by

$$q = \frac{Qm}{I} \tag{6}$$

Knowing that *Q* and *I* are constant for the whole section, it is concluded that the shear flow is directly proportional to *m*. regarding the ratio *Q/I* as a scaling factor, the shear flow distribution will be identical to the distribution of *m* but with different units. An added advantage of the value q is that it does not vary abruptly with changes in the local thickness, as does τ .

In a typical hull cross-section, with changes in orientation and thickness of the plates, the calculation of *m* will be much easier if performed in segments. The integration always starts at the 'open' end of any branch, not necessary at the centre-line, and can be of a hatch end or other opening.

In Figure 2, additional deck plating will result in increase of shear flow at point C due to added bending stress forces. The area of all plating and decks above it have to be taken into consideration for the value of m, giving

$$m_C = m_A + m_B \tag{7}$$

and

$$q_C = q_A + q_B \tag{8}$$

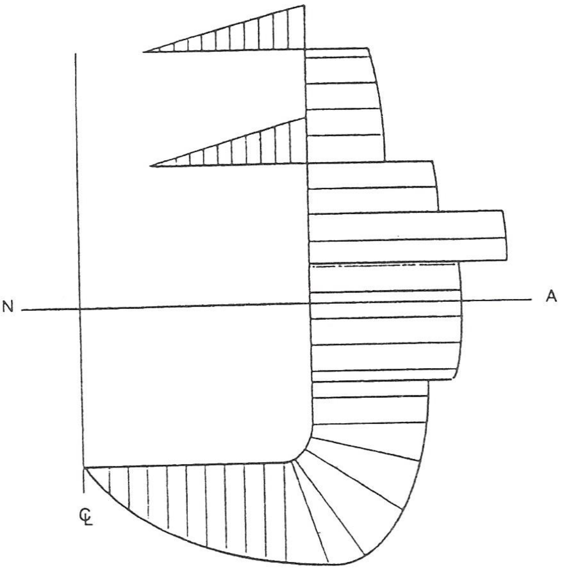


Fig. 2 Shear Flow Conservation at Corners and Branch Points

2.2 Shear Flow In Multicell Selection

For multicell sections, there will be closed loops or cells in the cross section of the hull, for example when there are wing tanks or double bottom tanks in structural design.

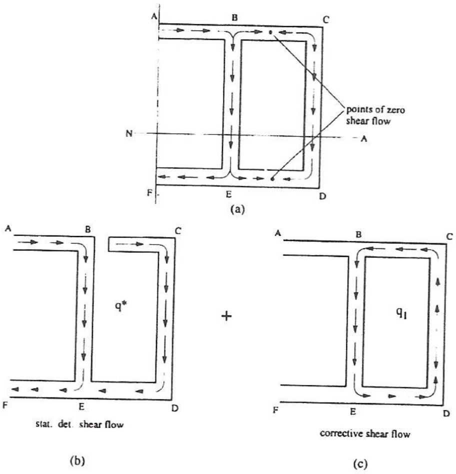


Fig.3 Calculation of Shear Flow in Multicell Sections

Values of m can only be calculated in the open branches of AB and FE, as the shear flow divides at point B (and reunites at point E). This makes the problem statically indeterminate and therefore additional information in necessary to form a static determinate condition. The technique for solution includes two main steps, that is, to make the problem statically determinate, a number of restraints is removed and displacement should be zero at these restraint points.

These restraints are internal self-restrain in which a portion of the hull girder will impose a restrain on an adjacent portion (and the second imposing an equal and opposite restraint on the first).

Figure 3 shows the equivalent shear flow after rendering the problem into a statically determinate one. When a longitudinal cut is made at point B, the hull girder is changed into an open section with open branches at point A, B, and F; all being zero shear flow distribution points. The general rule is to apply *n* cuts to a section with *n* closed cells. The value of m corresponding to this artificially cut section is donated m^*, where

$$m^* = \int_0^s y(s)t\,ds \tag{9}$$

Therefore the value of shear flow becomes

$$q^*(s) = \frac{Q}{I} m^*(s) \tag{10}$$

Longitudinal slip will occur between the cut edges and to remove this error, some corrective shear flow within that section must be added. This is introduced in the form of *N* separate, constant values of shear flow, $q_i\left(i = 1,\ldots.,N\right)$, one for each closed cell. The sum of q_i and q^* will give the correct total shear flow q. Therefore

$$q = q^* + \sum_{i=1}^{N} q_i \tag{11}$$

For a prismatic thin-walled of section of unit length, the longitudinal slip that would occur due to the cut is equal to the cyclic integral of the longitudinal shear strain from one edge of the cut to the around any closed path in the section. Therefore

$$slip = \oint \gamma ds = \frac{1}{G}\oint \tau\, ds = \frac{1}{G}\oint \frac{q}{t} ds \tag{12}$$

in which γ is the shear strain at any point in the cross section. In the current application the path of integration for each cut is taken to be the perimeter of the closed cell associated with the cut (that is the cell being 'opened' by that cut). Consequently, the condition of zero slip at each cut is replaced by the condition that for each cell, the foregoing cyclic integral is zero, giving

$$\oint_{cell\ j} \frac{q}{t} ds = 0 \qquad (j = 1, \ldots\ldots\ldots, N) \tag{13}$$

where G has been omitted due to the zero value.

In Fig. 3, only one closed cell is considered, therefore

$$q_1 \oint_{BCDEB} \frac{ds}{t} = - \oint_{BCDEB} \frac{q^*}{t} ds \tag{14}$$

and the resulting corrective shear flow is

$$q_1 = -\frac{\oint_{BCDEB} \frac{q^*}{t} ds}{\oint_{BCDEB} \frac{ds}{t}} \tag{15}$$

consequently the real shear flow becomes

$$q = q^* + q_1 \tag{16}$$

$$= q^* + \left| - \frac{\oint_{BCDEB} \frac{q^*}{t} ds}{\oint_{BCDEB} \frac{ds}{t}} \right| \tag{17}$$

$$= \frac{Q}{I} \left(m^* + \left| - \frac{\oint_{BCDEB} \frac{q^*}{t} ds}{\oint_{BCDEB} \frac{ds}{t}} \right| \right) \tag{18}$$

It is important to take notice that the shear flow q^* is always positive at any point if the direction of flow is clockwise compared to the closed cell.

2.3 Shear Flow in Sections Containing Different Elastic Modulus

Ship sections with different construction material in its cross section will result in different elastic moduli. The shear flow distribution will change at these different elements. For sections with different construction material, giving different values of the elastic modulus, the formula for bending moment stress will be,

$$\sigma = T_i \frac{my}{I_{tr}} \tag{19}$$

and

$$\tau t\, dx = \frac{m_B - M_A}{I_{tr}} \int_0^s T_i y t\, ds \tag{20}$$

in which

T_i = transformation factor

I_{tr} = equivalent second moment of area

An equivalent homogenous section with the wall thickness of $T_i t$ will be obtained, meaning the thickness has been scaled up or down in proportion to the corresponding T_i. Consequently, the integral function, m will de denoted as m_{tr} .

$$m_{tr} = \int_0^s yT_i t \, ds \tag{21}$$

The formula for shear flow will the be

$$q = \frac{Qm_{tr}}{I_{tr}} \tag{22}$$

However in order to obtain the shear stress, the true local thickness should be used in the formula, thus

$$\tau = \frac{Qm_{tr}}{I_{tr} t} \tag{23}$$

The shear stress in the material interface doesn't change abruptly but the slope of the shear flow does. This is shown in Figure 4, with a section containing aluminium and steel as the construction material.

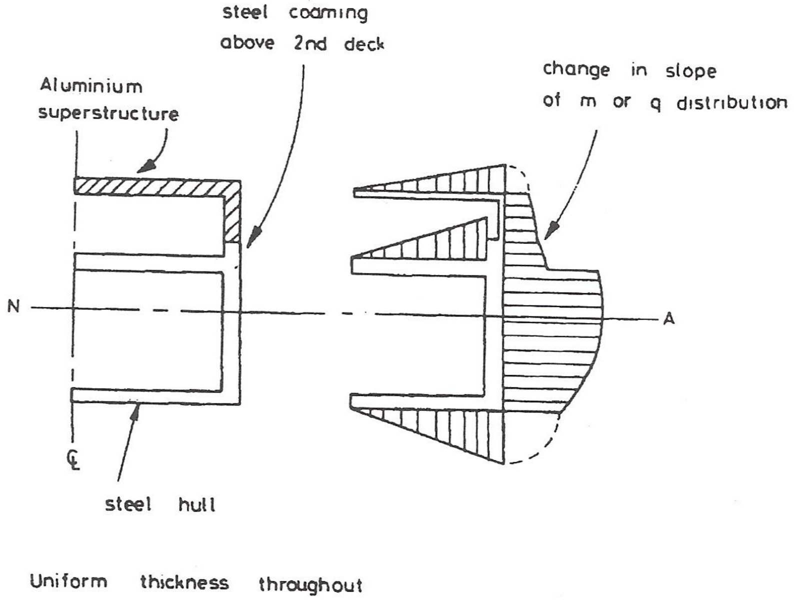


Fig. 4 Shear Flow Distribution in a Section with Different Elastic Moduli

3.0 DEVELOPMENT AND EXECUTION OF *SFLOW*

The flow chart in Fig. 5 shows clearly the development and running procedure of the computer program to perform the calculation of shear flow distribution and to visualise the distribution pattern using graphic tools in the program.

In the development of *SFLOW*, the main objective is to obtain the values of integral function, m as this will directly give the information regarding the shear flow distribution. Integration formulas in the analysis are simplified to its final integration form for simple development of its programming codes.

The separate module that calculates the neutral axis and overall second moment of area for a ship section is already incorporated within the source code formulation functions for open section analysis, different elastic moduli section analysis and multicell section analysis. The program is able to evaluate plates that are incline and curved bilge having the shape of a quartet circle. The flow chart of analysis for this module is shown in Fig. 6.

The graphic representation of shear flow is developed to show clearly the distribution pattern of shear flow in the cross section of a certain ship. The boundary lines of the distribution consist of straight lines, curves and arcs, as to show exactly the distribution pattern of the shear flow. This will eventually visualise the critical points of shear flow in the section.

The flow chart for the development of source codes for graphical display is shown in Fig. 7. Figure 8 shows a typical example of a hull structure of a VLCC that is subjected to a shear force of 6000 kN. Figure 9 gave the display of the required second moment of area and values of m at each point while Fig. 10 display the shear flow in graphical mode as well as the maximum shear stress.

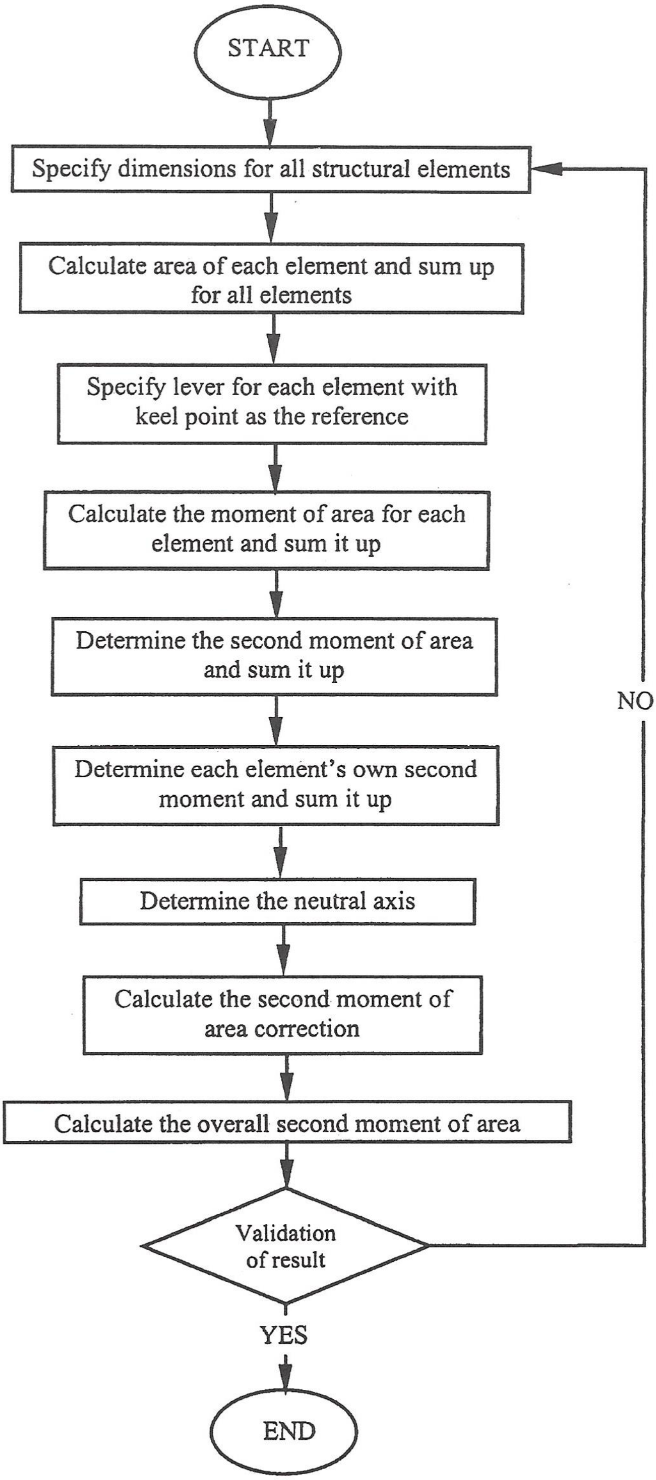


Fig. 5 The Overall Flow of the Development of SFLOW

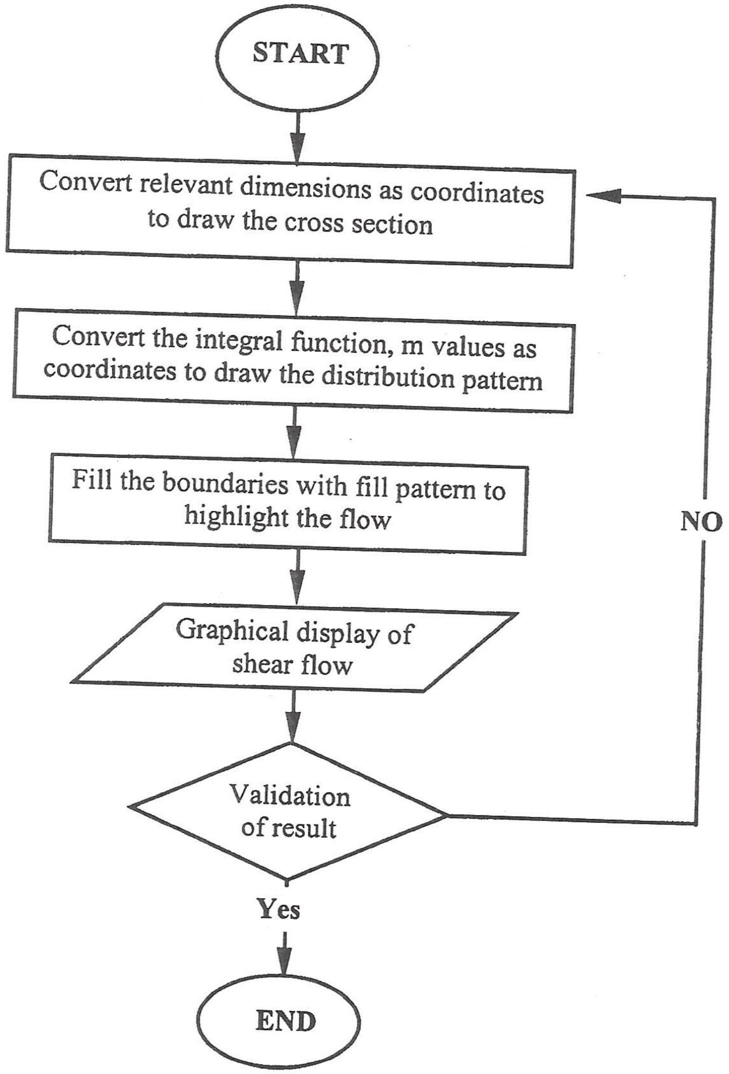


Fig. 6 The flow Chart of the Module to Calculate I_{na} and the Neutral Axis

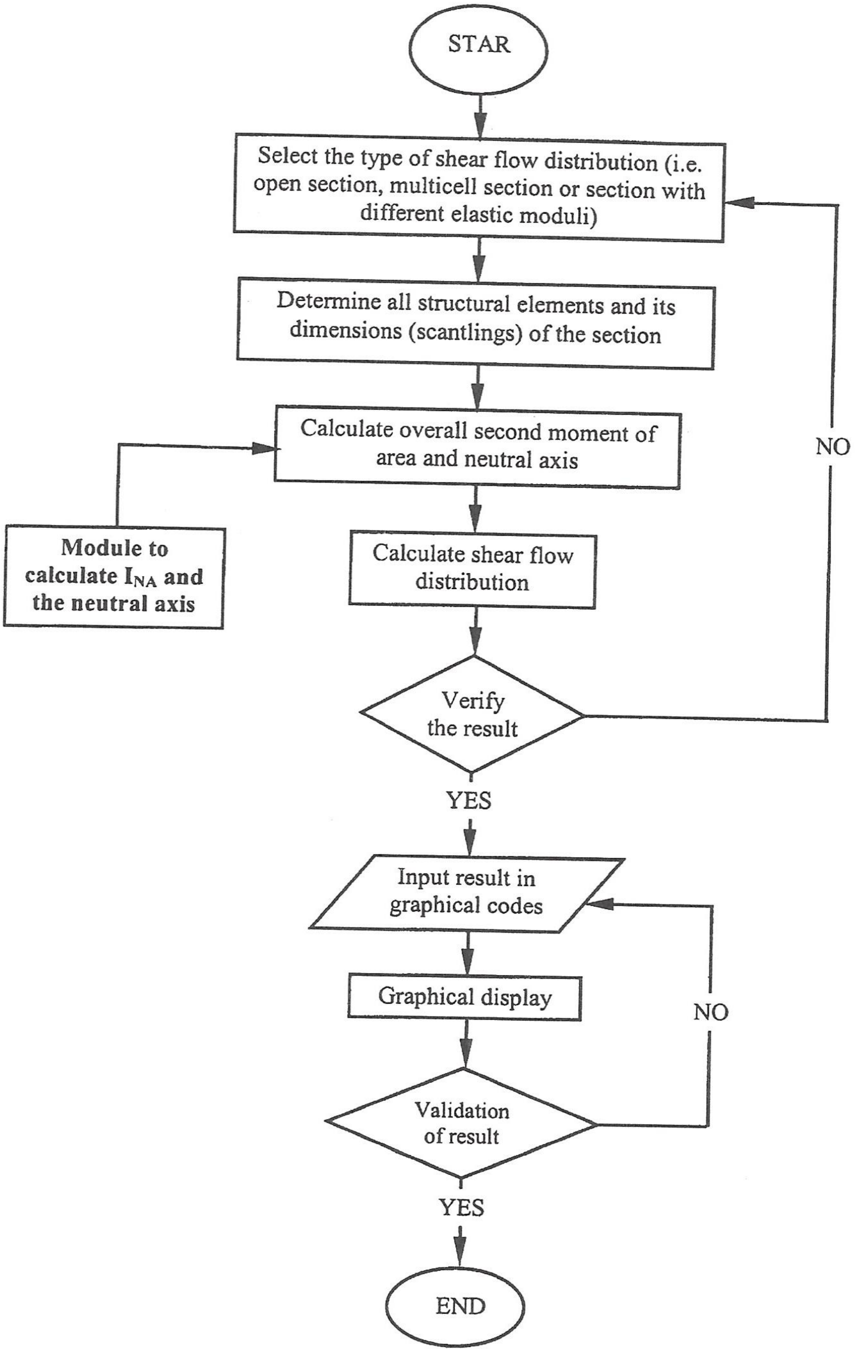


Fig. 7 Flow Chart for Development of Graphical Display in *SFLOW*

5.0 CONCLUSION

The computer program SFLOW has been developed successfully to calculate and display graphically the shear flow distribution in ships section of type VLCC. The analysis can be of an open section, section with different elastic moduli or multi cell section. Validation of *SFLOW* with comparison to manual calculations results accentuate the accuracy and precision of the output results. Assumptions and limitation in the program has been outlined to suit normal and current design practice.

The development of the shear flow graphical display feature in *SFLOW* has taken into consideration aspects of logical and accurate representation to correspond with the numeric values. A suitable scantling factor has been chosen to sit the logical range of dimensions in ship design. Appropriate proportion of difference in the display between the shear flow at various structural elements has been catered for. The final result is an optimum scale of graphical display and an accurate shear flow representation.

In developing the error prompts for SFLOW input limitations, some technical aspects of ship design in limiting the dimension of thickness for plating and the B/D ratio for the design of tankers is included. The thickness should comply to the ABS Rules, while the B/D ratio as specified by Watson (1976) [10] for minimum stability requirement. Therefore the program SFLOW not only calculates the shear flow distribution but has the function to check the design of design of the vessel being analysed, conforming to the ABS Rules of plane thickness and the minimum requirement for transverse stability.

User-friendly and flexibility characteristics development within *SFLOW* include the option to print the results, to proceed with continuos analysis with the end menu development, incorporating the data input limitations and flexibility of analysing various typical design of VLCCs.

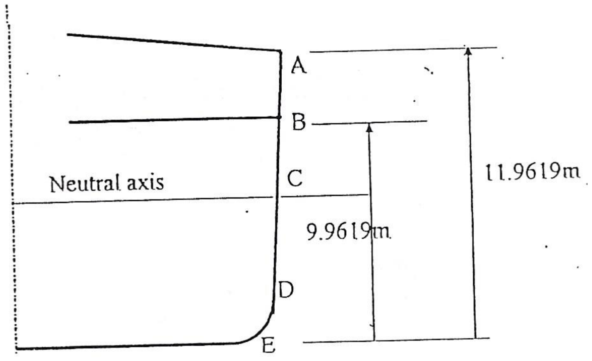


Figure 8 Typical Mid Section for Analysis

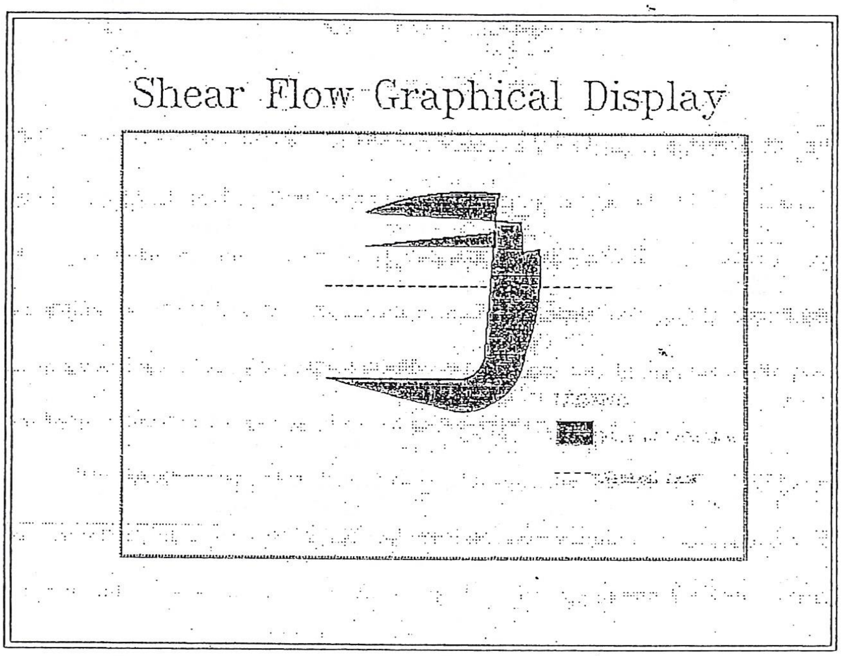
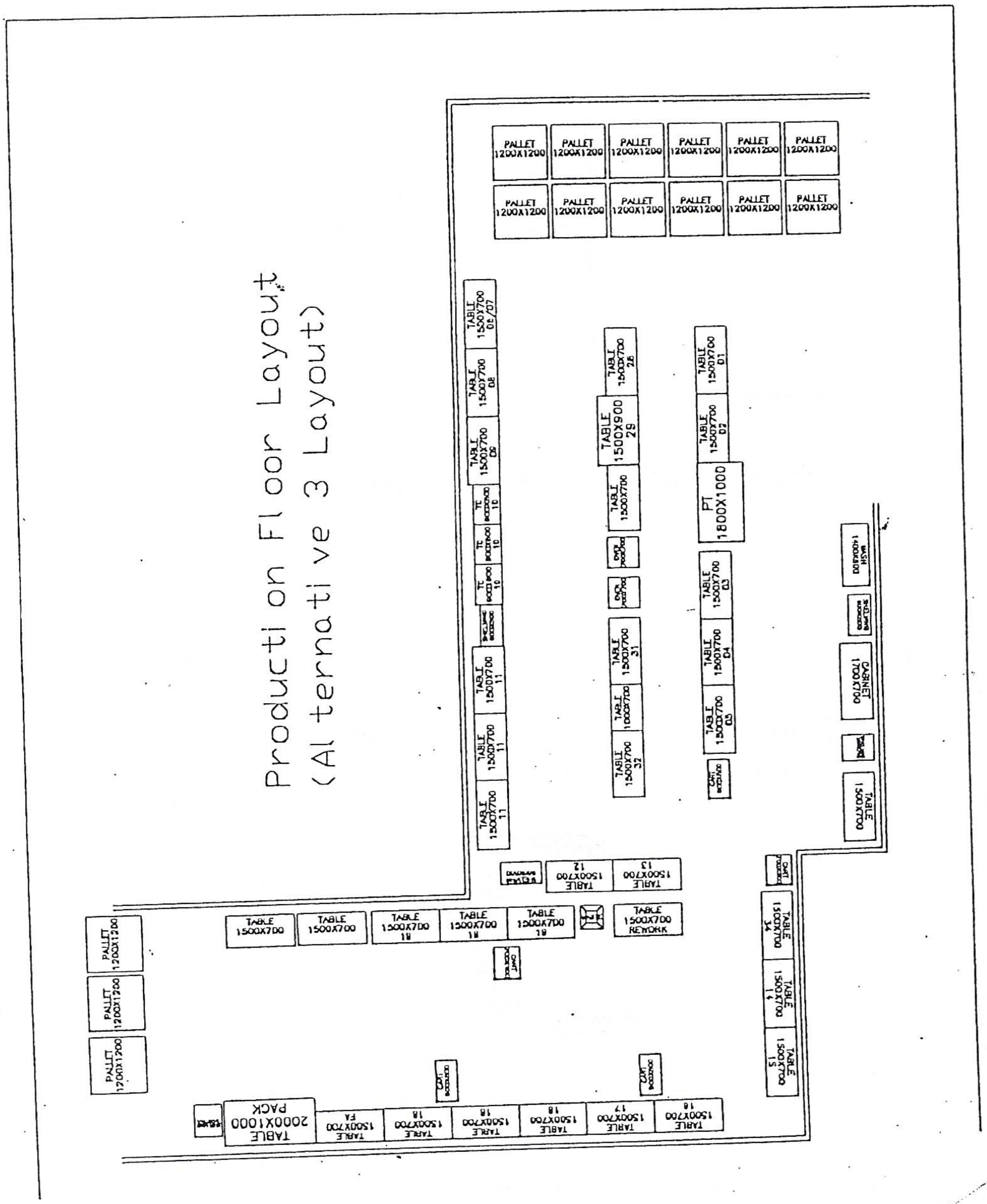
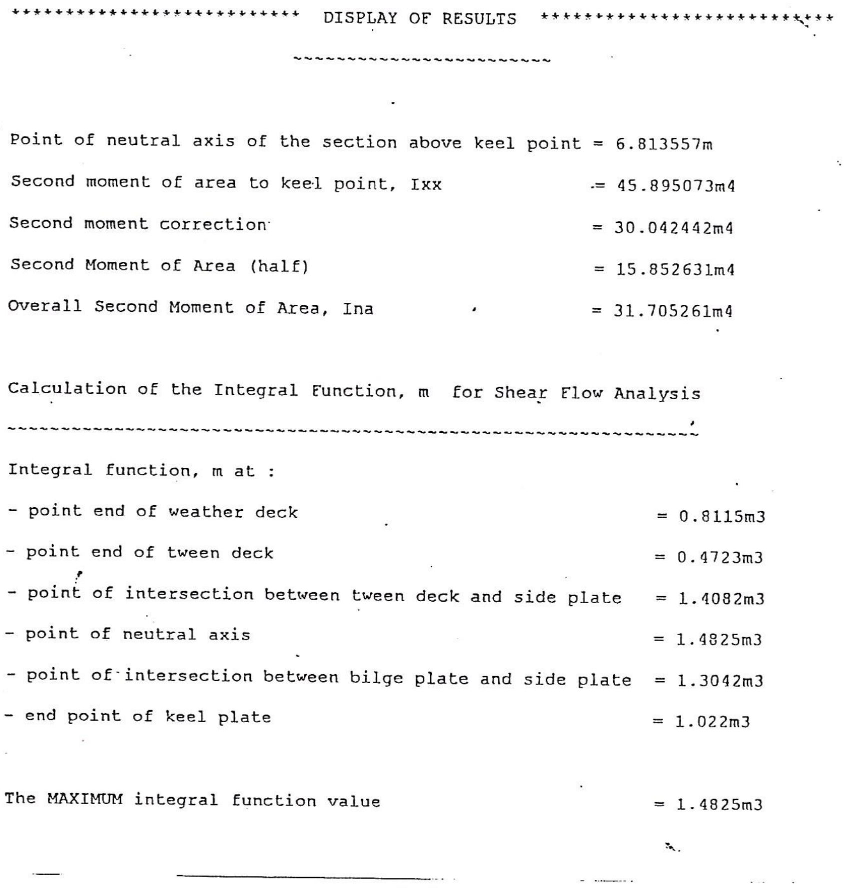


Figure 10 Shear Flow Graphical Display

APPENDIX A


Production Floor Layout
(Alternative 3 Layout)
PALLET 1200X1200
TABLE 1500X700
TABLE 1500X900 29
PT 1800X1000
TABLE 1500X700 REWORK
TABLE 2000X1000 PACK
CABINET 1700X700

Results obtained using *SFLOW* : -



```
**************************  DISPLAY OF RESULTS  **************************
                            ~~~~~~~~~~~~~~~~~~~~~~~~~


Point of neutral axis of the section above keel point = 6.813557m

Second moment of area to keel point, Ixx              = 45.895073m4

Second moment correction                              = 30.042442m4

Second Moment of Area (half)                          = 15.852631m4

Overall Second Moment of Area, Ina                    = 31.705261m4


Calculation of the Integral Function, m  for Shear Flow Analysis
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Integral function, m at :

- point end of weather deck                                  = 0.8115m3

- point end of tween deck                                    = 0.4723m3

- point of intersection between tween deck and side plate    = 1.4082m3

- point of neutral axis                                      = 1.4825m3

- point of intersection between bilge plate and side plate   = 1.3042m3

- end point of keel plate                                    = 1.022m3


The MAXIMUM integral function value                          = 1.4825m3
```

Figure 9 Results obtained using SFLOW

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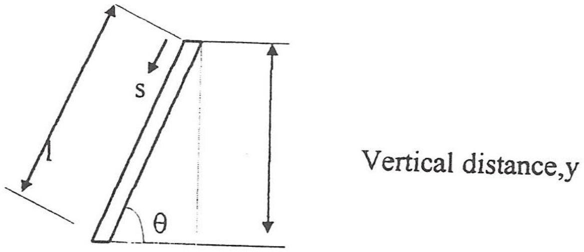
APPENDIX A

Formulation of Programming Codes for Inclined Plating and Bilge Analysis

The formula for integral function, m is donated as

$$m = \int yt\,ds$$

For inclined plating, the value of y will differ as s increases. The increase of s in the formula will give an increase of y by certain formula. The following gives the analysis to formulate the relationship.



$$y = s\sin\theta$$

$$m = \int yt\,ds \qquad (t\ \textit{is the thikness of the plate})$$

$$\therefore m = \int s\sin\theta\, t\,ds$$

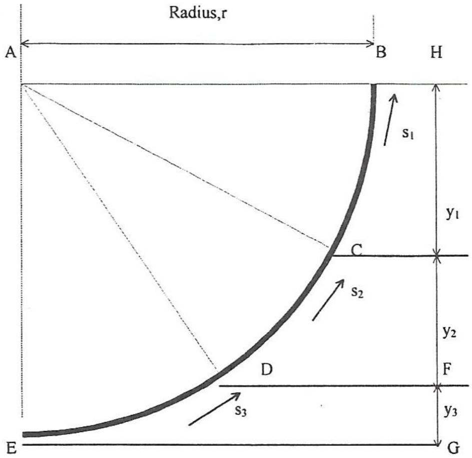
$$= \left[\frac{s^2}{2} t\sin\theta\right]_0^s$$

Therefore using C++, by including the header library file of <math.h> in advance, the formulation code for the inclined plating becomes

```
m=(pow(1,2)/2)*t*sin(angle);
```

with the value of angle in radians.

For a curved bilge having the shape of a quartet circle, the formulation of codes has to be simplified for the reason that a complete analysis is complex and time demanding. Therefore the curved bilge is simplified into three joining inclined platings and the formulation of codes will be much simple.



The curve bilge is divided into three inclined platings of BC, CD, and DE. For the a bilge with the quartet circle shape, ∠BAC = ∠DAE = (90/3)°=30o For plate ED, ∠DEG = (90-75)° = 15°

Thus $y_3 = s_3 \sin 15^o$

$$y = n\_axis - s_3 \sin 15^o$$

$$m_3 = \int yt\, ds$$

$$= \int \left(n\_axis - s_3 \sin\left(15^o\right)\right)t\, ds$$

$$= t\left[n\_axis(s_3) - \frac{s_3^2}{2}\sin\left(15^o\right)\right]_0^s$$

For plate DC,

∠DEG = (360-(75+90+90+60))° =45°

(from sum of degrees in a 4-sides polygon AHFD equals 360°)

Thus $y_2 = s_2 \sin 45^o$

$$y = n\_axis - y_3 - s_2 \sin\left(45^o\right)$$

$$m_2 = \int yt\, ds$$

$$= \int \left(n\_axis - y_3 - s_2 \sin\left(45^o\right)\right)t\, ds$$

$$= t\left[n\_axis(s_2) - s_2 y_3 - \frac{s_2^2}{2}\sin\left(45^o\right)\right]_0^s$$

For plate CB,

$\angle DEG = ((180-30)/2)^o = 75^o$

Thus $y_1 = s_1 \sin 75^o$

$$y = n\_axis - y_3 - y_2 - s_1 \sin\left(75^o\right)$$

$$m_1 = \int yt\,ds \quad \left(\textit{t being the thickness of the plate, s being the length of the plate}\right)$$

$$= \int \left(n\_axis - y_3 - y_2 - s_1 \sin\left(75^o\right)\right)t\,ds$$

$$= \left[n\_axis(s_1) - y_3(s_1) - y_2(s_1) - \frac{s_1^2}{2} t \sin\left(75^o\right)\right]_0^s$$

knowing that $s_1 = s_2 = s_3 = s$

with length of each plate, $s = \dfrac{r \sin 30^o}{sn\,75^o}$

therefore the total integration function of m for all three joining platings will be

$$m = m_1 + m_2 + m_3$$

$$3(n\_axis)ts - \left(0.5\sin 75^o + 1.5\sin 45^o + 2.5\sin 15^o\right)ts^2$$

Thus using C++ the formulation becomes

```
s_bilge = r_bilge*sin(M_PI*30/180)/sin(M_PI*75/180);
m_intbilge =m_intkeelplt+3*t_bilge*(n_axis-
l_keelplt*sin_ikeelplt *s_bilge-
t_bilge*pow(s_bilge,2)*(2.5*sin(M_PI*15/180)+1.5*sin(M_PI*45/180)_0.
5*sin(M_PI*75/180));
```

APPENDIX B

Thickness of Plates

Thickness of plates must conform to the Classification Rule. In the development of *SFLOW*, the limitations are based on the American Bureau of Shipping (ABS) Rules.

The limitation is applied when the construction material of ordinary mild steel is used. The limitation may vary if different materials are used but this is not catered for in the development of *SFLOW*, as the requirement here is just to obtain of feasible and logical range of plate thickness for a logical data input to be used in the analysis of shear flow distribution.

After due construction of each equation specifying the plate thickness, the following able shows the range of plate thickness to be implemented in *SFLOW* data input limitation.

Structural Elements	**Plate Thickness**	
	Minimum (m)	**Maximum (m)**
Deck Plating	0.005	0.100
Side Plating	0.005	0.100
Keel Plate	0.005	0.100
Inner Bottom	0.005	0.100

The *SFLOW* computer program will prompt the user when input for thickness is out of range.

Breadth (B)/Depth(D) Ratio Limitation of Tankers' Design

The limitation of B/D Ratio is based on the paper 'Some Ship Design Methods' by Watson and Gilfillan, published in the 1976 Trans. Royal Institution of Naval Architects (RINA). The limitation defined is a minimum B/D ratio of 1.90 for all tankers design as to cater for the transverse stability of the vessels. In the development of SFLOW, the function to prompt the user when this requirement is not satisfied is done, and put under the function name ratio_error( ).

SFLOW Data Type

Invalid data input will also result in error producing the graphical display of the shear flow. If this occurs, the prompt DOMAIN ERROR or OVERAFLOW ERROR within the Turbo C++ environment will appear.