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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%)

5- "Technical Evaluation of Transport- Related GHG Abatement Techniques", AEJ, April. (Egypt-1995), Shama, M. A., and Hassan, A. (50%)

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%)

9- "The problem of corrosion of ship structures", MARINES 96, Second Conference, Cairo, October, (Egypt-1996), Shama, M. A., (100%)

10- "Impact on Marine Environment of Ship Structural Failures and Casualties", AEJ, Jan., (Egypt-1997), Shama, M. A., (100%)

11- "Energy and Env. in Eng. Education", AEJ, Vol.36. (Egypt-1997), Shama, M. A. (100%)

12- "Energy and Environment Dimension in Ship Manufacturing Processes", PRAD's 2001, Sept., 8th Int. Conf. on Practical Design of Ships and other Floating Structures, (China-2001). Shama, M. A., (100%)

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

14- "Life Cycle Assessment of Ships", IMAM 05, Sept. International Maritime Association of Mediterranean Sea, (Portugal-2005), Shama, M. A. (100%)

15- "Environmental Dimension in the Ship's Life Cycle", MARDACON 9, December, Int. Con. "Towards a Cleaner and Safer Maritime Context", (Egypt-2005), Shama, M. A. (100%)

The Problem of Corrosion of Ship Structures

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Paper presented to the Second Conference, **Marines 1996,** *Cairo, October. 1996*

Summary

The main environmental and operational factors affecting the initiation, spreading and rate of corrosion of ship structures are given. The main problems of general and local corrosion of cargo ships, bulk carriers and oil tankers are briefly discussed. The methods commonly used to control and prevent the initiation and spreading of corrosion are briefly indicated. The consequences of corrosion associated with degradation of ship structural strength are stressed. The effect of material deterioration due to corrosion on the buckling strength and stiffness of a plate panel is investigated. The effect of uniform corrosion on the section modulus and inertia of stiffeners are presented. The impact of material wastage due to corrosion of the deck structure on the ship section geometrical characteristics is clarified. The effect of corrosion on the magnitude of the factor of safety is examined. Structural degradation problems associated with the corrosion of HTS are clarified. It is shown that the buckling strength and the flexural rigidity of a panel of plating could be significantly reduced when the plate panel experiences the normal rates of wastage due to corrosion. The deterioration of the geometrical characteristics of stiffeners could vary between 15% and 38% depending on the section configuration. The deterioration of ship section modulus and inertia could be significant for the normal rates of corrosion of the deck structure.

Introduction:

Corrosion is the most common defect in steel vessels, see Fig.(1), and is the dominant cause of structural failures for ships older than 8 years. Corrosion of ship structures result mainly from: age, inadequate maintenance, chemical or corrosive action of cargoes, local wear of steel plating and sections, etc. A corroded steel plate is not only thinner but more brittle and is thus more prone to the initiation and propagation of fatigue cracks. High stress concentration induces microscopic cracks in the highly stressed parts of the steel structure. These cracks propagate also into the coating and act as pockets where corrosion action begins. Local pitting can cause serious thinning of plates and sections at critical highly stressed areas. The cause of local pitting could be water condensation, lack of proper cathodic protection, material defects, faulty preparation and treatment of the material before painting, etc. The deterioration of a HTS plate due to general or pitting corrosion will be more significant than a mild steel plate having the same strength. Therefore, ships with greater use of HTS will experience serious problems of degradation of buckling and fatigue strength. This will certainly impair the expected service life of the vessel. Higher values of wastage of material may be accepted in certain areas for ships built to scantlings higher than those required by classification societies. This increased scantlings are often used by owners to account for loss of material due to corrosion and also to minimise the amount of material replacement required throughout the life of the ship.

The paper, therefore, addresses the corrosion problem of ship structures with particular emphasis on the impact of material wastage due to corrosion on the strength and stiffness of stiffeners, plate panels and the geometrical characteristics of ship sections.

Factors Affecting Corrosion and Rate of Corrosion
Corrosion of ship structures represent one of the main causes of structural failures (1,2,3) and is generally affected by the following factors: design parameters, fabrication parameters, protective coating parameters, operational parameters, maintenance and repair parameters, environmental parameters
The main environmental factors influencing the initiation of corrosion are: salinity of the sea water, temperature, pollution, marine fouling, humidity, presence of oxygen, etc.
The main operational factors participating in the initiation and spreading of corrosion are: type of cargo, cargo residues, mechanical abrasion, frequency of tank washing, presence of stray current, coating failure, etc. The main causes of coating failure are numerous, among them are: poor coatingpecifications, poor penetration resistance of the surface, low coating thickness, painting on moist surface, contamination between coats, insufficient curing time, poor handling of coated surfaces, high stress concentration, etc.
The rate of corrosion of ship structures varies with ships age, among ship types, over the same ship from one area to another, between bottom, vertical and top areas. Bottom plating and horizontal areas suffer general and local corrosion whereas top areas suffer general corrosion.
Corrosion occurs at a rate independent of plate thickness. There are several factors affecting the rate of corrosion such as: treatment of the steel before painting, effectiveness of the corrosion control system, condition of coating, orientation of the surface, type of cargo carried, presence of sulphur, characteristics of the environment, presence of water, frequency and extent of inspection and maintenance, etc. Corrosion rates could be significantly reduced by controlling the main factors causing corrosion. Good flexible coatings could be very useful against stress-induced corrosion. Inert gas systems are effective in reducing the rate of corrosion in tankers. Cathodic protection, based on sacrificial or impressed current system is also used as a reliable and cost-effective measure against corrosion of steel ships.The proper specifications of coatings in the building stage may represent a crucial factor for reducing corrosion and rate of corrosion of hull structure.

Consequences of Corrosion
Deficient hull girder and local strength may result from errors in design, material, fabrication and operation (1). The main factor causing strength deficiency is corrosion.. The impact of corrosion on structural strength and stiffness of ship hull girder and local structural members are: reduction of local and hull girder scantlings, increase of local and hull girder stresses, reduction of hull girder and local load carrying capacity, increase of local stress concentration, reduction of hull girder and local safety factors, significant reduction of fatigue strength of structural connections, reduction of local and hull girder flexural rigidity and buckling strength. These structural deficiencies have a pronounced deleterious effect on ships service life, maintenance and repair costs (4,5). The effect of the quality of maintenance on the rate of strength deterioration is shown in Fig.(2). Curve "A" indicates a cost-effective maintenance system. Curve "B" indicates an effective but costly maintenance system. Curve "C" indicates an inadequate maintenance system that will cause excessive structural deterioration and frequent structural failures (6). Fig. (3) shows the effect of corrosion on the shape of the S-N curve. It is clear that uncontrolled corrosion of ship structure could lead to a significant reduction of the fatigue strength (7,8) .

Effect of Corrosion on the Strength of General Cargo Ships
Corrosion of general cargo ships occurs at several places such as the deck structure, the lower part of the holds or twin deck frames, the lower part of transverse bulkheads, aft end of double bottom tanks and certain areas of tank tops where water is trapped due to ineffective drainage system. Transverse

bulkheads between cargo holds experience excessive corrosion in the lower boundaries and in way of bilge wells. High wastage occurs in ballast tanks and in inaccessible structural areas where inspection and maintenance are difficult such as the top parts of transverse bulkheads. Ease of access to the various parts of cargo and ballast tanks is necessary if efficient inspection, maintenance and monitoring system is required.

Deck plating comprises a highly stressed portion of the ship hull girder and is of critical importance to the longitudinal strength of the vessel. Corrosion of the deck structure is expected to occur because of the frequent deck washing, water condensations, local deck deformations, mechanical abuse from deck cargo, etc. Fig. (4) shows the distribution of corrosion failures among the different structural elements of the deck structure. The geometrical characteristics of stiffeners, frames, girders, etc. could be reduced significantly with the normal rates of material wastage. The reduction of the section modulus and second moment of area could vary between 15% and 38% depending on the section configuration. Fig.(5) shows that the section modulus and inertia of an angle section 200x100x13 mm could be reduced by more than 25% for normal values of material wastage. Accelerated corrosion of the deck structure may aggravate the consequences of these modes of failure. The reduction of ship section geometrical characteristics due to material wastage of deck structure due to corrosion is shown in Fig.(6). It is shown that a 30% reduction in the sectional area of the deck plating, due to corrosion, could cause a 15% reduction in ship section modulus.

Bottom plating sustains a major portion of the hull bending moment in addition to the local loads induced by hydrostatic and hydrodynamic pressures. Its strength may be reduced significantly by general and localized corrosion (9). Fig.(7) shows the distribution of structural failure due to corrosion among the bottom structural elements. The severe corrosion of the bottom plating can seriously impair hull girder and local strength of the midship section.

Effect of Corrosion on the Strength of Bulk Carriers

Structural failures of bulk carriers due to corrosion have been recognized and reported in several papers (10). The strakes of side shell plating between wind and water are highly susceptible to severe uniform corrosion and localized pitting. This area is generally subjected to high values of shear stresses (11,12) particularly at about 0.3L and 0.7L from A.P. High material wastage of these areas could have an adverse effect on the shear buckling strength of the side shell plating, particularly for HTS. Hopper, top side and double bottom tanks, ballast holds and void spaces, etc. are subjected to excessive material wastage by corrosion. The tops of transverse bulkheads and the underside of the deck structure are also subjected to severe corrosion. The corrosion of these structural parts cause severe deterioration of local and hull girder load carrying capacity. The corrosion of top wing tanks is responsible for many structural failures that caused several total ship loss, with possible damage to the environment if the cargo is of the dangerous or poisonous type.

Effect of Corrosion on the Strength of Oil Tankers

The rate of corrosion of oil tankers is significantly influenced by the following main factors: tank washing, tank contents, tank atmosphere when empty, presence of inert gas, etc. All parts of ballast tanks and transverse bulkheads between cargo tanks and ballast tanks are subjected to severe corrosion. Lower and top strakes of transverse and longitudinal bulkheads are generally subjected to excessive corrosion. Deterioration of deck longitudinals by corrosion may be more rapid and extensive than that of deck plating. The wastage may reach 50% in some parts. Fig.(8) shows an example of corrosion in a deck longitudinal and a proposed method for reinforcement. Corrosion of double hull tankers can be extensive in ballast tank spaces as inspection can be difficult and times consuming compared with single hull tankers. Design of double hull tankers, therefor, should provide adequate facilities for inspection and maintenance operations such as additional horizontal members in wing tanks and adequate ventilation.

Hull fractures and failures in oil tankers are generally attributed to detail design aspects in areas of stress concentration particularly at bracket toes and longitudinal connections to transverse web frames (1,13,14). The stress concentration factors at these connections are relatively high and

could represent a serious hazard when material wastage due to corrosion reaches high values, see Fig.(9).
The use of HTS allows lighter scantlings and results in a more flexible structure. Greater flexibility of primary structure results in more load being shed to secondary structures. In this case, the strength of the ship is more dependent on the integrity of the structure as a whole. Excessive flexibility may also lead to fatigue problems at design details. HTS structures exposed to stress cycling at higher stress levels will have a shorter fatigue life than the equivalent mild steel structure. Therefore, the deterioration of strength due to corrosion is far more significant for HTS than for mild steel. The increased flexibility of ship structures due to the extensive use of HTS or due to the improper distribution of material over the ship section may cause local breakdown of protective coatings and initiation of corrosion. The effect of material wastage for a panel of plating on the flexural rigidity is shown in Fig.(10) for three different plate thicknesses. It is clear from Fig.(10) that the flexural rigidity could be significantly reduced when a plate panel experiences the normal wastage due to corrosion.

Effect of corrosion on the factor of safety for buckling

The deterioration of ship structural elements due to corrosion will have direct impacts on the load carrying capacity, the critical buckling strength, fatigue strength, the factor of safety and the probability of structural failure. The variation of the critical buckling strength with time for a panel of plating is shown in Fig.(11), for an assumed parabolic model for the material wastage due to corrosion. It is shown that the critical buckling strength could be reduced by more than 30% when the thickness of the plate panel experiences the normal wastage due to corrosion. Fig (12) shows the variation with material wastage of the factor of safety and the critical buckling strength for a panel of plating subjected to compressive stresses. It is shown that the factor of safety for flexural buckling reduces by about 30% for the normal rate of wastage by corrosion. Fig.(13) shows the increase with time of the probability of failure "Pf" for fatigue and buckling strength of a ship structural member subjected to the normal rates of corrosion.

Conclusions

The main conclusions drawn up from this investigation are:

1-A good inspection, maintenance and monitoring system for assessing and protecting hull structures from corrosion represent a main factor for reducing rate of corrosion, strength deficiencies and subsequently extending ships life.

2-High quality surface preparation and protective coatings have significant effects on reducing the rates of corrosion.

3-The geometrical characteristics of ship sections , the buckling strength and the flexural rigidity of plating panels could be seriously reduced by the normal wastage due to corrosion.

4-The deterioration of the section modulus of frames, longitudinals, girders, stiffeners, etc. varies between 15% and 38% depending on the section configuration.

5-In order to prevent / reduce the initiation of pitting corrosion, it is necessary to eliminate any critical defects prior to service and to prevent non-critical defects to grow to critical size during service.

6-The increased flexibility of ship structures due to the extensive use of HTS or due to the improper distribution of material over the ship section may cause local breakdown of protective coatings with subsequent initiation of corrosion.

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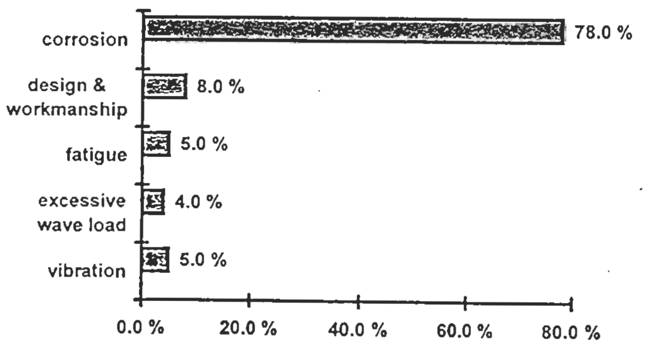


Fig.(1). Main Factors Affecting Hull Structural Failure

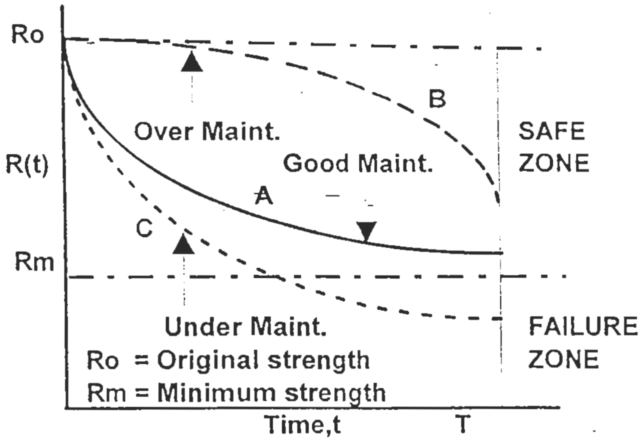


Fig.(2). Variation Of R(t) With Time

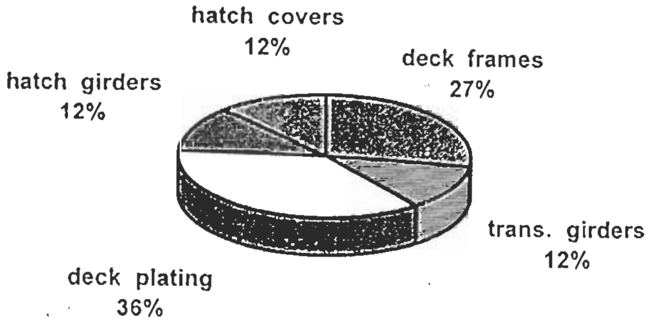
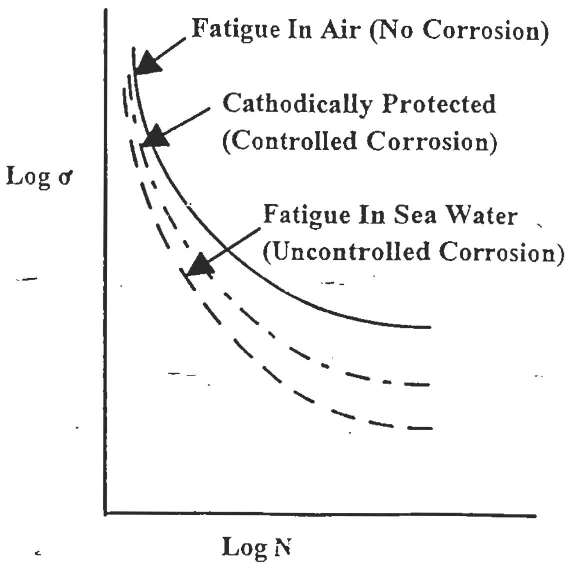


Fig.(4).Corrosion Failureof Deck Structure



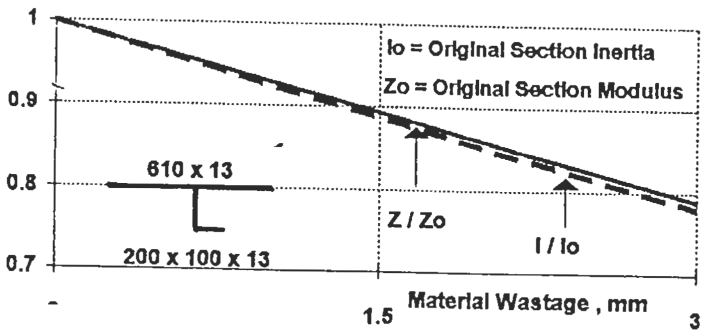


Fig.(5). Effect Of Material Wastage On Z/Zo and I/Io

Fig. (3). Effect Of Corrosion On Fatigue Curve

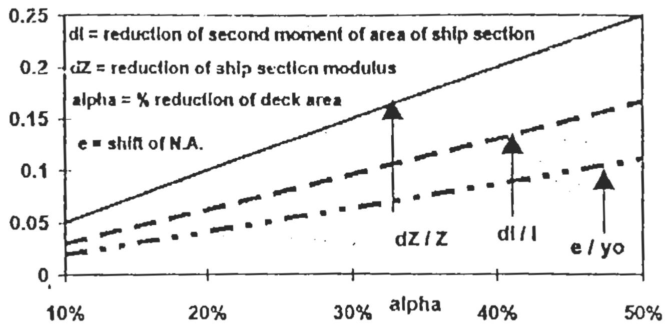


Fig.(6). Variation Of Ship Section Characteristics With Deck Deterioration

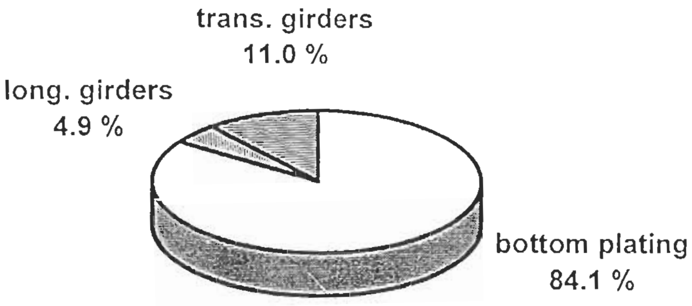


Fig.(7).Failure of Bottom Structure Due to Corrosion

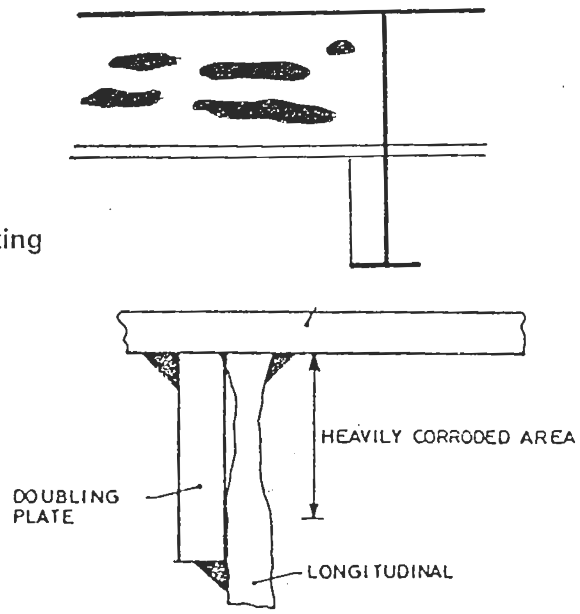


Fig.(8).Severe Corrosion of a Deck Longitudinal

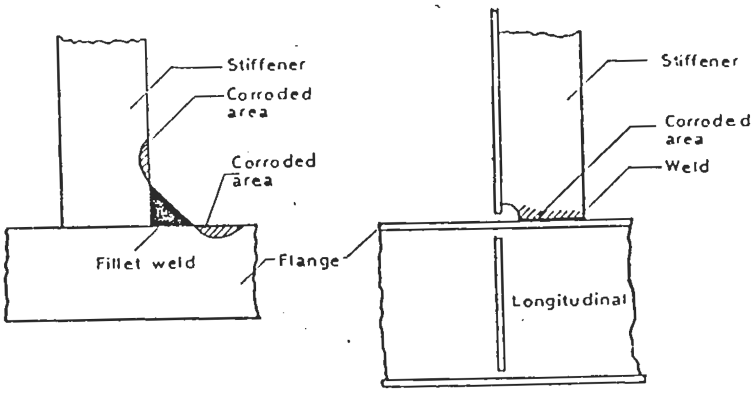


Fig.(9).Corroded Areas in a Stiffener - Longitudinal Connection

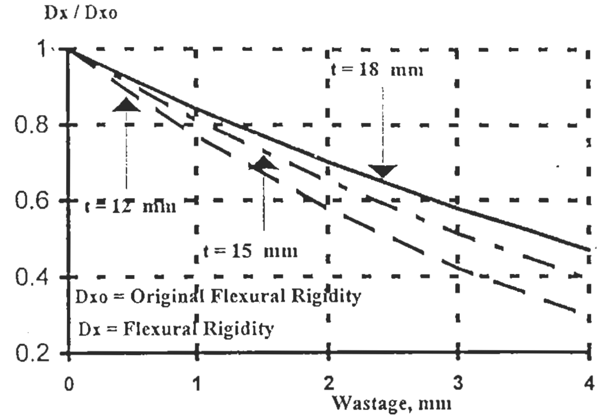


Fig.(10). Effect Of Plating Wastage On Flexural Rigidity

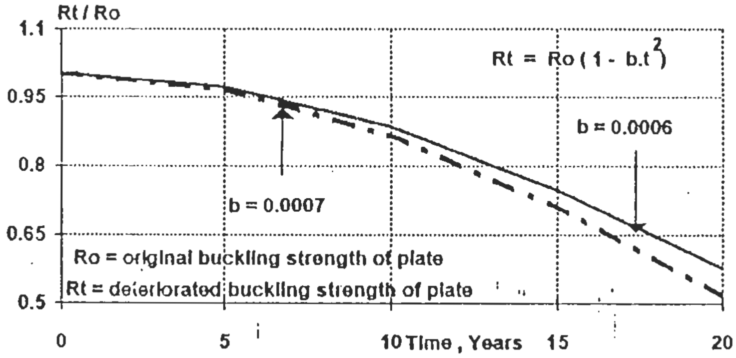


Fig.(11).Variation of Buckling Strength with Time, Parabolic Model

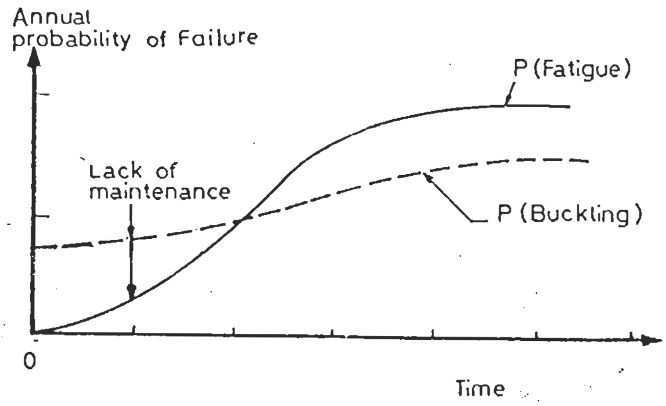


Fig.(13).Variation of Pf with Time

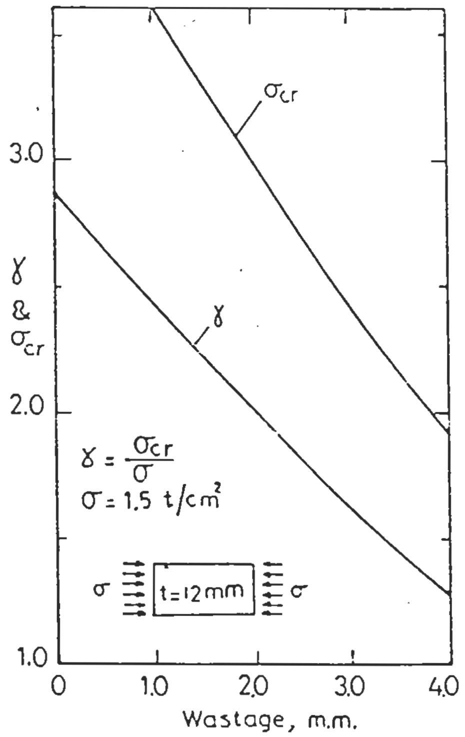


Fig.(12).Variation of γ & σcr with Wastage in mm