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# On Ship Reliability and Safety

by

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1- "Safety Assurance: Methods of Assessment for Ship Structures", IMAEM, September, (Italy-1981), Trieste, Second Conference, Shama, M. A.,

2- "ON the Economics of Safety Assurance", Soc. of Marine Engineers & Shipbuilders, Dec., (Egypt – 1984), 7th Symp. on Offshore Eng. and Technology, Shama, M. A.,

3- "Marine Structural Safety and Economy", SNAME, March, (USA-1991), Symposium, Marine Structural Inspection, Maintenance, and Monitoring, Shama, M. A.,

4- "Application of Reliability Assessment to Welded Tubular Joints", AEJ, Oct., (Egypt-1992), Shama, M. A., El- Gammal, M. Elsherbeini,

5- "Estimation of Fatigue life of Welded Tubular Connections Containing Defects", AEJ, No. 4, Oct., (Egypt-1992), Shama, M. A., El- Gammal, M. Elsherbeini,

6- "Impact on Ship Strength of Structural Degradation Due to Corrosion", AEJ, July., (Egypt-1995), Shama, M. A.,

7- "Shear Strength of Damaged Coastal Oil Tanker under Vertical Shear Loading", AEJ, April, (Egypt-1996), Shama, M. A., Leheta, H. W. and Mahfouz, A. B.

8- "Shear Strength of Damaged Seagoing Oil Tanker Under Vertical Shear Loading", Jan, (Egypt-1996), Shama, M. A., Leheta, H. W. and Mahfouz, A. B.

9- "Impact on Ship Strength of Structural Degradation Due to Corrosion", (Kuwait-1996), Second Arabian Corrosion Conference, Shama, M. A.

10- "Risk Management", AEJ, Vol. 37, No.2, March, (Egypt-1998), Shama, M. A.,

11- "Reliability of Double Hull Tanker Plates Subjected to Different Loads with Corrosion Effects", AEJ. Vol. 41, No. 4, (Egypt-2002), Shama, M. A., H. W. Leheta, Y. A. Abdel Nasser and A. S. Zayed,

12-, "Impact of Recoating and Renewal on the Reliability of Corroded Hull Plating of Double Hull Tankers", AEJ. Vol. 41, No. 4, (Egypt-2002), Shama, M. A., H. W. Leheta, Y. A. Abdel Nasser and A. S. Zayed,

# SHEAR STRENGTH OF A DAMAGED SEAGOING OIL TANKER UNDER VERTICAL SHEAR LOADING

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## ABSTRACT

Ship structural failures and casualties represent main causes of marine pollution. The main object of this paper is to examine the shear carrying capacity of a damaged ship section of a seagoing oil tanker under vertical shear loading. A case study is presented, in which the shear flow distribution for different assumed structural damage locations are calculated and presented. The effect of structural damage at specified locations, on the ship section, on the shear flow distribution is examined. The shear forces carried by the vertical members of the ship section, for each assumed damage location are calculated. The maximum allowable shear forces for all damage cases are also computed.It is concluded that the shear strength of damaged oil tankers under vertical shear loading should be an integral part of the structural design stage so as to ensure sufficient safety margin, for the future design of oil tankers. The structural design of seagoing oil tankers should be based not only on safety requirements but also on the minimization of harmful environmental impacts.

*Keywords:* *Seagoing oil tankers, Shear strength, Damaged ship section, Shear forces, Shear stresses, Failure modes.*

*Nomenclature*

| | |
|---|---|
| $A$ | Sectional area of the cell under consideration, $m^2$ |
| $a_{ij}$ | Area of stiffening member i within element j |
| $a_j$ | Area of the path line from the zero shear point to the point j |
| $B$ | Breadth of the ship, m. |
| $B_w$ | Breadth of wing tank, m. |
| $b$ | Length of plate, m. |
| $D$ | Depth of the ship, m. |
| $E$ | Modulus of elasticity, tonnes/ $m.^2$ |
| $F_j$ | Shear force on any vertical member over the ship section |
| $F_{L1}$ | Shear force carried by the port longitudinal bulkhead plating, tonnes |
| $F_{L2}$ | Shear force carried by the starboard longitudinal bulkhead plating, tonnes |
| $F_{s1}$ | Shear force carried by the port side shell plating, tonnes |
| $F_{s2}$ | Shear force carried by the starboard side shell plating, tonnes |
| $I$ | Second moment of area of the ship section, $m^4$ |
| $K$ | Constant depending on the panel end conditions<br>$= 5.34 + 4 / a^2$, for simply supported ends<br>$= 8.98 + 5.6/a^2$, for fixed ends |
| $L$ | Length of the ship (L.B.P.), m. |
| $l_j$ | Length of member ' j ', m. |
| $N_d$ | Total number of possible damage cases |
| $Q$ | Applied shear force on ship section, from longitudinal strength calculations, tonnes |
| $Q_{all}$ | Allowable shear force carried by the vertical member, tonnes |
| $Q_{L1}$ | The maximum shear force carried by the port longitudinal bulkhead plating, tonnes |
| $Q_{L2}$ | The maximum shear force carried by the starboard longitudinal bulkhead plating, tonnes |

| | |
|---|---|
| $Q_{max}$ | The maximum shear force which can be carried by all the vertical members, tonnes |
| $Q_{s1}$ | The maximum shear force which can be carried by the port side shell plating, tonnes |
| $Q_{s2}$ | The maximum shear force carried by the starboard side shell plating, tonnes |
| $q$ | Shear flow, tonnes / m. |
| $q_1$ | The corrective shear flow, tonnes / m. |
| $s$ | Frame spacing, m. |
| $t$ | Thickness of thin-walled section, m. |
| $t_d$ | Thickness of the deck plating, m. |
| $t_s$ | Thickness of the side shell plating, m. |
| $t_b$ | Thickness of the bottom plating, m. |
| $t_e$ | Effective thickness of member , m. |
| $t_j$ | Thickness of a particular member of the ship section, m. |
| $t_{eij}$ | Effective thickness of the side shell plating, m. |
| $t_{be}$ | Effective thickness of the bottom plating, m. |
| $t_{Le}$ | Effective thickness of the central longitudinal bulkhead plating, m. |
| $t_{de}$ | Effective thickness of the deck plating, m. |
| $t_{se}$ | Effective thickness of the side shell plating, m. |
| $y_b$ | The distance of the bottom plating from the neutral axis of the ship section, m. |
| $y_d$ | The distance of the deck plating from the neutral axis of the ship section, m. |
| $y_j$ | The distance of point ' j ' from the neutral axis , m. |
| $\alpha$ | Aspect ratio for the plating panel of the sides or the longitudinal bulkhead |
| $\beta$ | Slenderness ratio for the plating under consideration |
| $\gamma$ | Factor of safety |
| $\Phi$ | Constant, refer to Appendix (A). |
| $\Phi_{L1}$ | Constant, refer to appendices (A) and (D). |
| $\Phi_{L2}$ | Constant, refer to appendices (A) and (D). |
| $\Phi_{s1}$ | Constant, refer to appendices (A) and (D). |
| $\Phi_{s2}$ | Constant, refer to appendices (A) and (D). |
| $\nu$ | Poisson's ratio |
| $\sigma_a$ | Stress due to hull girder bending stress at section 'i', tonnes/ $m^2$ |
| $\sigma_{eij}$ | Equivalent stress at point 'j' in section 'i', tonnes/ $m^2$ |
| $\sigma_{ij}$ | Stress due to hull girder bending stress at point 'j' in section 'i', tonnes / $m^2$ |
| $\sigma_y$ | Yield stress, tonnes / $m^2$ |
| $\tau$ | Actual shear stress, tonnes / $m^2$ |
| $\tau_{all}$ | Allowable shear stress, tonnes / $m^2$ |
| $\tau_{cr}$ | Critical shear stress, tonnes / $m^2$ |
| $\tau_E$ | Euler buckling shear stress, tonnes / $m^2$ |
| $\tau_{ij}$ | Shear stress at section 'i' and point 'j' , tonnes / $m^2$ |
| $\tau_y$ | Yield shear stress, tonnes / $m^2$ |

## 1. INTRODUCTION

Over the past 20 years, many large oil spills causing severe pollution to the marine environment have occured all around the world. The most famous, not because of quantity of oil spilled, but because of its location off the coast of the United States of America, is that of the EXXON VALDEZ, grounded in March 1989.

Since then, interest has been spurred in the marine community to study the safety of oil tankers and the impact of tanker incidents on the marine environment. The report of the International Ship and Offshore Structures Congress [1], has detailed all major work on the subject.

Sometimes, statistics can help put events into perspective. Recent figures related by ITOPF (International Tanker Operators against pollution Forum) do just that. Table (1) shows all major oil spills, where the most expensive and infamous spill, the EXXON VALDEZ, rates just 37,000 tonnes compared to the 200,000 tonnes plus incidents involving the ATLANTIC EMPRESS, ABT SUMMER, and CASTILLO DE BELLVER [2].

Shama [3] has studied ship casualties and their environmental impacts and presented numerous statistics covering their types and causes. Another study, dealing with the environmental safety of coastal oil tankers, approached the problem with special concern over the reserve strength subsequent to structural failure [4].

A couple of studies dealing with the distribution of shear stress and the shear carrying capacity of intact ship sections [5,6] have been used in the present paper as they present detailed methods for the shear flow and shear carrying capacity calculations.

Table 1. Major oil spills, [2]

| Ship name | Year | Location | Oil Lost (tonnes) |
|---|---|---|---|
| Atlantic Empress | 1979 | off Tobago, West Indies | 280,000 |
| ABT Summer | 1991 | 700 naut. miles off Angola | 260,000 |
| Castillo de Bellver | 1983 | off Saldanha Bay, South Africa | 257,000 |
| Amoco Cadiz | 1978 | off Brittany, France | 227,000 |
| Haven | 1991 | Genoa, Italy | 140,000 |
| Odyssey | 1988 | 700 naut. miles off Nova Scotia, Canada | 132,000 |
| Torrey Canyon | 1967 | Scilly Isles, U.K. | 119,000 |
| Urquiola | 1976 | La Coruna, Spain | 108,000 |
| Hawaiian Patriot | 1977 | 300 naut. miles off Honolulu | 99,000 |
| Independenta | 1979 | Bosphorus, Turkey | 93,000 |
| Braer | 1993 | Shetland Islands, U.K. | 85,000 |
| Khark 5 | 1989 | 120 naut. miles off Atlantic coast of Morroco | 80,000 |
| Jakob Maersk | 1975 | Oporto, Portugal | 80,000 |
| Aegean Sea | 1992 | La Coruna, Spain | 72,000 |
| Katina P. | 1992 | off Maputo, Mozambique | 72,000 |
| Nova | 1985 | The Gulf, 20 naut. miles off Iran | 70,000 |
| Wafra | 1971 | off Cape Agulhas, South Africa | 65,000 |
| Assimi | 1983 | 55 naut. miles off Muscat, Oman | 53,000 |
| Metula | 1974 | Magellan Straits, Chile | 53,000 |
| Exxon Valdez | 1989 | Prince William Sound, Alaska, USA | 37,000 |

This paper aims at studying the effect of minor structural damages at specified locations on the ship section, on the shear flow distribution and shear carrying capacity of large seagoing oil tankers. The main concern is to design a structurally-safe oil tanker with enough reserve strength to sustain minor damages to its hull without further propagation of damage or failure, and hence release of the oil cargo to the sea, leading to oil pollution.

A case study with the following damage location cases is carried out:

i. Damage of side shell plating at the neutral axis of the ship-section, case (1).
ii. Damage of the bilge plating, case (2).
iii. Damage of the longitudinal bulkhead plating at its lower end, case (3).
iv. Damage of the keel plating, case (4).
v. Damage of the bottom plating near bulkhead, case (5).

In this study, the actual ship section is replaced by an idealized section having a deck, sides, bottom, and longitudinal bulkheads. The idealized ship section should retain the same configuration and geometrical properties, namely, total sectional area, shear area , position of neutral axis and second moment of area [4,7].

## 2. CALCULATION OF SHEAR FLOW DISTRIBUTION

The procedure for calculating the shear flow distribution over the ship section of seagoing oil tankers is based on the method presented in [5,6,8]. The shear flow distribution is obtained for the intact ship case and for each assumed damage location given in section (1).

The calculation of shear flow distribution, shear forces carried by the vertical members of the ship section for each assumed damage location are carried out using the computer program " SHA2". The flow chart of the computer program "SHA2" is shown in Figure (1),

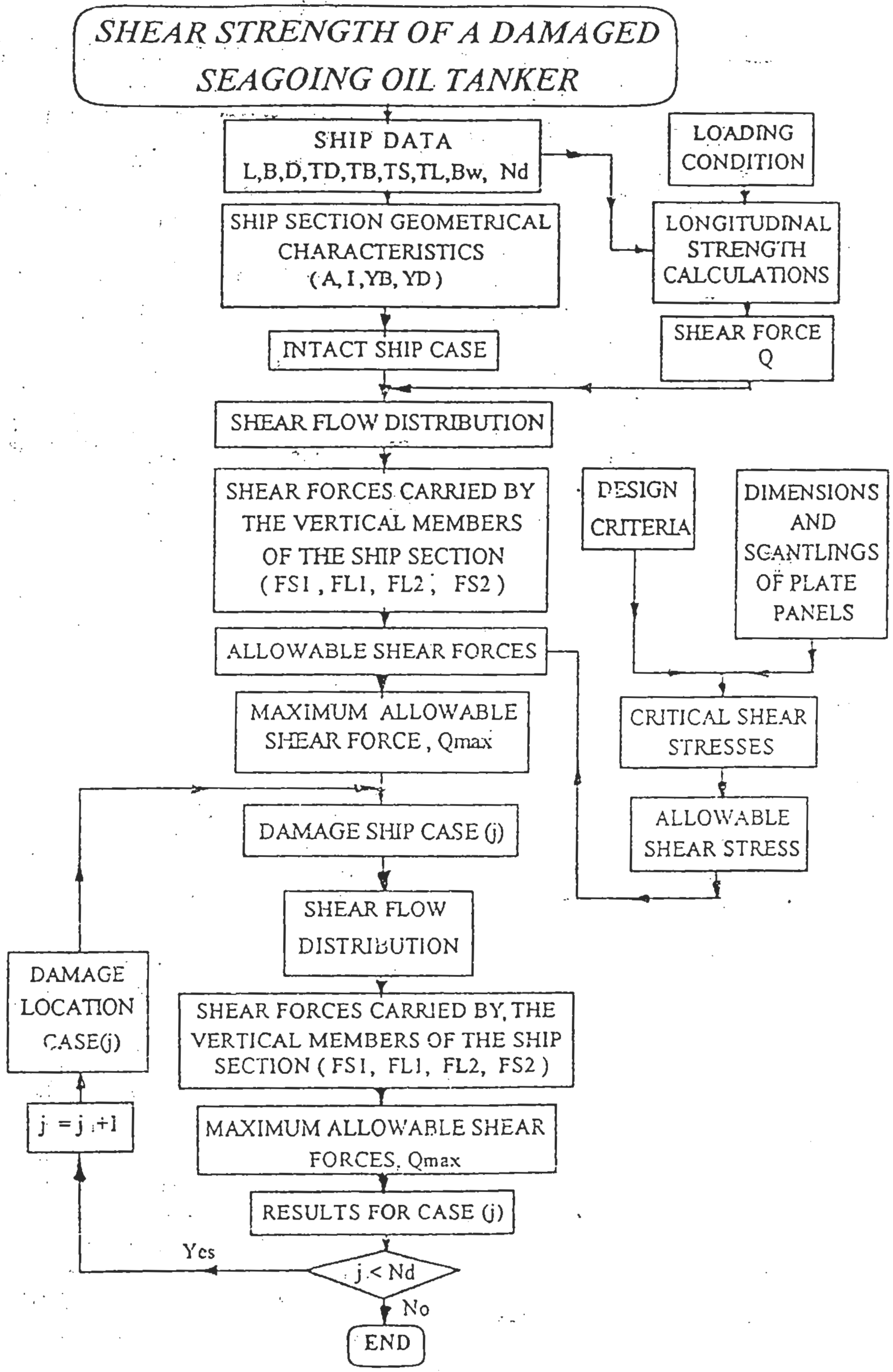

**Figure 1.** Flow chart for the computer program "SHA2".

where the following data are input:
TD= thickness of deck plating, TB= thickness of bottom plating, TS= thickness of side plating, TL= thickness of longitudinal bulkhead, Bw = width of wing tank, and Nd= total number of damage cases.

## 3. PLATE FAILURE MODES

In general, plate elements have some measure of post buckling reserve strength. This study specifies both plate buckling and plate collapse modes of failure under pure edge shear loading [9].

### 3.1 *Shear Buckling and Collapse Mode of Failure of Side Shell and Longitudinal Bulkhead Plating*

In order to ensure adequate strength against plate shear buckling, the maximum shear force which the side shell and longitudinal bulkhead plating can sustain, can be determined from the condition that the maximum expected shear stress should not exceed the critical value, i.e.

$$\tau \leq \tau_{cr}$$

The calculation of the critical shear stress, allowable shear stress and allowable shear force for a panel of plating, subjected to pure shear loading, are given in appendix (A).

The collapse strength of all plate elements under vertical shear loading is to be identical to the shear buckling mode of failure as given above.

## 4. CASE STUDY

The calculation of shear flow distribution, shear forces carried by the vertical members of the ship section and shear stresses are obtained for a seagoing oil tanker having the following main particulars, L.B.P = 260 m., B = 40 m., D = 20 m., and the width of the wing tank = 10 m. The geometrical characteristics of the ship section are given in Appendix (B). The shear flow distribution for the intact ship case is shown in Figure (2). The numbering of points on the ship section is shown in Figure (3).

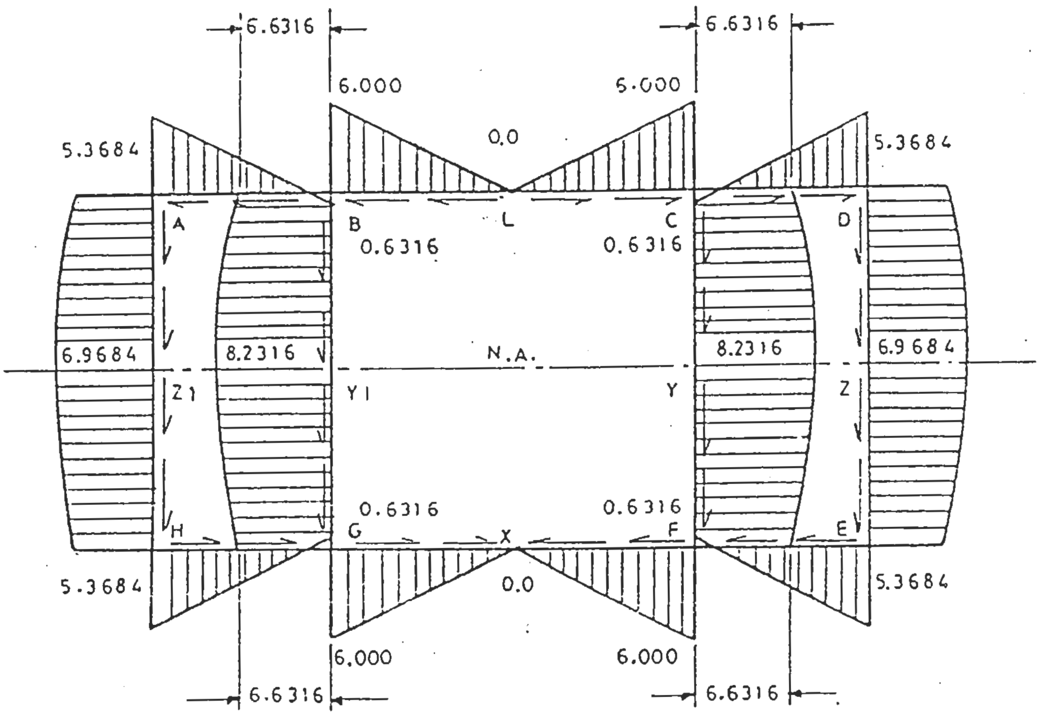

**Figure 2.** Shear flow distribution for the intact ship case, no. (0).

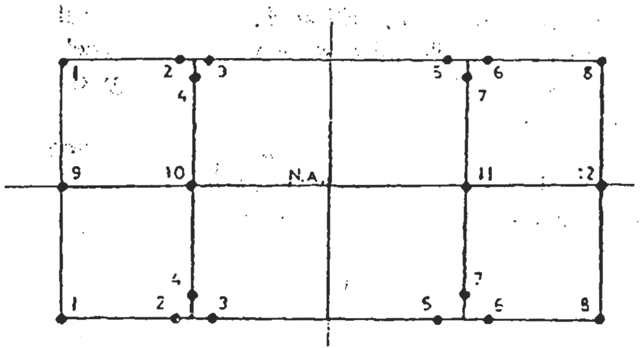

**Figure 3.** Numbering of points on the midship section of seagoing oil tanker.

The method of calculation of the shear flow distribution is applied to the assumed structural damage locations given section (1).

### 4.1 *Effect of Structural Damages at Specified Locations on the Ship Section on Shear Flow Distribution :*

It is shown from Figures (4), (5), (6), (7) and (8) that, the shear flow distribution over the ship section after the assumed local structural damages, changes drastically from the original distribution of the intact ship section shown in Figure (2). After damage takes place, the redistribution of the shear flow will occur. The comparison between the shear flow values for each damage case and the original values for the intact ship case are presented in Tables (2), (3), (4) and (5). Also the corresponding precentages of increases in the shear flow values for each damage case over the intact ship values are presented in the above tables.

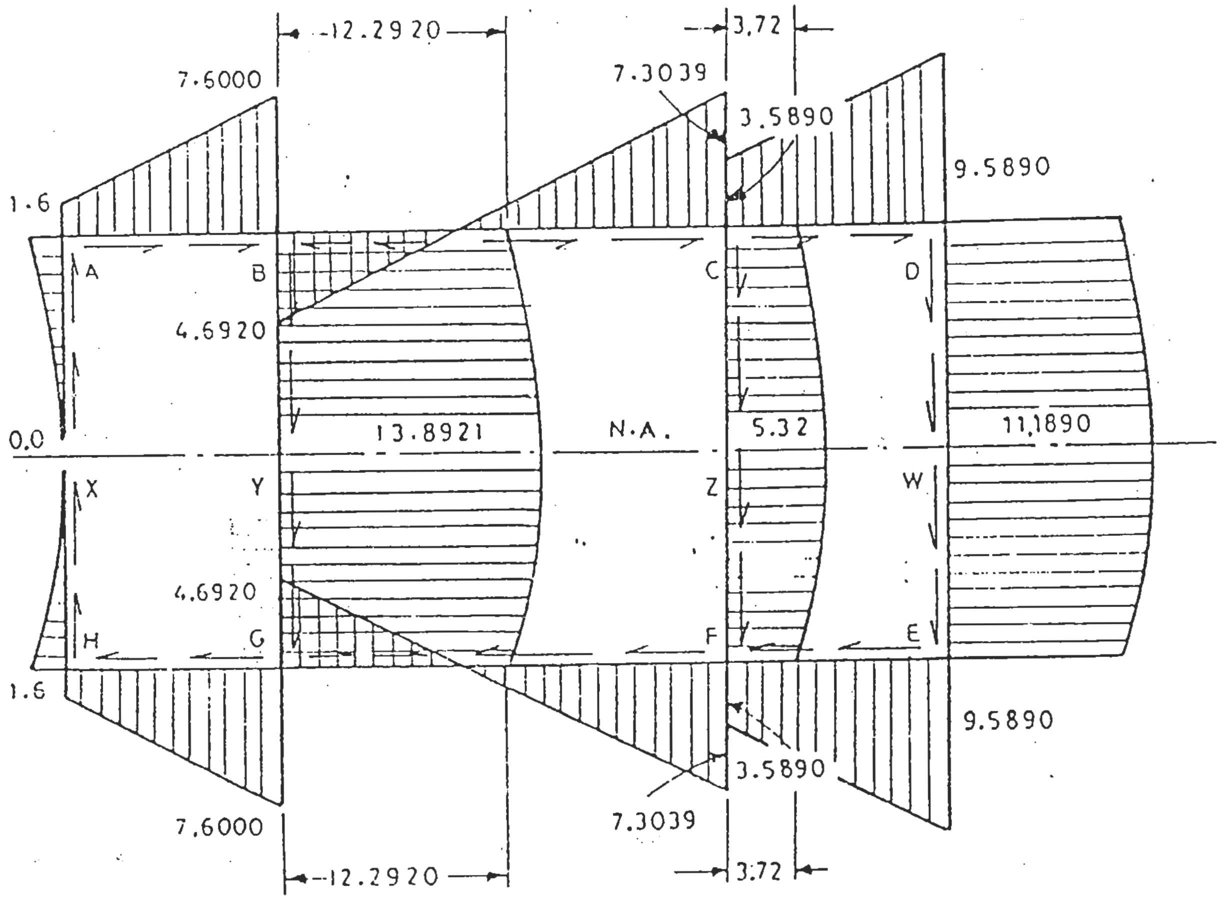

**Figure 4.** Shear flow distribution for case no. (1).

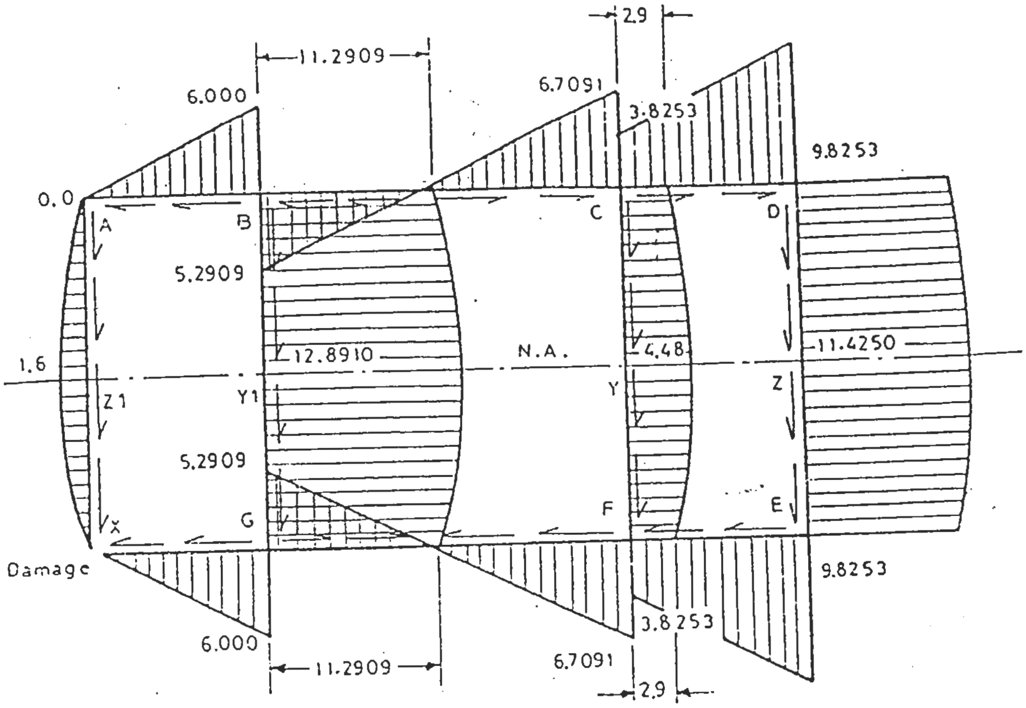

**Figure 5**. Shear flow distribution for case no. (2).

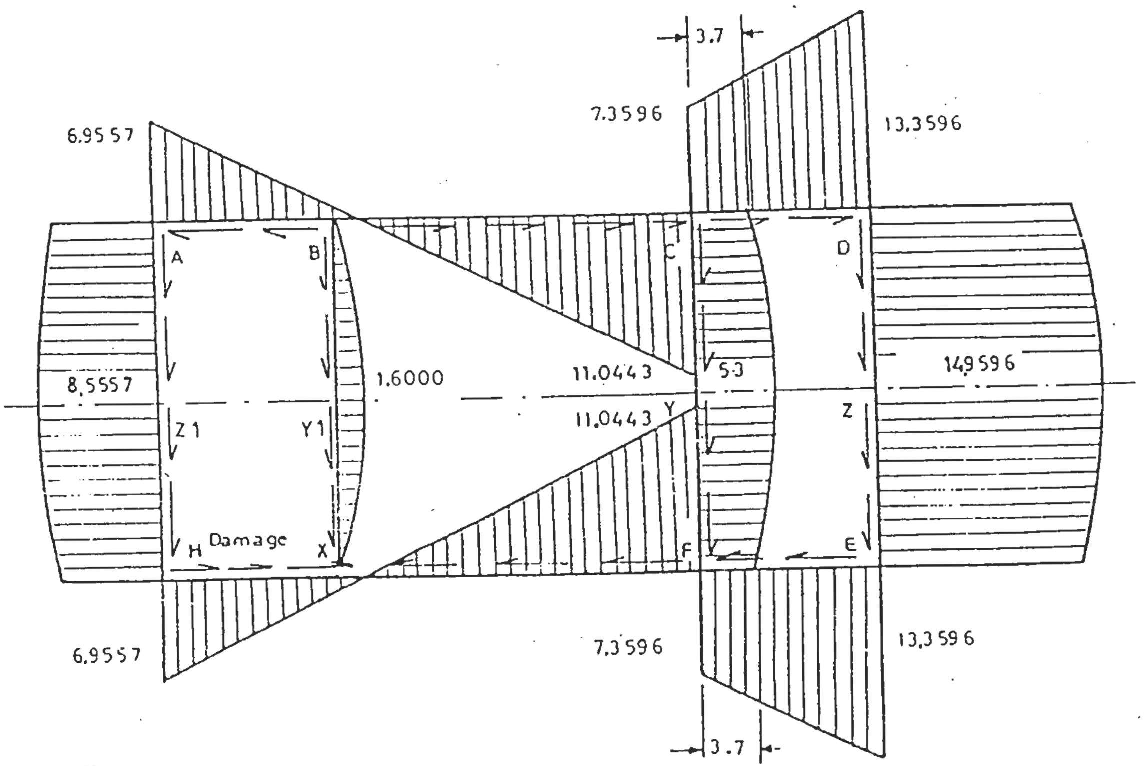

**Figure 6**. Shear flow distribution for case no. (3).

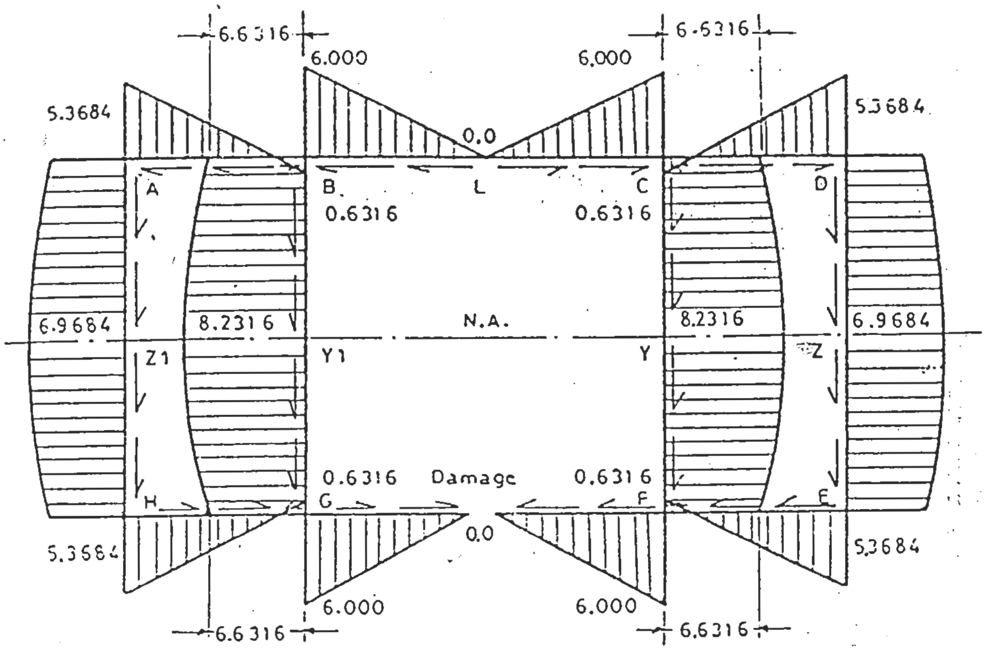

**Figure 7.** Shear flow distribution for case no. (4).

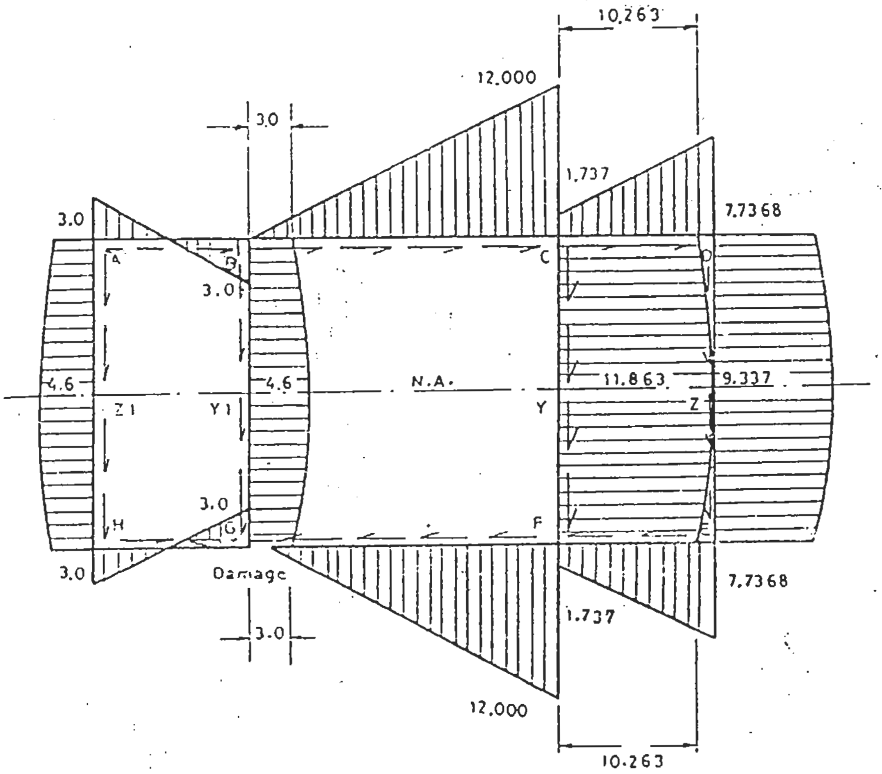

**Figure 8.** Shear flow distribution for case no. (5).

The members, seriously affected by the redistribution of shear flow subsequent to the assumed damage locations of the ship section of a seagoing oil tanker, are given in Table (6). It is evident from these calculations and analyses that, when a seagoing oil tanker is assumed to be damaged at specific locations, the shear flow will be redistributed over the ship section. The redistribution will result in significant increases in the maximum values of the shear flow on the side shell, deck, bottom and longitudinal bulkheads plating.

The importance of taking those high increases in the shear flow values subsequent to minor structural damages results from the fact that the actual flexural stress at any point over the ship section should take into account the shear stress at that point. This could be achieved by using the following equivalent stress formula:

$$\sigma_{cij} = \sqrt{\sigma_{ij}^2 + 3\tau_{ij}^2}$$

Therefore, very high values of equivalent stresses may be induced in sections other than those subjected to the highest bending stress or those subjected to high shear stresses.

### 4.2 *Shear Forces carried by the Vertical Members of the ship Section*

The shear forces resulting from the shear flow distribution over any vertical member of the ship section, can be calculated by integrating the shear flow distribution over the length of that particular member, as given in Refs.[5,6,8] and appendix (C).

**Table 2.** Comparison between the shear flow values of case (1) and intact case (0)
Location on ship section.

| Case | 2 | 4 | 5 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|
| 0 | 0.6316 | 6.6316 | 6.0000 | 0.6316 | 5.3684 | 8.2316 | 6.9684 |
| 1 | 7.6000 | 7.3039 | 7.3039 | 3.5890 | 9.5890 | 13.8921 | 11.1890 |
| % | 1203 | 110 | 122 | 568 | 178 | 168 | 160 |

**Table 3.** Comparison between the shear flow values of case (2) and intact case (0)
Location on ship section.

| Case | 2 | 5 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|
| 0 | 0.6316 | 6.0000 | 0.6316 | 5.3684 | 8.2316 | 6.9684 |
| 2 | 6.0000 | 6.7091 | 3.8253 | 9.8253 | 12.8910 | 11.4250 |
| % | 950 | 112 | 605 | 183 | 157 | 164 |

**Table 4.** Comparison between the shear flow values of case (3) and intact case (0)
Location on ship section

| Case | 1 | 2 | 5 | 6 | 8 | 9 | 12 |
|---|---|---|---|---|---|---|---|
| 0 | 5.3684 | 0.6316 | 6.0000 | 0.6316 | 5.3684 | 6.9684 | 6.9684 |
| 3 | 6.9557 | 0.9557 | 11.0443 | 7.3596 | 13.3596 | 8.5557 | 14.9596 |
| % | 130 | 151 | 184 | 1165 | 249 | 123 | 215 |

**Table 5.** Comparison between the shear flow values of case (5) and intact case (0)

Location on ship section.

| Case | 2 | 5 | 6 | 8 | 11 | 12 |
|---|---|---|---|---|---|---|
| 0 | 0.6316 | 6.0000 | 0.6316 | 5.3684 | 8.2316 | 6.9684 |
| 5 | 3 | 12 | 1.7368 | 7.7 | 11.863 | 9.3368 |
| % | 475 | 200 | 275 | 143 | 144 | 134 |

**Table 6.** Members seriously affected by the redistribution of the shear flow

| Case | Side shell | Deck | Bottom | Long. Bulkhead |
|---|---|---|---|---|
| 1 | Y | Y | Y | Y |
| 2 |  | Y | Y |  |
| 3 | Y | Y | Y |  |
| 4 |  |  |  |  |
| 5 | Y |  |  | Y |

**Table 7.** Shear forces carried by the vertical members.

| Case | $F_{s1}$ | % | $F_{L1}$ | % | $F_{L2}$ | % | $F_{s2}$ | % |
|---|---|---|---|---|---|---|---|---|
| 0 | 128.70 | 100 | 154.00 | 100 | 154.00 | 100 | 128.70 | 100 |
| 1 | -10.66 | 8 | 267.17 | 173 | 95.71 | 62 | 213.11 | 166 |
| 2 | 21.33 | 17 | 247.15 | 160 | 79.01 | 51 | 217.84 | 170 |
| 3 | 160.44 | 1250 | 21.33 | 14 | 95.03 | 62 | 288.52 | 224 |
| 4 | 128.70 | 100 | 154.00 | 100 | 154.00 | 100 | 128.70 | 100 |
| 5 | 81.33 | 63 | 81.33 | 53 | 226.6 | 147 | 176.1 | 137 |

The vertical shear forces $F_{L1}$, $F_{L2}$, $F_{s1}$ and $F_{s2}$ for each case of damage, are given in Table (7), together with the corresponding values obtained for the intact condition. The percentage increase of the shear forces for each vertical member over the corresponding value of the intact case is also given in Table (7).

From Table (7), it is seen that the side shell plating will be subjected to an additional shear force of 124 % of the intact case value, when one of the longitudinal bulkheads is damaged at its lower end .

The vertical members of the ship section subjected to the highest values of shear forces subsequent to each assumed case of failure are shown in Table (8).

It is evident from Table (8) that, the damage cases that have a pronounced effect on the:

i. Port side shell plating, is case No.(3)
ii. Port longitudinal bulkhead plating, are cases No.(1) and No.(2)
iii. Starboard longitudinal bulkhead plating, is case No.(5)
iv. Starboard side shell plating, are cases No.(1), No.(2), No.(3), and No.(5)

**Table 8.** Members subjected to highest shear forces subsequent to each damage case.

| Force<br>Case | $F_{s1}$ | $F_{L1}$ | $F_{L2}$ | $F_{s2}$ |
|---|---|---|---|---|
| 1 | - | 173 | - | 166 |
| 2 | - | 160 | - | 170 |
| 3 | 125 | - | - | 224 |
| 4 | - | - | - | - |
| 5 | - | - | 147 | 137 |

**Table 9.** Maximum shear force obtained from buckling criteria.

| Case | $\Phi_{s1}$ | $Q_{s1}$ | $\Phi_{L1}$ | $Q_{L1}$ | $\Phi_{L2}$ | $Q_{L2}$ | $\Phi_{s2}$ | $Q_{s2}$ | $Q_{max}$ |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.5008 | 15644 | 0.5915 | 13245 | 0.5915 | 13245 | 0.5008 | 15644 | 13245 |
| 1 | 0.0 | 0.0 | 0.9983 | 7848 | 0.3822 | -20499 | 0.8040 | 9744 | 7848 |
| 2 | 0.1150 | 68127 | 0.9263 | 8458 | 0.3222 | 24316 | 0.8210 | 9543 | 8458 |
| 3 | 0.6148 | 12743 | 0.1150 | 68127 | 0.3789 | 20677 | 1.0750 | 7288 | 7288 |
| 4 | 0.5008 | 15644 | 0.5915 | 13245 | 0.5915 | 13245 | 0.5008 | 15644 | 13245 |
| 5 | 0.3306 | 23698 | 0.3306 | 23698 | 0.8525 | 9190 | 0.6709 | 11678 | 9190 |

### 4.3 *Shear Buckling of Side Shell and Longitudinal Bulkhead Plating*

The calculation of the critical and allowable shear stresses for the vertical members follows the procedure given in appendix (A) and the results are given in appendix (D), where the maximum allowable shear force carried by side shell and longitudinal bulkhead plating is obtained. Table (9) gives the maximum allowable shear force carried by the vertical members for the assumed structural damage locations given in section (1).

It is shown in Table (9) that, the maximum allowable shear force for all the assumed damage cases is 7288 tonnes, when one of the two longitudinal bulkheads is assumed to be damaged at its lower end. This figure gives the strength capability of the ship section for the assumed scenarios of damage cases. This value, in our case study,was found to be less by about 45 % than the allowable shear force of the original intact case.

## 5. CONCLUSIONS

A brief investigation of the principal conclusions that may be aggregated from the work conducted in this research are illustrated as follows:

1. Very high shear stress values could be induced in the deck, bottom, side shell and longitudinal bulkheads of oil tankers subsequent to minor damages in the ship section.
2. Very high equivalent stresses could be included in the deck and bottom plating subsequent to minor structure damages, in other locations of the ship section.
3. Minor structural damage in certain locations over the ship section of an oil tanker could cause major structural collapse of the ship section due to shear buckling of side shell or longitudinal bulkheads.
4. The maximum allowable shear force for all assumed damage locations (neutral axis, bilge, bulkhead, keel and bottom damage cases) for the case study seagoing oil tanker is 7288 tonnes. This figure gives the strength capability of the ship section of a seagoing oil tanker for the assumed scenarios of the damage cases. This value is less by 45 % than the allowable shear force of the original intact ship.
5. During the ship design stage, the shear strength should be studied for each assumed structural

damage location.

6. The procedure commonly adopted for the structural design of oil tankers should take into account possible modes of failure subsequent to assumed minor damages in certain critical areas of the ship section.
7. In order to reduce oil spills as a result of structural failures of oil tankers, the philosophy of ship structural design of these tankers should be based not only on safety aspect of the intact structure but should also take account of the reserve strength for all possible scenarios of the damaged structure.

*Appendices*

## APPENDIX (A):

### SHEAR BUCKLING OF SIDE SHELL AND LONGITUDINAL BULKHEAD PLATING

The calculation of the critical shear buckling stress of a panel of plating, subjected to pure shear loading is given by [9]:

$$\tau_E = \frac{E\pi^2}{12(1-\nu^2)} K \left(\frac{t}{s}\right)^2$$

If $\tau_E < 0.5\ \tau_y$

then $\tau_{cr} = \tau_E$

If $\tau_E \geq 0.5\ \tau_y$

then $\frac{\tau_{cr}}{\tau_y} = [1 - 0.25(\frac{\tau_y}{\tau_E})]$

$$\tau_y = \frac{\sigma_y}{\sqrt{3}}$$

$$\frac{\tau_E}{\tau_Y} = 1.56 \frac{K}{\beta^2}$$

$$\beta = \frac{b}{t}\sqrt{\frac{\sigma_y}{E}}$$

Assuming a factor of safety $\gamma$, then the allowable shear stress is:

$$\tau_{all} = \tau_{cr} / \gamma$$

let $\Phi = \frac{\sum a_i y_i}{I . t_j}$

Then, $Q = \tau / \Phi$

The maximum allowable shear force is, therefore given by:

$$Q_{all} = \tau_{all} / \Phi$$

## APPENDIX (B)

### THE GEOMETRICAL CHARACTERISTICS OF SHIP SECTION OF A SEAGOING OIL TANKER

The examination of the shear carrying capacity of a damaged ship section of a seagoing oil tanker is carried out for the following given data:

i-) Main Dimensions:

L.B.P = 260.0 m.
B = 40.0 m.
D = 20.0 m.

ii-) Effective Thickness

The effective thickness of deck, bottom, longitudinal bulkhead, and side shell plating are given by:
$t_{se}$ = 32 mm.
$t_{Le}$ = 32 mm.
$t_{be}$ = 60 mm.
$t_{de}$ = 60 mm.

iii-) Material Properties

$E = 2.2 * 10^7$ tonnes/m$^2$ $\nu = 0.3$

$\sigma_y = 24{,}160$ tonnes/m$^2$ $\tau_y = 13.950$ tonnes / m$^2$

iv-) Geometrical Characteristics of the Ship Section

$y_b$ = 10 m.
$y_d$ = 10 m.
A = 7.36 $m.^2$
I = 565.333 $m.^4$

iv-) Plate Geometry

$\alpha = b / s$

## APPENDIX ( C)

### CALCULATION OF SHEAR FORCES CARRIED BY THE VERTICAL MEMBERS OF THE SHIP SECTION

The shear force on any vertical member over the ship section, can be calculated by integrating the shear flow distribution over that particular member, as follows:

$$F_J = \int_0^{l_j} q\,ds \qquad (C.1)$$

The calculated shear force should satisfy the condition that the sum of the vertical shear forces must equal the applied vertical shear force, as obtained from longitudinal strength calculations .i.e.

$$Q = F_{s1} + F_{L1} + F_{L2} + F_{s2} \qquad (C.2)$$

## APPENDIX (D)

### MAXIMUM ALLOWABLE SHEAR FORCES CARRIED BY THE VERTICAL MEMBERS OF A SEAGOING OIL TANKER

Following the procedure given in section (4), the maximum allowable shear force that the ship section could sustain after an assumed damage is estimated as follows:

i- Side Shell Plating:
Assume the following data for the side shell plating:
$t_{se}$ = 32 mm. $t_s$ (actual) = 20 mm.

s, b = 0.76 m., 3 m
$\alpha$ = 3.947
K = 5.597 and $\beta = 4.97$

The elastic critical buckling shear stress for the side shell plating is given by:

$$\tau_E / \tau_y = 5.525 > 0.5$$

Then, $\tau_{cr}$ = 13318.75 tonnes / $m^2$

Assume a factor of safety for shear buckling, $\gamma = 1.7$
The maximum allowable shear stress is given by:

$$\tau_{all} = 7834.56 \text{ tonnes} / m^2$$

The maximum allowable shear forces carried by the side shell and longitudinal bulkhead plating are given by:

$$Q_{s1} = \tau_{all} / \Phi_{s1}$$
$$Q_{L1} = \tau_{all} / \Phi_{L1}$$
$$Q_{L2} = \tau_{all} / \Phi_{L2}$$
$$Q_{s2} = \tau_{all} / \Phi_{s2}$$

## REFERENCES

[1] Report of Committee V. 6," Structural Design for Pollution Control", ISSC,1994.
[2] *Fairplay*, November 30th, 1995.
[3] M.A. Shama, "Ship Casualties, Types, Causes and Environmental Impacts", *Alexandria Engineering Journal*, vol. 34, No. 2, April 1995.
[4] M.A. Shama, A.W. Leheta Heba and B. Mahfouz, Ayman, "Shear Strength of Damaged Coastal Oil Tankers under Vertical Shear Loading", *Alexandria Engineering Journal*, vol. 34, No. 2, April 1995.
[5] M.A. Shama, "Shear Stresses in Bulk Carriers Due to Shear Loading", *Journal of Ship Research*, vol. 19, No. 3, Sept. 1975, pp. 155-163.
[6] M.A. Shama, "Effect of Variation of Ship Section Parameters on Shear Flow Distribution, Maximum Shear Stresses and Shear Carrying Capacity Due to Longitudinal Vertical Shear Force", *European Shipbuilding*, vol. 18, No.5,1969.
[7] A.B. Mahfouz, *Shear Strength of Damaged Oil Tankers under Vertical Shear Loading*, M.Sc. Thesis, Faculty of Engineering, Alexandria University, 1995.
[8] Hughes, Owen F., *Ship Structural Design : A Rationally-Based, Computer-Aided Optimization Approach*, SNAME, New Jersey, 1987.
[9] American Bureau of Shipping, "Compressive Strength Assurance of Flat Plate Structures in Ships", February 25 th, 1985.