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للأستاذ الدكتور محمد عبد الفتاح شامة

Published Papers (1994-2005)

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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%)

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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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SHIP STRUCTURAL FAILURES: TYPES, CAUSES AND ENVIRONMENTAL IMPACTS

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ABSTRACT

The main objective of the paper is to shed some light on the role of ship structural failures in increasing pollution hazards to the marine environment and the role of the human factor in promoting ship structural failures. Therefore, some statistics and causes of the different modes of structural failures of general cargo ships are given. The paper, therefore, gives an overview of the main types and causes of the different modes of ship structural failures. These causes result mainly from human errors in design, material, fabrication, operation, inspection, maintenance and repair. The main direct and indirect causes of these human errors are given together with the corresponding consequences. The main types of structural failures experienced by the different structural elements of general cargo ships are presented together with some statistics of these failures. The main causes of deficient structural strength are given. Particular emphasis is placed on the distribution of failures along the length and depth of cargo ships. The different modes of failure of the deck structure, the bottom plating and longitudinal girders are especially considered. The different modes of failure of the deck plating, hatch covers, side shell plating and side frames are presented. The distribution of cracks along the length and across the depth of oil tankers is given. It is evident that poor design of structural details and human errors in design, fabrication, inspection, maintenance and repair are the main causes of ship structural failures.

Keywords: Structural Failures, Human Errors, Environmental Impacts, Structural Details, Ship Structures.

INTRODUCTION

Ship structural failures could represent, in many cases, the main hazards causing harmful environmental impacts. Hull girder or local structural failures may be responsible for oil pollution of the marine environment. The design and construction of local structural details represent, in many cases, the main cause responsible for the initiation and propagation of minor/ major structural failures. Therefore, in order to reduce/ prevent the risk of pollution hazard to the marine environment, ship structures should be designed and maintained to a level of structural safety compatible with economic operations and environmental protection. This could be achieved by studying the various types and causes of ship structural failures and their distribution along ship length and over her depth for the different ship types. This paper, therefore, gives an overview of the main types and causes of ship structural failures and their distribution over ship length and depth. Particular emphasis is placed on the role of the human factor in promoting ship structural failures and subsequently causing harmful impacts to the marine environment. The statistics given in the paper are obtained from several sources, among them are the references given at the end of the paper.

Types And Causes of Ship Structural Failures

A major requirement for any marine structure is to have low initial and operational costs, to be reasonably safe, not to have catastrophic failures , nor to have much trouble in service due to frequent minor failures. Safety today is concerned with the lives of passengers and crews and also with the possible damage to the marine environment that may result as a consequence of structural failures. Therefore, safety should be related to the economic, social and environmental impacts consequent to structural failure.

Structural failures may result from several causes which can be grouped into the following main categories;

i- occurrence of extreme values of load or strength
ii- errors in design assumptions, calculations, etc.
iii- errors in fabrication , construction and erection
iv- errors in material properties
v- accidental overloading due to collision, grounding, explosions, etc.
vi- inadequate inspection, poor maintenance strategies and ineffective repair work

Structural design procedures are almost totally based on the occurrence of extreme values of load or strength, or both, beyond the margins accepted for safety. Designing a structure for low values of probability of failure due to extreme load, or strength, may not, in general, improve the total probability of failure.

Figure (1) shows the main types and the direct and indirect causes of ship structural failures. The main direct causes result mainly from errors in:

- design
- material
- fabrication
- operation
- maintenance and repair

The most common causes of ship 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 prevention
- wear and tear
- accidents (collisions, groundings, etc.)

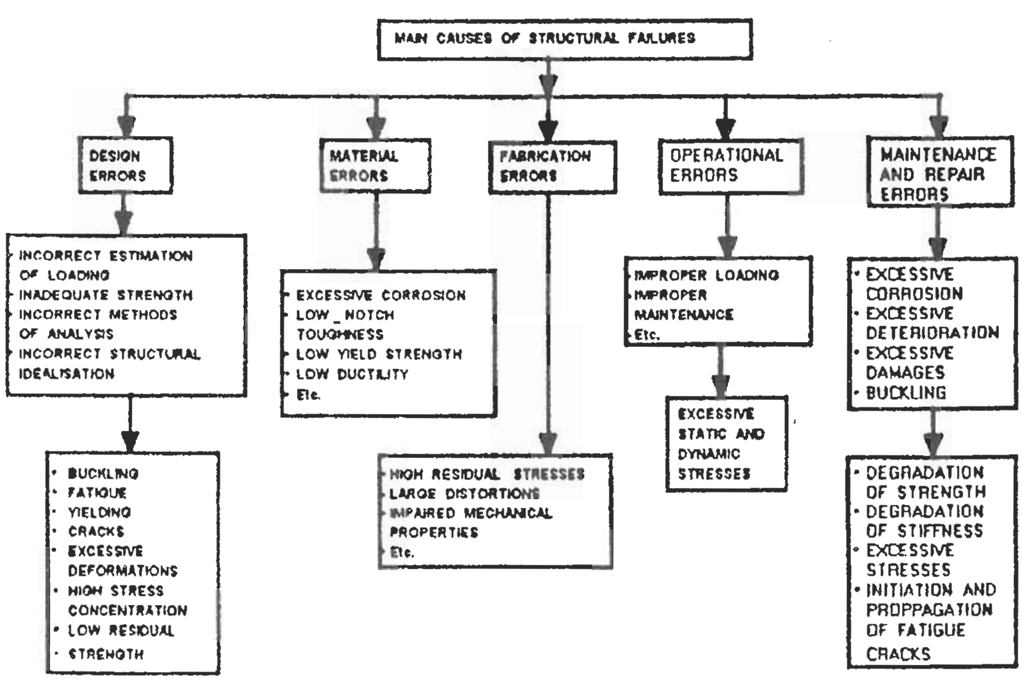

Figure 1. Main causes of structural failures.

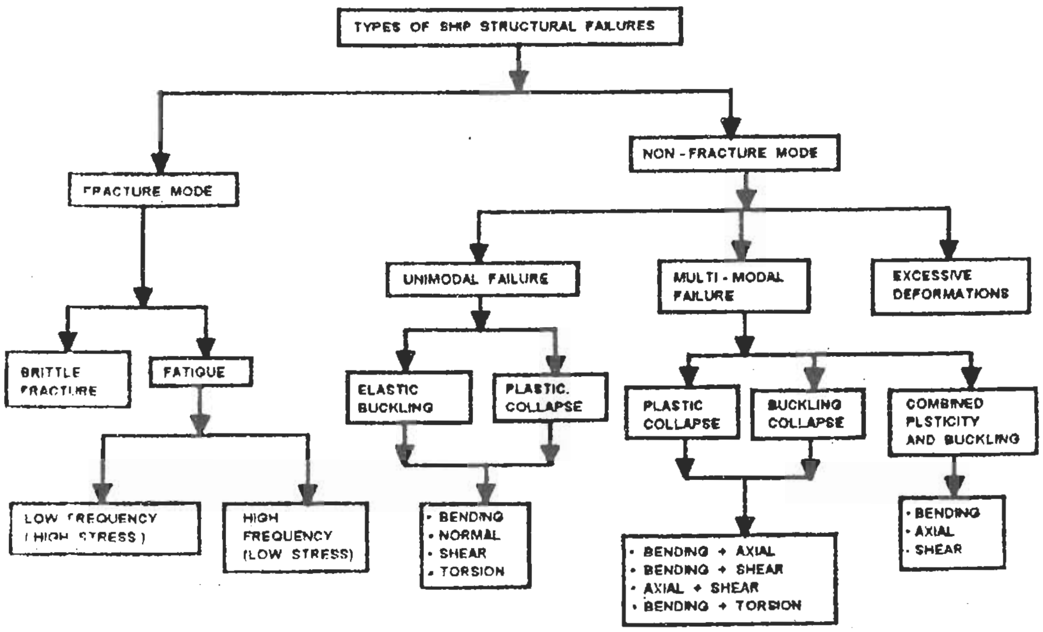

Figure 2. Types of ship structural failures.

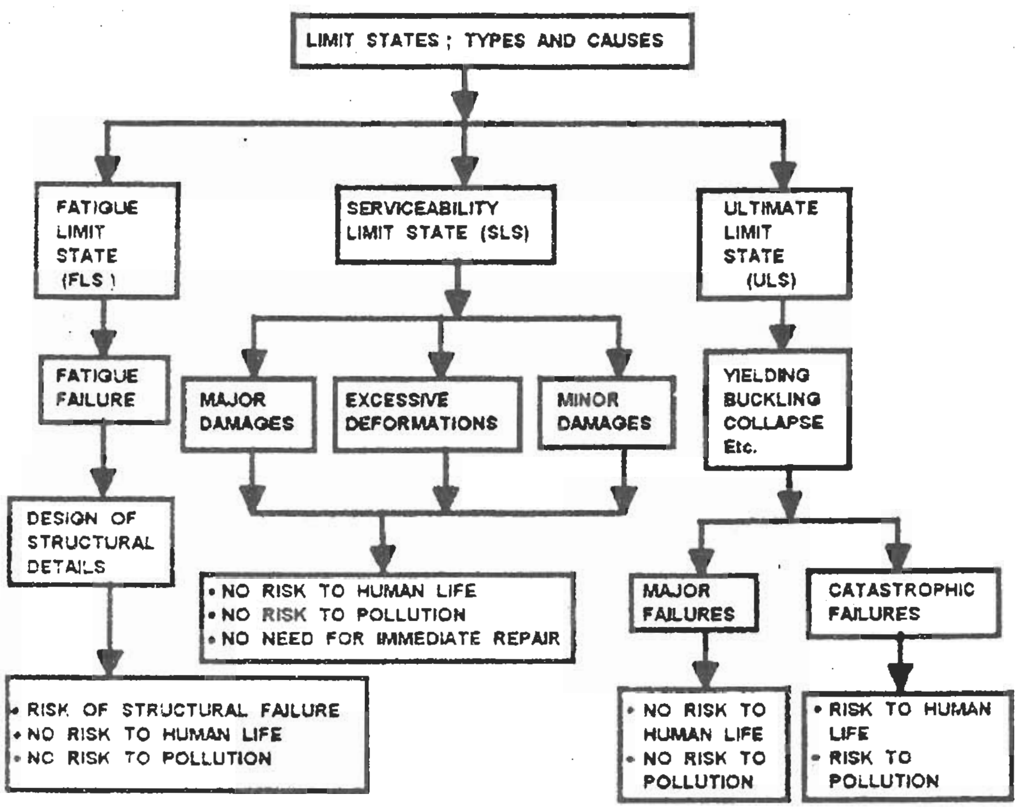

Figure 3. Limit states; types and causes.

Figure (2) shows the main types and modes of ship structural failures. The modes of failure are categorised as fracture and non-fracture types. The different categories of both types are also given in Figure (2).

Ship structural failures, global or local, may result from either overloading or underdesign. Structural failures are generally related to the various definitions of the limit states. Figure (3) shows the most commonly used definitions of limit states together with their main causes. Overloading occurs when the actual loads, on the structural system or any part of it, exceeds the design values.The main direct and indirect causes of overloading are given in Figure (4). Hull girder collapse may result from excessive bending moments and / or shear forces.

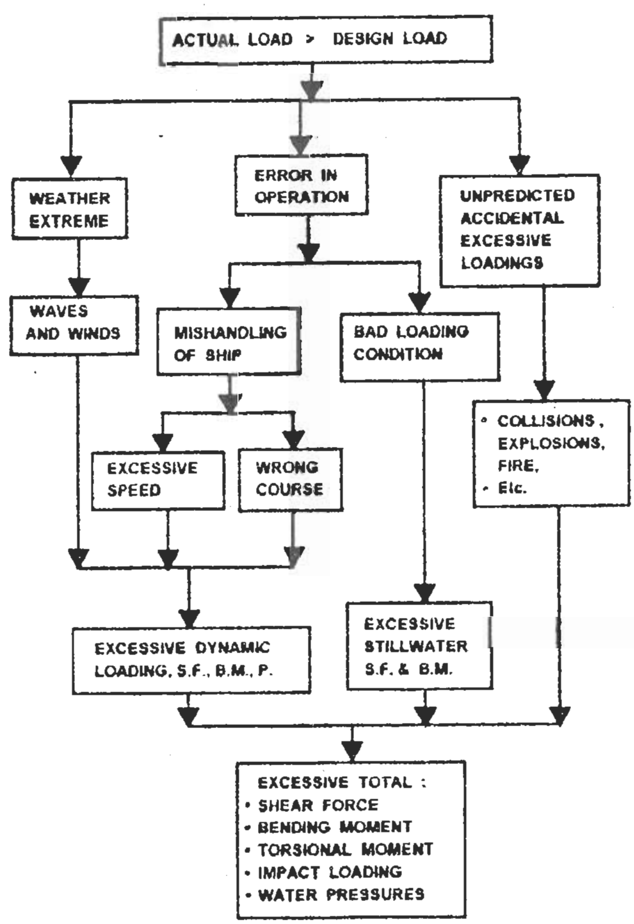

Figure 4. Main causes of overloading.

Underdesign of ship hull girder, or any part of its structural components, may result from several sources of errors associated with design, construction, fabrication, material and / or operation. Figure (5) illustrates the main causes believed to be responsible for underdesign or structural deficiencies of ship hull girder, or any part of it. Design errors are so numerous that they cannot be listed. A simple example of design errors is shown in Figures (6,7), which shows the influence of the increase of flare angle and / or reduction of bow rake angle on the increase of the rate of damage of the bow structure. Damages resulting from under design, poor workmanship or vibration could be significantly reduced / prevented by increasing strength and / or stiffness.

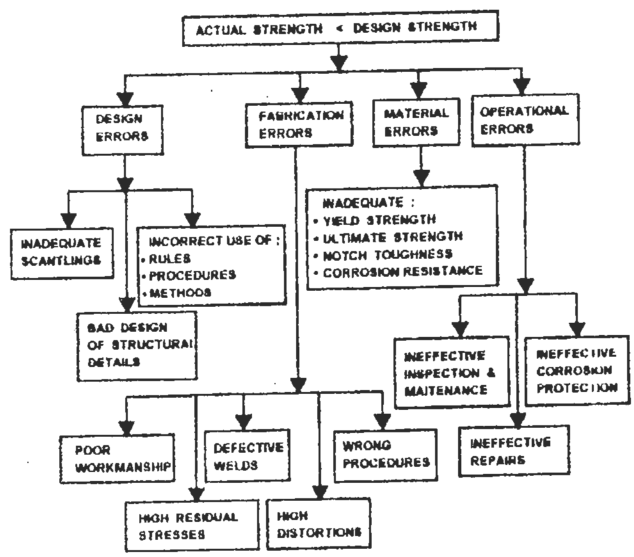

Figure 5. Causes of deficient strength.

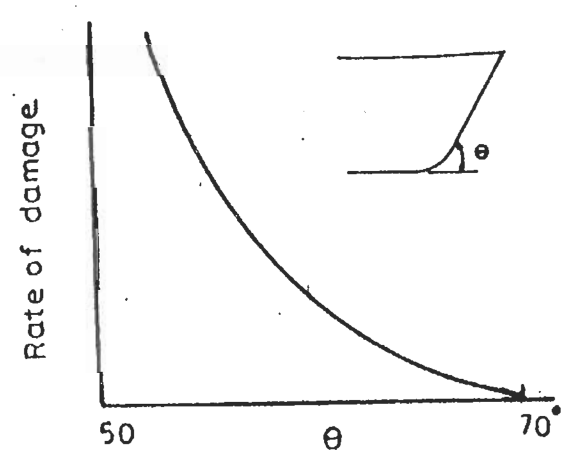

Figure 6. Rate of damage vs. Bow Rake angle.

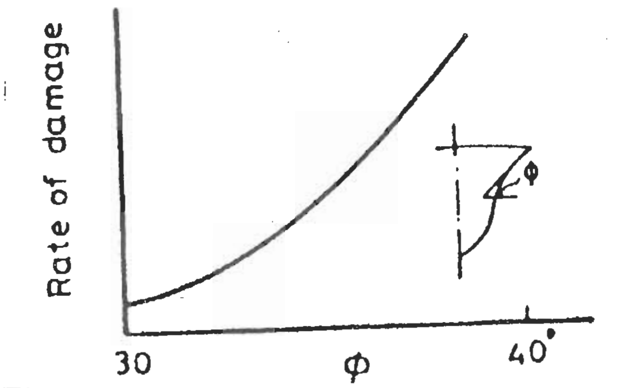

Figure 7. Rate of damages vs flare angle.

Many structural failures result from fatigue cracks, brittle fracture, corrosion and wear and tare. There is practically no ship entirely free of cracks and many ships are travelling with many cracks without serious consequences. These cracks differ widely from one ship to another with regard to origin, type, size, number and distribution over ship structural members. Some of the cracks develop at an early date of ship's life. This type of cracks result mainly from residual stresses, fabrication stresses, high stress concentration, etc. Other types of cracks develop and propagate at a later stage of ship's operational life. This type of cracks is basically fatigue cracks resulting mainly from the increased number of stress reversals.

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 notches in association with high stress concentration created by wrong design, geometrical discontinuities, etc. Material quality and grade play a major role in the initiation and propagation of brittle fracture and a minor role in fatigue fracture.

Statistics And Analysis Of Ship Structural Failures

Failure diagnosis, within the context of ship structures, can be defined as the assessment of the nature and possible causes of ship structural failures, whether this failure is a minor or a major one. This could be realised from the pattern of deformation, type, size and shape of crack or rupture, etc.

i. Distribution of Failures For General Cargo Ships

The distribution of the annual rate of ship structural damages / failures for the various structural elements of general cargo ships is shown in Figure (8). It is clear from Figure (8) that ship side frames, bottom floors and girders are the main ship elements subjected to structural damages. Figure (9) shows the distribution of hull fractures along ship length. It is clear from Figure (9) that the midship region is highly vulnerable to structural failures. The distribution of fractures in the bottom structure along ship length is shown in Figure (10). The letter "A" indicates aft end and the letter "H" indicates forward end.

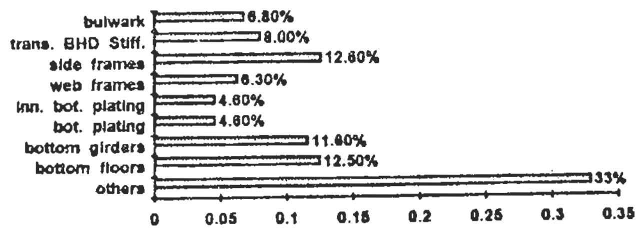

Figure 8. Damages to ship structural elements of general cargo ships.

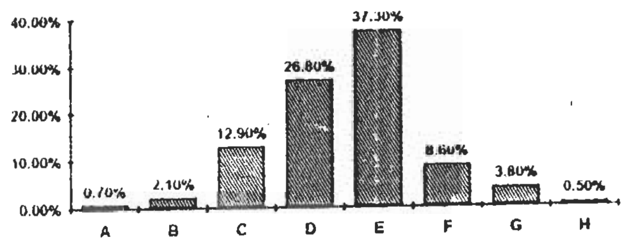

Figure 9. Longitudinal distribution of hull fractures.

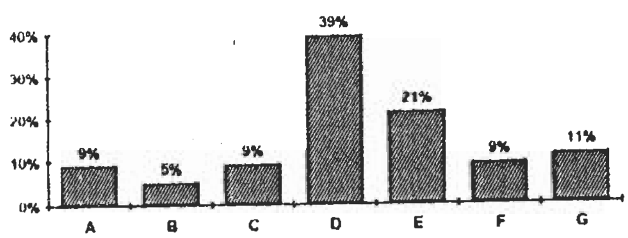

Figure 10. Longitudinal distribution of fractures along the bottom structure.

The different modes of failure of the bottom plating is shown in Figure (11) and of the longitudinal girders of the bottom structure is shown in Figure (12). It is shown that cracks are the dominant mode of failure and represent 70% of the various modes of failure of the bottom girders. The distribution of fractures of the upper deck along ship length is shown in Figure (13).

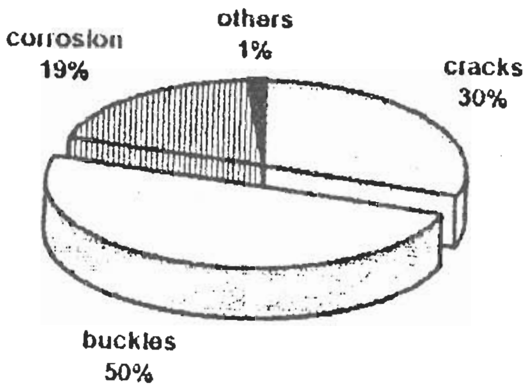

Figure 11. Failures of bottom plating.

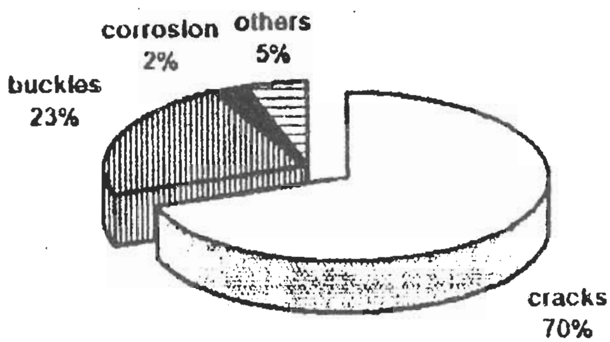

Figure 12. Failures of longitudinal girders in bottom structure.

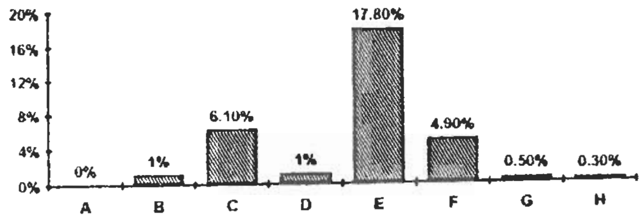

Figure 13. Longitudinal distribution of fractures along the upper deck.

The failure rates of the main structural elements of the deck structure is shown in Figure (14) for the various modes of failure. It is shown that deck plating, transverse girders and hatch girders are the main structural elements experiencing the various modes of structural failures. Figure (15) shows the distribution of crack failures among the different structural elements of the deck structure. It is shown that deck plating and hatch girders are highly susceptible to crack failures. Figure (16) shows the distribution of the buckling mode of failure among the different structural elements of the deck structure. It is also shown that deck plating and transverse girders are the main structural elements subjected to buckling failures. Table (1) shows the relative distribution of the different modes of failure for the deck plating and hatch covers.

Table 1. Failures Of Deck Structure.

item	deck plating	hatch covers
cracks	66%	41%
buckling	25%	29%
corrosion	4%	8%
others	5%	22%

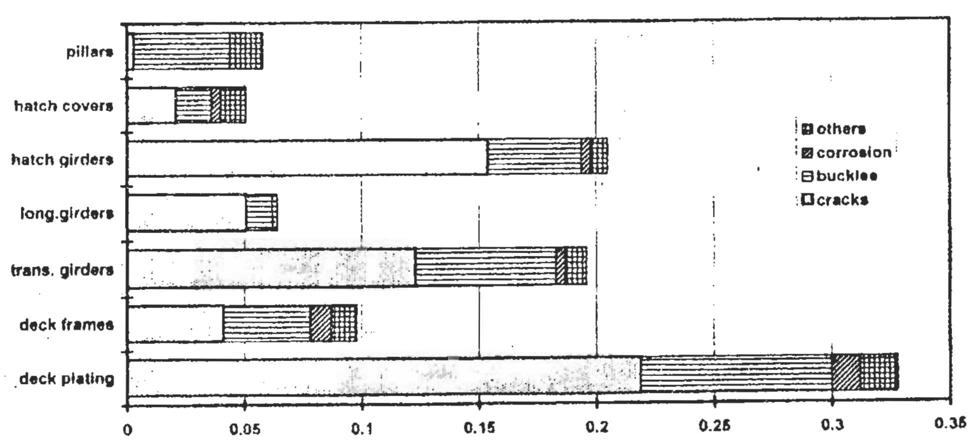

Figure 14. Failures of deck structure.

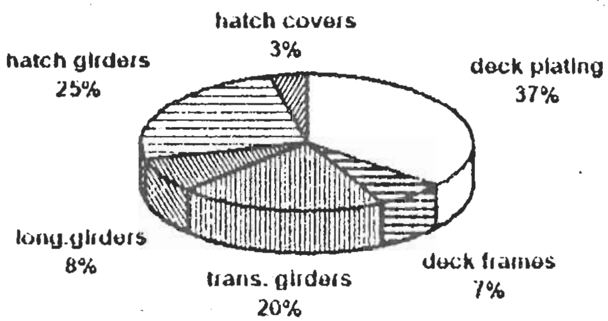

Figure 15. Cracks in deck and hatches.

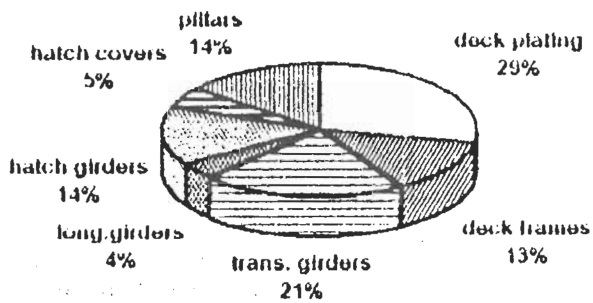

Figure 16. Buckling failures of deck structures.

It is clear from Table (1) that cracks and buckling are the most common modes of failure of deck plating and hatch covers. Figure (17) shows the distribution of fractures in the bulwark and rails along ship length . It is clear that the highest rates of fractures occur in the mid ship region. Figure (18) shows the distribution of fractures over the depth of the ship. The key to the letters are as follows :

A = superstructures
B = bulwark and rails
C = upper deck
D = tween deck
E = side shell and frames
F = inner bottom
G = bottom and bilge

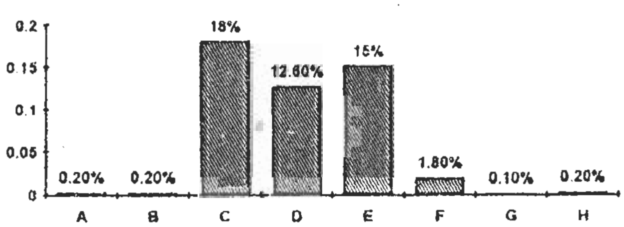

Figure 17. Long distribution of fractures over the bulwark & rails.

It is clear from Figure (18) that the upper deck, bulwark and rails are highly susceptible to fractures. Figure (19) shows the distribution of the different modes of failure of the side shell plating. It is clear that the side shell plating is very vulnerable to cracks and buckling. Figure (20). shows the different modes of failure of ship side frames. Crack failures of side frames represent 62% of all modes of failure.

For transversely framed ships, severe buckling of bottom plating within the midship region may result from the induced high values of compressive stresses resulting from the combined effects of stillwater and wave induced hogging moments. This can seriously impair hull girder and local strength of the midship section. A limited amount of buckling of tank top plating, however, may be acceptable in areas subjected to moderate compressive stresses. Buckling of floors or girders is an indication of structural weaknesses of these elements. Plate panels could also buckle under high shear and moderate compressive forces, particularly in ship areas subjected to high shear stresses.

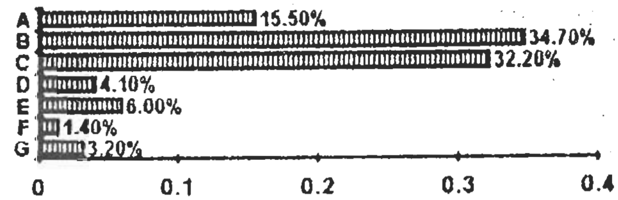

Figure 18. Vertical distribution of fractures.

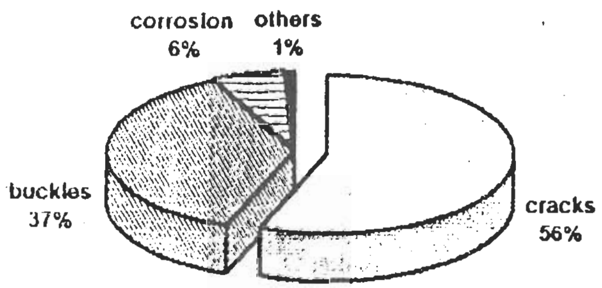

Figure 19. Failures of side shell plating.

Local buckling of plating may result from:

i- high compressive stresses
ii- high shear stresses
iii- lack of adequate stiffness or adequate stiffening
iv- the extensive and improper use of H.T.S.

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

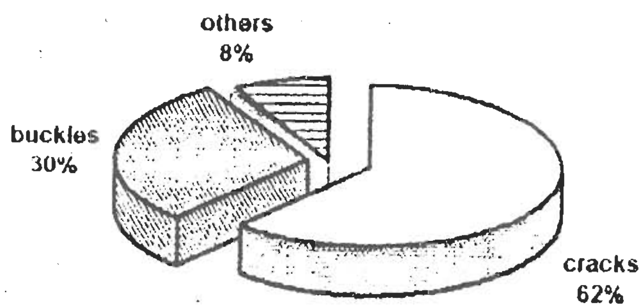

Figure 20. Failures of side frames.

ii- Structural Failures of Oil Tankers

Hull structural failures and fractures in oil tankers are generally attributed to local failures of structural details in areas of high stress concentration particularly at bracket toes and longitudinal connections to transverse web frames. The initiation and propagation of these local failures may subsequently cause major structural failures. It is evident that major structural failures of oil tankers could, in many cases, be responsible for oil pollution hazards .The design and construction of these local structural details, therefore, should receive utmost attention in order to prevent / reduce minor / major structural failures and their subsequent risk of pollution hazards.

Impact Of Poor Design, Construction And Fabrication Of Ship Structural Details On Ship Structural Damages And Failures

The annual cost of repairs of structural damages and failures depends a great deal on the quality of design, construction and fabrication of ship structural details. These structural details are, in general, very sensitive to geometrical and scantling variabilities, poor fabrication, construction and welding.

Figure (21) shows the distribution of cracks along the ship length of oil tankers. It is clear from Figure (21) that the midship part is subjected to about 87% of all the crack failures. Figure (22) shows the distribution of cracks over the main structural elements of the midship section. It is clear from Figure (22) that most of the cracks occur in the horizontal stringers and transverse bulkhead plating. In order to assess the causes of damages and failures of the different structural elements of any ship type, it is necessary to identify the type and direction of loading, areas of stress concentration, etc. Unacceptable high stresses may be induced in a badly designed structural detail subjected to the combined effects of tensile, compressive and shear forces, or even under pure shear loading. Fractures usually start in a localised, highly stressed area. Unstable fracture is the failure mechanism which appears suddenly and unexpectedly and can result in the most serious consequences. Safety against unstable fractures is closely related to material properties, especially in the weld zone.

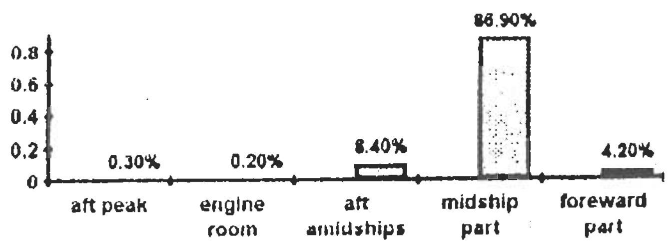

Figure 21. Distribution of cracks along the length of an oil tanker.

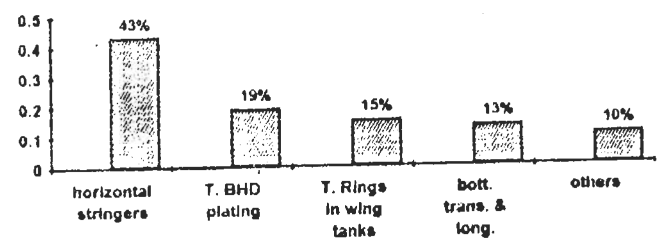

Figure 22. Cracks in oil tankers.

Fractures and cracks in local structural details and connections may result from:

i- inadequate bracket size

ii hard spots

iii- high stress concentration
iv- bad stress distribution

Poor design, construction and fabrication of ship structural details reduce their structural capability and reliability considerably by virtue of the high stress gradients, high stress concentration, notches, hard spots, etc. Figure (23) shows the composition of the total stress at any point in a ship's structure. The deficiency of strength of these structural details may induce serious consequences with regard to major structural failures. Improving design of these structural details should aim at reducing stress concentration factors in the highly stressed areas. It is evident that improving the design, construction and fabrication of these local structural details may allow stress levels to be raised for neighbering structural elements without affecting the overall capability and structural reliability of the ship hull girder. This will evidently lead to saving in ship overall weight and cost.

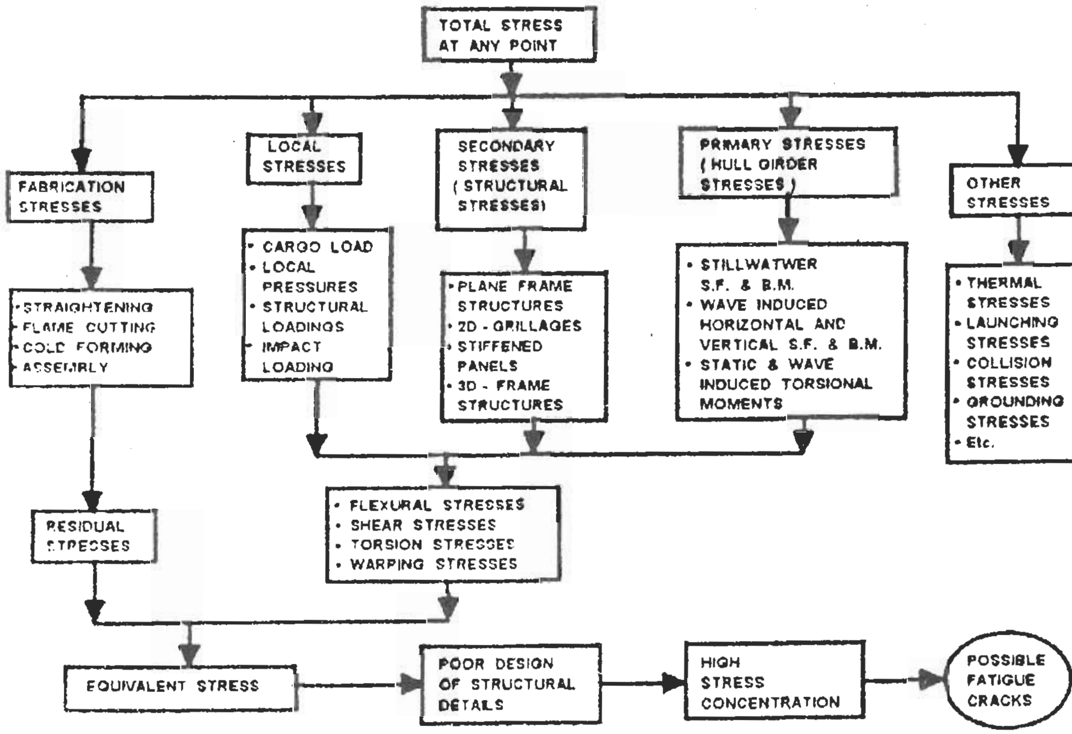

Figure 23. Total stress at any point.

It is therefore evident that small cracks and failures that may not immediately threaten ship structural safety, may subsequently cause serious economical and pollution problems. 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.

It is clear that the main types of structural defects affecting the strength of local structural details and subsequently the strength of ship hull girder are, see Figure (24):

- crack initiation, fatigue cracks
- weld failures
- buckling
- localised material deterioration
- corrosion
- excessive deformations, etc.

The most probable consequences of the presence of these structural defects are :

- increased size of defect
- crack propagation
- buckling failure
- reduction in thicknesses due to accelerated corrosion and deterioration of material

- deficient load carrying capacity, etc.

In order to eliminate or reduce the main causes of these local structural failures, it is necessary to improve the design and construction of ship structural details. Reference (15) gives examples of some of the common ship structural details with suggestions of possible design and construction improvements to prevent local failures.

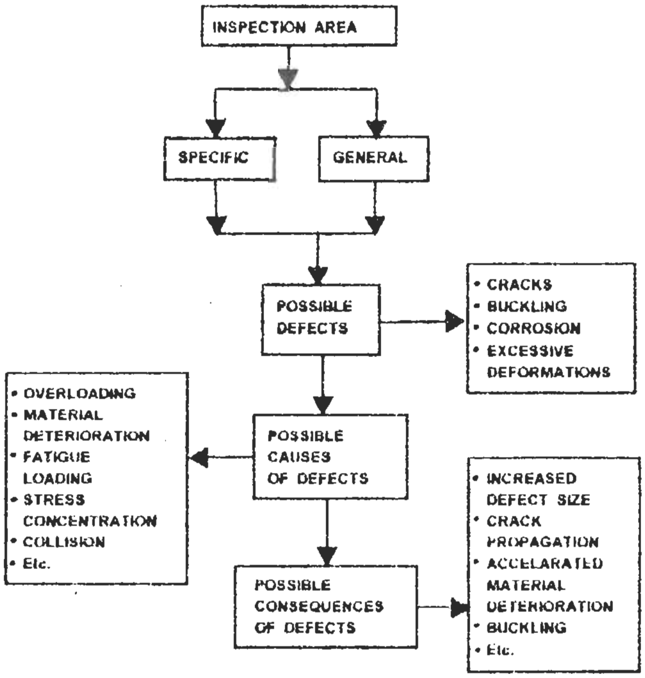

Figure 24. Structural defects; types, causes and consequences.

CONCLUSIONS

Ship structural failures,minor or major, represent one of the main indirect causes of marine pollution. For oil tankers, chemical carriers, gas carriers, etc. the hazards of marine pollution resulting from a major structural failure could be very extensive because of the nature of the cargo. For cargo ships, service crafts, etc., the impact of minor or major structural failures on the marine environment could be, in general, of limited nature as the cause of pollution hazard will be due to the fuel oil, lub. oil, etc remaining on board the ship.

Ship structural failures result mainly from poor design of structural details and human errors in design, material, fabrication, inspection, maintenance and repair. Poor design of structural details represent, in most cases, the main cause of the initiation of fatigue cracks, which when propagated may cause major structural failures.

Human errors may cause several types of structural defects, mainly ; initiation of cracks, buckling of plating, general or local corrosion or excessive deformations. The initiation 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 to serious structural failures.

It is evident that pollution hazards resulting from ship structural failures could be significantly reduced by:

- Eliminating human errors in design, inspection, maintenance and repair work. This could be partly achieved by continuous training and upgrading of engineers working in these specified fields and partly by using sophisticated methods of ship structural design.
- eliminating errors in material by proper specifications and inspections of the materials.
- improving design of ship structural details
- prevention of corrosion and material deterioration by using appropriate methods of material preparation before painting and using proper types and methods of corrosion prevention.
- reducing high residual stresses and distortions due to fabrication and assembly processes.
- prevention of overloading of ship structures by preventing ship operational errors. This could be achieved by continuous training and upgrading of crew and also by monitoring dynamic stresses.

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