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للأستاذ الدكتور محمد عبد الفتاح شامة

Published Papers (1994-2005)

on Energy and Environmental Protection

by Prof. Dr. M. A. Shama

1- "A Projection on the Future Demands and Capability of Offshore Technology" A.M.R.J. (Egypt-1976), Shama, M. A.,. (100%)

2- "A General Outlook to Offshore Technology", Egyptian Society of Marine Engineers and Shipbuilders, Forth seminar, Alexandria, April, (Egypt-1983), Shama, M. A., (100%)

3- "Costs of C02 Abatement in Egypt Using Both Bottom-Up and Top-Down Appr", Energy Policy, (USA-1994)Yehia El Mahgary, A. F. Ibrahim, M. A. F. Shama, A. Hassan, M. A. H. Rifai, M. Selim, I. Abdel Gelil, H. Kokor, Anhar Hegazi, A. Amin, F. Bedewi and Juha Forsstrom, (8%)

4- "Estimation of GHG Emissions in Egypt Up to the year 2020", World Resource Review, Vol. 6, No. 8, (USA-1994), Yehia El Mahgary, VTT-Energy, A. I. Abdel-Fattah, M. A. Shama, Alexandria, Faculty of Eng., M. Selim, I. Abdel Gelil, Anhar Hegazi, NREA, Egypt, M. A. Rifai, Azhar University, A. Amin, F. Bedewi EEA, Egypt, and J. Forsstrom, (11%)

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6- "Ship Casualties Types, Causes and Environmental Impacts", AEJ, April. (Egypt-1995), Shama, M. A. (100%)

7- "Ship Structural Failures: Types Causes and Environmental Impact", AEJ, July. (Egypt-1995) Shama, M. A., (100%)

8- "GHG Emissions Inventory for Egypt and Emission Mitigation Options",VTT, Energy, (Filand-1995), Yehia El Mahgary, VTT-Energy, Finland, M. A. Shama, A. F. Ibrahim and A. Hassan, Alex. University, Egypt, M. A. Rifai, Azhar University, Egypt, I. Abdel Gelil, M. Selim and H. Kokor, ECPO, Egypt, Anhar Hegazi, NREA, Egypt, A. Amin, F. Bedewi EEAA, Egypt, and Juha Forsstrom, VTT-ENERGY,Finland, (8%)

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13- "Life Cycle Assessment of Ships", Alexandria Engineering Journal, AEJ, (Egypt-2004) Shama, M.A. (100%)

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IMPACT ON MARINE ENVIRONMENT OF SHIP STRUCTURAL FAILURES AND CASUALTIES

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ABSTRACT

The paper gives an overview of the role of environmental conditions, technical deficiencies, random and human errors in causing and promoting ship casualties. The main types, causes and negative impacts of ship casualties are highlighted. Some statistics of the distribution of the annual rate of damages to the main structural elements of cargo ships, oil tankers and bulk carriers are given. The various direct and indirect causes of ship structural damages and failures are clarified. The effects of minor structural failures/damages at specified locations on the ship section of a coastal and sea-going oil tankers on the shear flow distribution, maximum shear stress and the shear carrying capacity of the ship section are demonstrated. The effects on the magnitude and distribution of hull girder shear and bending stresses of a general cargo ship of assumed damage locations are also given. It is shown that: i- minor structural failures and damages could cause serious major structural failures with subsequent risk of oil pollution, ii- in order to reduce/prevent marine oil pollution, adequate measures should be directed to eliminate/reduce all possible ship technical deficiencies and human errors in the various stages of ship design, construction, operation, inspection, maintenance and repair.

Keywords: Environment, Ship casualties, Structural failures, Shear stresses, Oil tankers, Oil pollution.

INTRODUCTION

The air pollution hazard from ships and other marine structures results from emissions of CO2, CO, NOx, etc. from the main and auxiliary engines. Marine diesel engines contribute about 7% of the world's NOx production (1). The production of NOx from slow speed engines is higher than from medium and high speed engines (1). However, using 10% exhaust gas recirculation (EGR) can reduce NOx by about 30% without adversely affecting fuel consumption.

Under normal conditions of ship operation, the marine pollution hazard results from waste water, dirty ballast, garbage, anti-fouling paints, etc. Tanker operations and accidents contribute about 11% of the total quantity of oil polluting the sea. Industrial wastes and other shipping sources, offshore operations and terminals contribute the remaining 89% of the oil polluting the sea (2). The scope and scale of the marine oil pollution hazard depends a great deal on the type of the marine accident, the structural failure and the type and size of the ships involved in the accident. For oil tankers the scope of marine pollution is extensive, whereas for small cargo ships and service crafts, the scope of marine pollution is rather limited. Many large oil spills causing extensive pollution to the marine environment have occurred at several places around the world over the last 20 years (3 to 7). Table (1) gives some of the well known oil pollution accidents. These pollution disasters have forced several national and international bodies to study the safety of oil tankers and the impact of accidents on the marine environment (8 to 13).

Although accidents at sea can never be eliminated completely, improved measures can reduce the rate at which they occur. It is therefore necessary to have improved methods of ship design, accurate assessment of structural capability of damaged ships and accepted methodologies for estimating the expected oil spill from oil tankers as a result of grounding, collisions etc.

Table 1. Some Marine Serious Casualties.

Name	Main Causes	Consequences
Titanic (1912)	– Design Errors – Crew Negligence	– Buckling & Shearing of hull plating – Flooding of 6 Forward Compartments – Sinking of the Ship – Loss of 1500 P of Total 2228 P
Liberty Ships (1940-1950)	– Brittle Fracture	– Major Structural Failures – Sinking of Some Ships
Torrey Canyon (1967)	– Grounding	– Oil Spill - 117,000 t
Alexander L. Kielland (Platform)	– Structural Collapse Due to Hydrogen Induced Cracking	– Sinking of Platform – Oil Pollution
Amoco Cadiz (1978)	– Grounding	– Oil Spill - 230,000 t
Atlantic Express (1979)	- Collision	– Oil Spill - 140,000 t
Exxon Valdez (1989)	– Grounding	– Oil Spill - 42,000 t
Estonia Ferry Boat	Poor Design of Bow Visors	– Flooding of Deck, Capsizing – Loss of 910 P of Total 1050

The Role of Environmental Conditions

Ship casualties, such as explosion, fire, grounding, collision, sinking, capsizing, etc. result from: certain environmental conditions, technical deficiencies, random and human errors. Figure (1) shows that collision, fire and grounding represent the main types of ship casualties [3]. The main environmental conditions responsible for the initiation and promotion of ship casualties may include: heavy weather, fog, storms, sudden change of weather, darkness, etc.

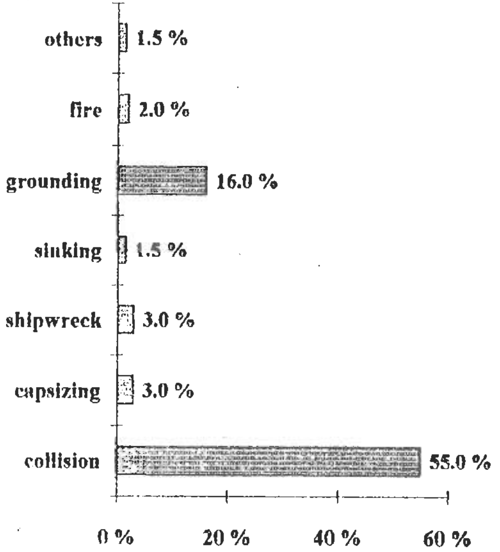

Figure 1. Distribution of main types of vessel casulaties.

Ship structural damages are considered one of the main outcomes of many types of ship casualties. The main causes of structural damages are: collision, heavy weather and grounding, as shown in Figure (2). The common damages due to heavy weather include: bottom damage (caused by slamming), bow damage (caused by pounding or panting), damage to deck girders, beams, pillars, hatch-coamings, deckhouses, etc. (caused by shipping green seas), damage to masts, bulwark, rails, deck houses (caused by severe rolling motions and shipping green seas), damage to the aft end structure (caused by high vibration stresses).

The distribution of the annual rate of structural damage of general cargo ships, oil tankers and bulk carriers are shown in Figures (3,4,5). The distribution of the main causes and annual rates of structural damages of the midship region in way of cargo tanks of oil tankers is shown in Figure (6). Wear and tear represent a major cause of failure of the bottom structure. Many ship structural damages of unknown causes are actually due to the combined effects of heavy weather, overload, under design, poor workmanship, wear and tear, corrosion or vibration. A high proportion of damages of side shell, transverse and longitudinal bulkhead structures result from unspecified causes (3).

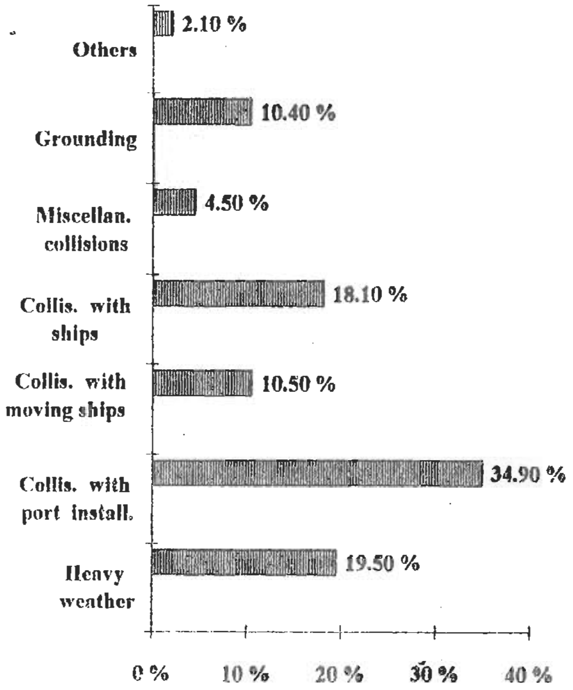

Figure 2. Causes of ship Structural damages.

Structural deterioration caused by corrosion of steel ships results from environmental conditions, age, inadequate maintenance, local wear, some improper features of design of structural details, chemical or corrosive action of the cargoes carried, etc.(14).

The Role of Technical Deficiencies

The main elements of technical deficiencies responsible for some of ship casualties, damages and structural failures include: poor design, poor construction, inadequate inspection, ineffective repair and maintenance work, failure of navigation equipment, failure of main engines, etc. Most ship structural failures result from errors in design, material, fabrication, inspection, maintenance and repair. Poor design of structural details represent, in most cases, the main cause of initiation of fatigue cracks, which when propagated may cause major structural failures. Ship structural failures, minor or major, represent one of the main causes of marine pollution.

For oil tankers, chemical carriers, gas carriers, etc., the hazard of marine pollution resulting from structural failures could be very extensive because of the nature of the cargo. For cargo ships, service crafts, etc., the impact of a minor/major structural failure on the marine environment is limited as the cause of pollution hazard is due to the fuel oil, lubricating oil, etc. remaining on board the ship.

The Role of the Human Element

Statistics show that less than 25% of marine fatalities is due to ship losses (15). Work accidents account for 25% and social factors on board account for more than 50%. The main human factors involved in promoting ship casualties are (3,16); lack of competency of the crew due to lack of proper education and training, poor crew performance due to overworking, high stress, tiredness and sickness, improper evaluation of consequences due to miscalculation of situations, etc. Many aspects of ship design, construction, operation, inspection, maintenance and repair are heavily influenced by human judgment and associated possible errors (3). The involvement of the human element in accidents could include: human errors in design (inadequate specifications of load and safety factors), human errors in fabrication (high residual stresses, large distortions, welding defects), human errors in operation (ignorance, incomplete knowledge, forgetfulness, wrong decisions taken on a miscalculated risk), organizational errors (due to deficient communications, undefined responsibilities, inadequate motivation, poor social and working conditions, etc.) (3,16). Human errors, like random errors, could result in various types and grades of failures with varying consequences.

Human errors may be also indirectly responsible for the presence of several types of structural defects, mainly; initiation of cracks, buckling of plating, general or local corrosion or excessive deformations. The presence of these structural defects may not induce immediate danger to the ship hull girder as a whole or even to any of its main structural elements, but could represent a serious hazard as the ship gets older. The direct and indirect impacts of these defects are: increased defect size, crack propagation, accelerated material deterioration, increased buckling, etc. These increased defects could lead directly to serious structural failures and indirectly to marine pollution. This requires a full understanding of the main types and causes of ship structural failures, the consequences of these failures and their direct or indirect relation to the causing human errors. Identification and analysis of the types and causes of these human errors are, therefore, essential elements of the measures needed to reduce/eliminate the hazards of marine pollution. This could be realized by: proper training and continuous upgrading of the crew, improving the working load and conditions of the crew, effective inspection, maintenance and repair work, etc.

Types and Causes of Structural Failures

Structural failures may result from several causes which can be grouped as follows (17): errors in design assumptions, methods and calculations, errors in fabrication , construction and erection, errors in material properties, accidental overloading due to collision, grounding or explosion, excessive strength degradation, occurrence of extreme values of load or strength, inadequate inspection, poor maintenance and ineffective repair work, etc. The most common causes of structural failures are: overloading, fatigue loading, brittle fracture, under design, poor design of local structural details, incorrect methods of construction, poor workmanship, incorrect repair procedures, inadequate corrosion control and prevention, wear and tear, accidents, etc. Material quality and grade play a major role in the initiation and propagation of brittle fracture and a minor role in fatigue fracture.

There is practically no ship entirely free of cracks and many ships are travelling with many cracks without serious consequences. Some of the cracks develop at an early date of ship's life. This type of crack results mainly from residual and fabrication stresses, high stress concentration, etc. Other types of cracks develop and propagate at a later stage of ships'operational life. This type of crack is basically a fatigue crack resulting mainly from the increased number of stress reversals and the presence of high stress values. Fatigue fractures originate at the surface and propagate very slowly and generally may take years to develop and become a serious hazard. Brittle fracture often occurs at a subsurface defect and generally occurs suddenly and propagates rapidly. Both types of fractures can start at defects due to welding or gas cutting in association with high stress concentration created by wrong design, geometrical discontinuities, etc. The design and construction of local structural details are, in most cases, responsible for the initiation and propagation of minor/major structural failures. The design and construction of these local structural details, therefore, should receive utmost attention in order to prevent/reduce structural failures and the subsequent risk of pollution hazard. It is essential, therefore, to over-design critical and highly stressed ship structural details and connections so as to cater for the greater variances in their structural capability and reliability.

Structural Damages and Failures of General Cargo Ships

The distribution of the annual rate of ship structural damages / failures of general cargo ships reveals that ship side frames, bottom floors and girders are the main ship elements subjected to structural damages, see Figure (3). Figures (7,8) show the distribution of hull fractures along ship length and over her depth. Cracks are the dominant mode of failure and represent 70% of the various modes of failure of the bottom girders and 62% of side frames.

For transversely framed ships, severe buckling of bottom plating within the midship region may result from the induced high values of still water and wave hogging moments.This can seriously impair hull girder and local strength of the midship region.

The use of HTS induces several problems with regard to fatigue, corrosion and buckling modes of failure (14). The use of HTS permits thinner plates and sections to be used in highly stressed areas so as to avoid using very thick mild steel plates and sections. This HTS thin plates and sections make buckling and fatigue very possible modes of failure, especially when the material experiences pronounced general/local corrosion (14).

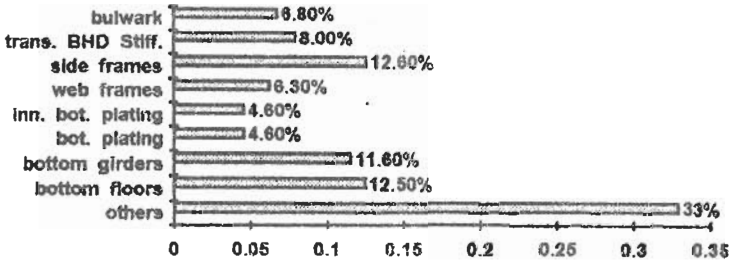

Figure 3. Damages of Structural elements of general cargo ships.

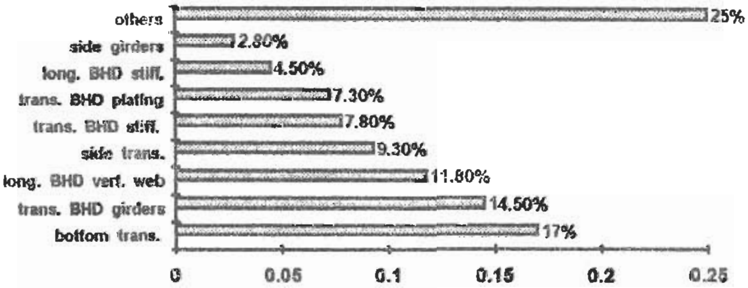

Figure 4. Damages of Structural elements of oil Tankers.

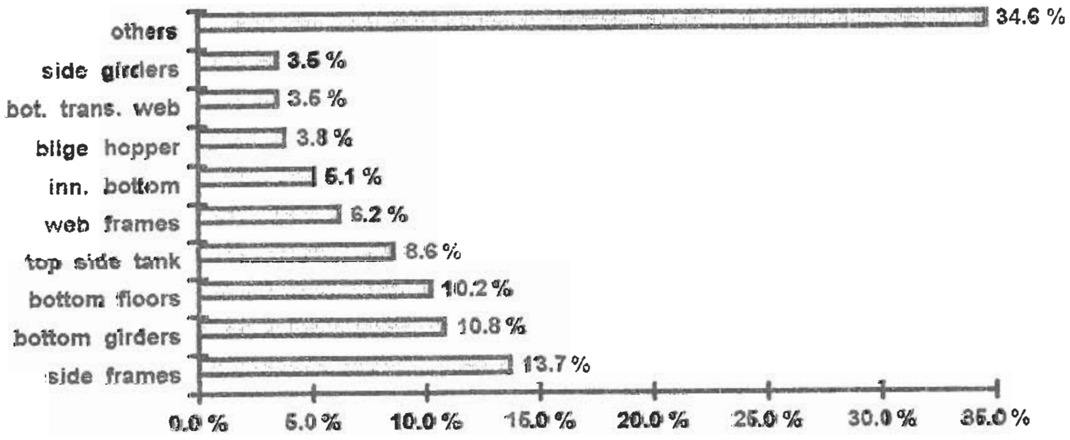

Figure 5. Damages of Structural elements of Bulk Carriers

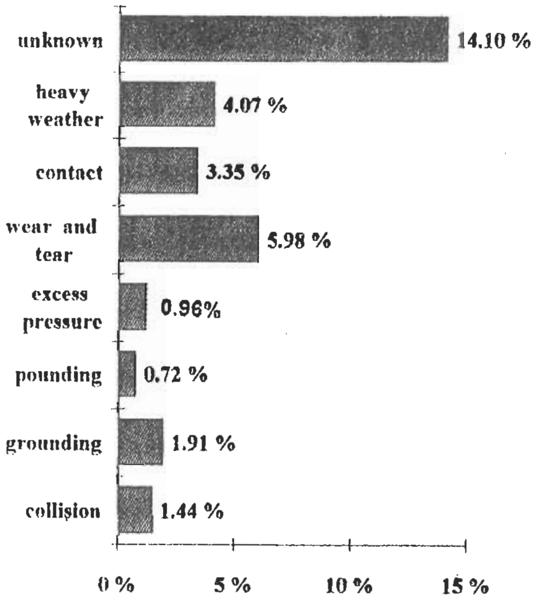

Figure 6. Annual rate of damage to the Midship region of oil Tankers.

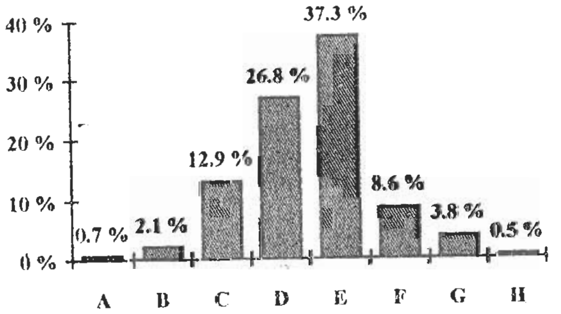

Figure 7. Longitudinal distribution of Hull fractures.

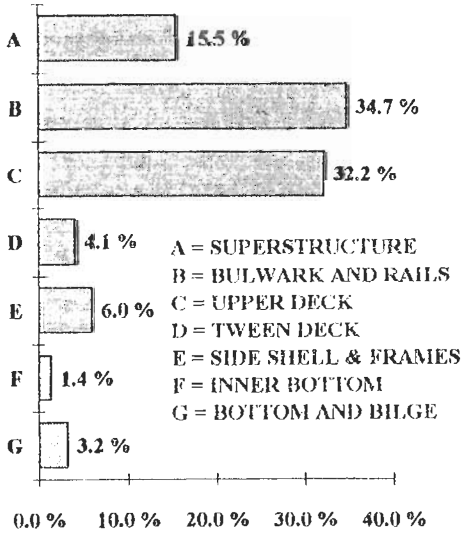

Figure 8. Vertical distribution of Hull Fractures.

Structural Damages and Failures of Oil Tankers

Ship structural details and connections are very sensitive to geometrical and scantling variabilities. Fractures usually start in a localized, highly stressed area of a badly designed structural detail due to poor fabrication and welding defects. Structural failures in oil tankers are generally attributed to failures of structural details in areas of high stress concentration, particularly at bracket toes and longitudinal connections to transverse web frames. The main types of structural defects affecting directly the strength of local structural details and indirectly the strengths of ship hull girder are: crack initiation, weld failures, buckling, excessive deformations, corrosion, etc. The most probable consequences of the presence of these structural defects are: increased size of defect, crack propagation, buckling, reduction in thicknesses, deficient load carrying capacity, etc.

The initiation and propagation of these local failures may subsequently cause major structural failures (18,19). Figures (9) shows that the midship part is subjected to about 87% of all crack failures. Small failures of oil tankers that may not immediately threaten ship structural safety, may subsequently cause serious economical and pollution problems.

Therefore, in order to reduce/ prevent the risk of a pollution hazard to the marine environment, oil tankers should be designed and maintained to a level of structural safety compatible with economic operations and environmental protection (17).

Strength and Consequences of Damaged Ship Structures

Several investigations have been conducted experimentally and theoretically in several places around the world to examine the strength and consequences of a damaged ship structure. Shama (20) examined the effect on the magnitude and distribution of bending and shear stresses over the ship section of a general cargo ship subjected to assumed damage conditions. Table (2) shows some results of this study, see Figures (10,11,12).

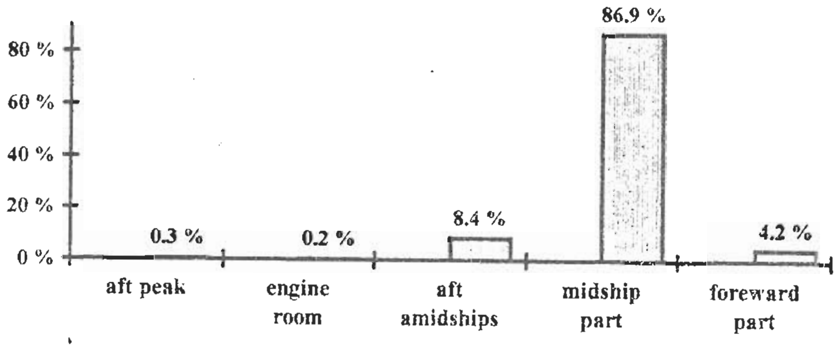

Figure 9. Distribution of Cracks along the length of oil Tankers.

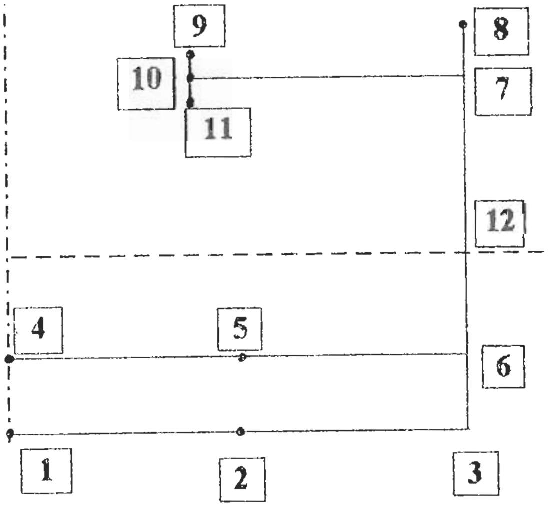

Figure 10. Numbering of ship section.

It is clear that structural damages at certain locations over the ship section could have significant effects on the magnitude and distribution of the hull girder bending and shear stresses. References (21,22) investigates the effect on shear stress distribution, maximum shear stresses and shear carrying capacity of coastal and sea-going oil tankers experiencing assumed damages at certain locations over the ship section. It is evident from Tables (3,4) that the redistribution of the shear flow over the assumed damaged ship section gives very high values of shear stresses in the side shell, longitudinal bulkhead, deck and bottom plating, see Figures (13,14). These high values of shear stresses when combined with hull girder bending and local stresses may induce unacceptable high values of the von mises equivalent stress. It is also evident from tables (5,6) that the shear force carried by the side shell and longitudinal bulkheads for certain damage conditions of the ship section could be significantly higher than the corresponding values of the intact ship section. Tables (7,8) give the maximum allowable shear force for the various assumed damage conditions based on the assumption that shear buckling of plating is the expected mode of failure.It is clear that the shear carrying capacity of the ship section is significantly reduced for certain damage conditions.

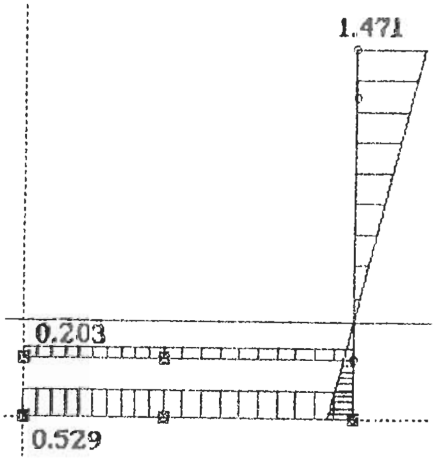

Figure 11. Bending stress distribution.

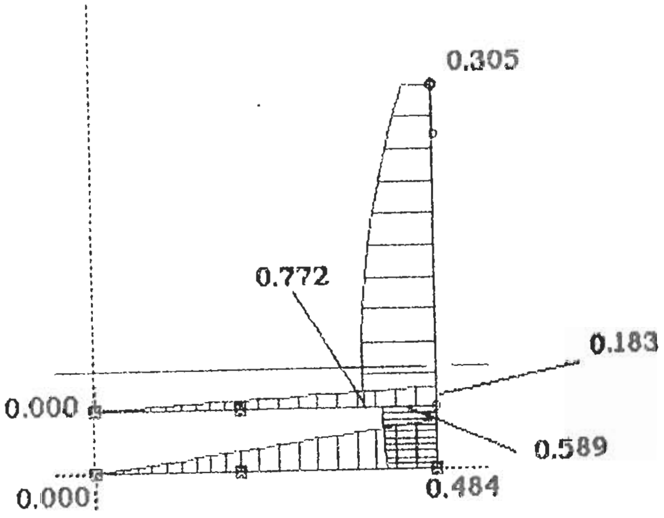

Figure 12. Shear stress distribution.

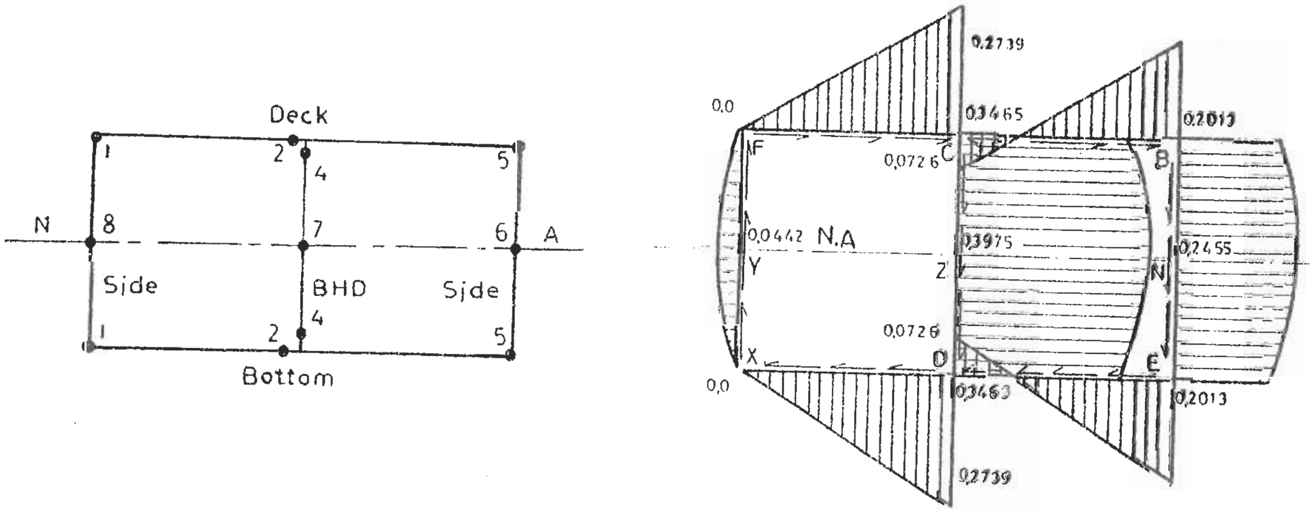

Figure 13. Shear flow distribution for the Bilge damage case (Coastal oil tanker).

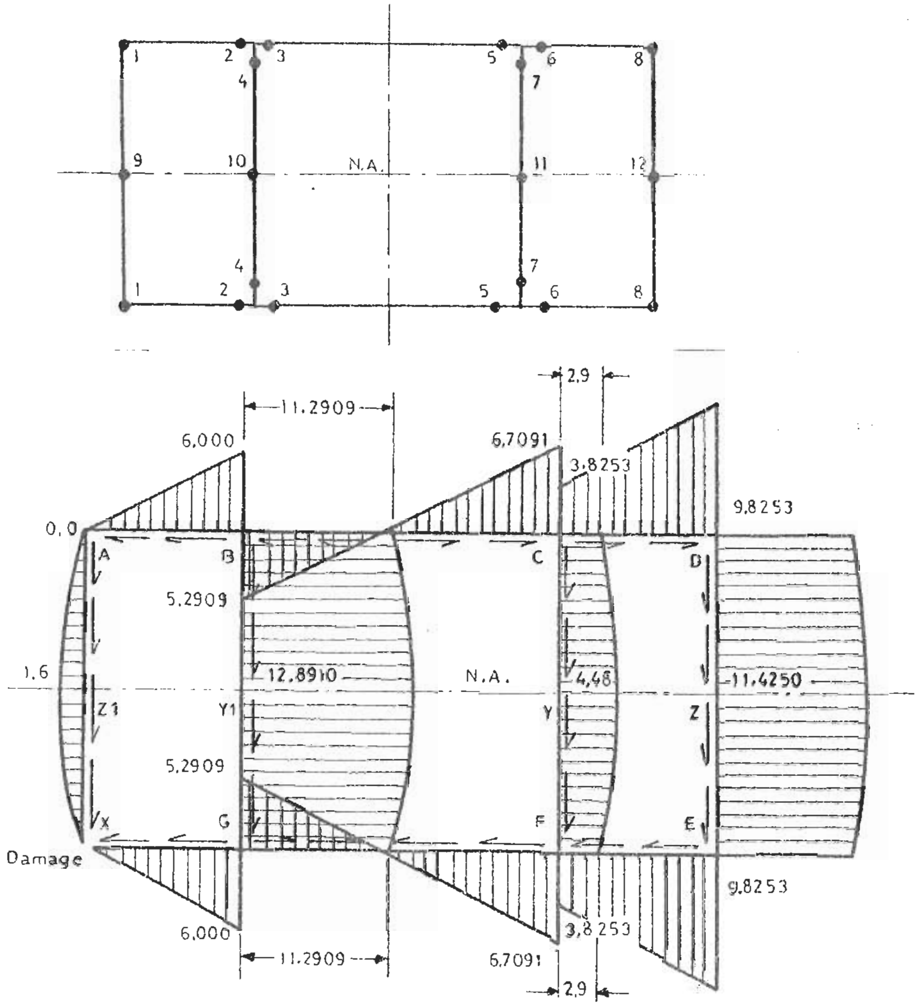

Figure 14. Shear flow distribution for the bilge damage case (sea-Going oil Tanker).

Table 2. Bending Stresses of a Damaged Cargo Ship.

Joint	σo	σ/σo			
		case 2	case 3	case 4	case 5
1	0.415	1.024	1.275	-	-
2	0.415	1.024	1.275	1.270	1.928
3	0.252	0.980	0.805	1.333	2.206
4	0.252	0.980	0.805	1.333	2.206
5	0.585	1.142	2.514	1.102	1.195
6	0.706	1.132	-	1.113	1.245
7	0.585	1.142	-	1.102	1.195
8	0.664	-	-	1.108	1.229
9	0.509	-	-	1.092	1.149

Table 3. Increase in Shear Stresses at Some Selected Points Over the Tanker Ship Section.

Case	τ_i/τ_0						
	1	2	4	5	6	7	8
1	0.358	2.11	1.26	1.72	1.53	1.22	-
2	-	1.82	1.15	1.63	1.46	1.13	0.264
3	2.218	-	-	2.22	1.90	0.14	1.900
4	2.220	-	0.47	1.07	1.05	0.55	1.900

Table 4. Increase in Shear Stresses at Some Selected Points Over the Tanker Ship Section.

Case	τ_i/τ_0									
	1	2	4	5	6	8	9	10	11	12
1	0.298	12.03	1.853	1.22	5.680	1.78	-	1.680	0.646	1.60
2	-	9.500	1.703	1.12	6.050	1.83	0.226	1.570	0.544	1.64
3	1.300	1.510	-	1.84	11.65	2.49	1.230	0.194	0.644	2.15
4	0.559	4.750	0.452	2.00	2.750	1.43	0.660	0.559	1.440	1.34

Table 5. Shear Forces Carried by the Side Shell Plating and the Central Longitudinal BHD of the Coastal Oil Tanker.

Case	KS_1	KS_2	KL	αS_1	αS_2	αL
0	0.239	0.239	0.522	1.000	1.000	1.000
1	0.023	0.378	0.645	0.096	1.582	1.235
2	0.046	0.360	0.593	0.192	1.506	1.136
3	0.474	0.474	0.052	1.983	1.983	0.100
4	0.474	0.252	0.274	1.983	1.054	0.525

where. $KS_j = QS_j / Q$, $j = 1.2$, $\alpha S_j = KS_j / K_0 S_j$, $j = 1.2$, $\alpha L = K_i L / K_0 L$, $i = 0.1.2...4$
$KL = Q_L / Q$, Q = applied shear force

Table 6. Shear Force Carried by Side Shell Plating & Long. BHD's For Sea-Going Oil Tankers.

Case	KS_1	KS_2	KL_1	KL_2	αS_1	αS_2	αL_1	αL_2
0	0.227	0.227	0.272	0.272	1.0	1.0	1.0	1.0
1	-0.019	0.377	0.472	0.169	-0.083	1.661	1.735	0.621
2	0.038	0.389	0.437	0.140	0.167	1.696	1.607	0.515
3	0.284	0.510	0.038	0.168	1.25	2.247	0.139	0.617
4	0.144	0.311	0.144	0.401	0.634	1.37	0.529	1.474

where: $Kk_j = Qk_j / Q$, $j = 1.2$, $k = S.L$,
Q = applied shear force

$\alpha_i \kappa_j = K_i \kappa_j$, $i = 0.1....4$, $j = 1.2$, $\kappa = S,L$

Table 7. Maximum Allowable Shear Forces for the Different Assumed Damage Conditions Based on the Shear Buckling Criteria (Coastal Oil Tankers).

Case	0	1	2	3	4
γ	1.0	0.817	0.885	0.967	0.967

Table 8. Maximum Allowable Shear Forces for the Different Assumed Damaged Conditions Based on the Shear Buckling Criteria (Sea-Going Oil Tankers).

Case	0	1	2	3	4
γ	1.0	0.592	0.638	0.550	0.694

$\gamma = (Q)_D/(Q_a)_o$

where: $(Q_a)_D$, $(Q_a)_0$ = Maximum allowable Shear Force in the Damaged and Original Conditions

CONCLUSIONS

1- Accidents at sea can never be eliminated completely but improved measures can reduce the rate at which they occur. These measures could be summarized as follows:
- proper and continuous training and upgrading of crew
- improving the working conditions of the crew
- ensuring effective inspection, maintenance and repair work
- maintaining ship equipment and machinery at the highest possible level
- correcting any minor structural deficiencies as soon as it is noticed, etc.

2- Ship accidents represent. directly or indirectly. one of the main causes of marine oil pollution. Controlling and reducing the causes of marine accidents should pave the way to reducing the harmful effects and negative impacts on the marine environment.

3- Oil tankers should be designed to sustain an acceptable amount of damage without suffering extensive structural collapse or sinking.

4- In order to reduce/prevent the risk of marine pollution hazard, ship structures should be designed, constructed and maintained not only to ensure adequate structural safety and economic operation but also to satisfy the needs of environmental protection. This could be realized by:
- reducing human errors in design, construction, maintenance and repair work
- eliminating errors in material specifications, inspection and selection
- improving design of ship structural details so as to cater for the greater variances in their structural capability and reliability
- improving control and prevention of corrosion and material deterioration
- prevention of overloading of ship structures by reducing ship operational errors

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