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Fatigue life estimation of ship structure

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Abstract- This paper deals with the estimation of fatigue life of a ship structure based on International Association of Classification Society's(IACS) recommendations. The structural analysis of ship structure is carried out using ANSYS software and the fatigue life has been estimated.

Index terms- cumulative fatigue damage, design life, fatigue life of ship structure, finite element method, fracture mechanics, hot spot stress, shell 93

1. INTRODUCTION

SHIPS are large complex vehicles which are durable in their environment for long periods with a high degree of reliability. A ship is constructed primarily as a network of welded cross-stiffened plates, referred as "grillage" . The plating is stiffened by steel sections such as flat bars, inverted Tees etc. The ship structure in general may be longitudinally stiffened or transversely stiffened with stiffners and bulkheads. Steel for hull construction is usually mild steel containing 0.15 to 0.23 per cent carbon, and a reasonably high manganese content. Both sulphur and phosphorus in the mild steel are kept to a minimum (less than 0.05 per cent). In its entire life this complex structure will be submitted to distinguished load conditions beginning with the ship launching and continuing with each sailing and interval docking for survey and repair.

Fatigue of structural components in ships is a long known problem and has been investigated in depth owing to its relevance in design. Fatigue occurs due to inevitable microscopic damage accumulation in material due to cyclic loading mainly the wave loads so that after certain amount of time or stress reversal structural failure occurs. This may lead to problems that vary in scale from unwanted and costly repairs to a large crack propagation that endangers entire structure. Inspite of the significant scientific effort involved in understanding fatigue phenomena, fatigue failure is still a significant problem to be tackled completely from the designer point of view.

According to Hughes O F & Paik J K [1], the factors which contribute to the fatigue of ship structure are the local configuration and geometry of weld details which produce a local increase in stress , weld material defects and internal discontinuities such as under cuts, porosity, slag inclusions, lack of fusion or penetration etc.; bad workmanship including such problems as misalignment, angular distorsion and insufficient quality of welding which introduces additional stress concentrations, use of higher tensile steels and cyclic loads especially wave induced loads. Environment assisted fatigue is a subject of special attention because the marine environment is highly corrosive.

The aim of fatigue assessment is to ensure that all parts of the hull structure subjected to static and dynamic loading have an adequate fatigue life. To ensure that the structure will fulfill its intended function till the predicted design life a fatigue assessment has to be carried out for each individual type of structural detail which is subjected to extensive dynamic loading. The calculated fatigue life provides a true life span of the components or the entire structure. Fatigue life estimation of a three compartment hull model is envisaged in the present study.

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2. FATIGUE ANALYSIS OF SHIP STRUCTURE

2.1 Fatigue life prediction methods

Fatigue life of structures are predicted using the S-N curve approach based on strength of material concept and the fracture mechanics approach. The former is based on strength of material assumptions such as linear isotropic flawfree material whereas the later is based on the fact that the material is with defects and likely to allow crack initiation and development.

The Fracture mechaics approach commonly makes use of Paris law and Erdogan fatigue crack propagation law. The later assumes a power relationship between the crack growth rate da/dn and the stress intensity range, ΔK. A robust fatigue life assessment is based on proper calculation of ΔK. The fracture based fatigue prediction has been adopted to ship structural design by ISSC ,2009 [2]

2.2 FE model for fatigue life estimation

As per IACS [3] recommendations for bulk carrier, the finite element model is normally to cover the considered tank/hold, and in addition one tank/hold outside each end of the considered tank/hold ie. the model extent is a three cargo hold of a bulk carrier. The boundary conditions to be applied to the model are Both ends of the model are to be simply supported, The nodes on the longitudinal members at both end sections are to be rigidly linked to independent points at the neutral axis on the centreline and the independent points of both ends are to be fixed. The boundary conditions are shown in Table 1 and Table 2.

TABLE 1
BOUNDARY CONDITIONS-RIGID LINKS OF BOTH ENDS FOR FE MODEL

Nodes on longitudinal members at both ends of the model	Translational			Rotational		
	D_x	D_y	D_z	R_x	R_y	R_z
All longitudinal members	RL	RL	RL			
RL – rigidly linked						

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TABLE 2
BOUNDARY CONDITIONS-SUPPORT CONDITION OF THE INDEPENDENT POINT FOR FE MODEL

Location of the independent point	Translational			Rotational		
	D_x	D_y	D_z	R_x	R_y	R_z
Independent point on aft end of the model	Fix	Fix	-	-	-	Fix
Independent point on fore end of model	Fix	Fix	Fix			Fix

3. FINITE ELEMENT ANALYSIS

3.1 Description of structure

Structural scantlings of the ship have been designed in accordance with the provisions of Rules and Regulations for the Classification of Ships of Lloyds Register of Shipping [4]. The ship has a design life of 25 years. The ship parameters used in the design are given in the following Table 3.

TABLE 3
SHIP PARAMETERS

L_{BP}	B_{mld}	D_h	C_B
147m	21m	13m	0.81

L_{BP} is the length between perpendiculars, B_{mld} is the moulded breadth, D_h is the depth of the ship and C_B is the block co-efficient

Scantlings of the cargo hold model is shown in Fig.1. The model consists of three cargo holds with dimension 24m × 21m × 13m. The structural members considered for this model are the longitudinal stiffeners of double bottom and deck plate, longitudinal girders, inner bottom and outer bottom plating, transverse floors, web frames, deck plate, side plate, bulkhead and bulkhead stiffeners. The model has 12314 elements and 49063 nodes.

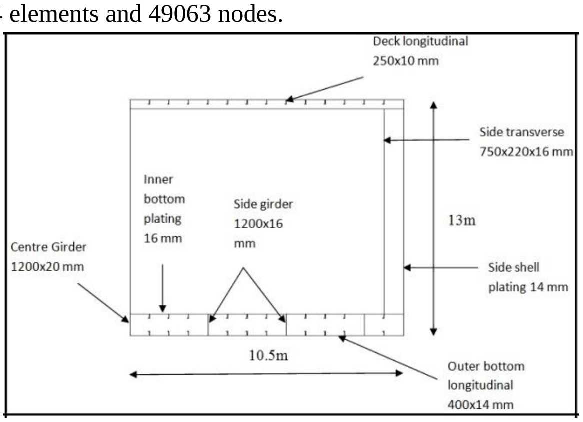

Fig.1 Cross section of cargo hold model (half model)

3.2 Description of software and finite element

The software used for analysis is ANSYS. It offers a comprehensive range of engineering simulation solution sets providing access to virtually any field of engineering simulation that a design process requires. The element type used for this model is shell93 which has 8 nodes and having six degrees of freedom at each node. The thickness and material properties of the element has to be specified and the final output will be nodal displacements and stresses

3.3 Description of FE model

Hot spot stresses for fatigue assessment are to be obtained by the global cargo hold models where the areas for fatigue assessment are modeled by very fine meshes.. All structural members are modeled by shell93 and FE model is shown in Fig.2.

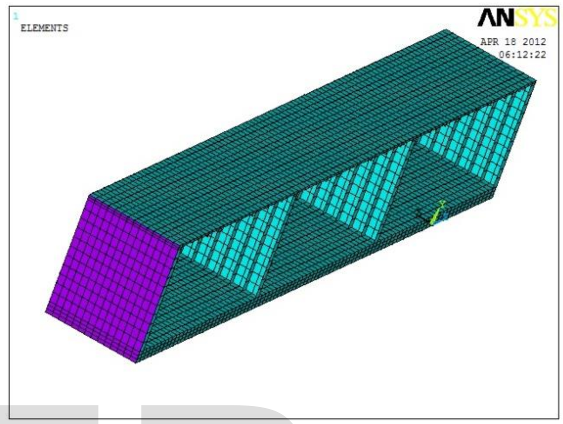

Fig.2 FE model

3.4 Load cases

The load applied for the analysis is the wave bending moment and the loading conditions are full load conditions and ballast conditions. For the present analysis unit bending moment has been applied at midship section.

3.5 Linear elastic analysis

Linear elastic analysis is carried out with the boundary conditions explained in the Table 1 and Table 2 and the load as unit bending moment on all the nodes of the midsection of the FE model. The modulus of elasticity and Poisson's ratio for the ship building grade steel is 2.1×10^{11} N/m^2 and 0.3 respectively.

Deformed shape and longitudinal stress are shown in the Fig.3 and Fig.4 respectively. The maximum value of stress is acting on the deck structure and is at the mid section of the model.

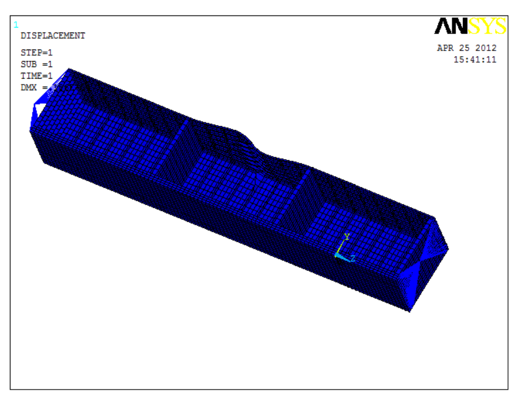

Fig.3 Deformed shape

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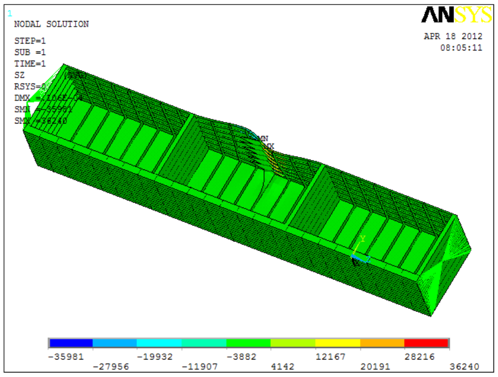

Fig.4 Longitudinal stress

4 FATIGUE LIFE CALCULATION

Fatigue strength is assessed based on an equivalent notch stress range obtained by multiplying an equivalent hot spot stress range by a fatigue notch factor. The hot spot stress range corresponding to the predominant load case for each loading conditions are calculated and used to calculate the equivalent hot spot stress range.The fatigue life calculation procedure given in IACS,2010[3] has been given as follows

The predominant load case 'I' in fatigue assessment for each loading condition is the load case for which the combined stress range for the considered member is the maximum among the load cases 'H', 'F', 'R' and 'P'.

$\Delta\sigma_{W,\ I(k)} = \max_i (\Delta\sigma_{W,\ i(k)})$ (1)

Where $\Delta\sigma_{W,\ i(k)}$ is the combined hot spot stress range, in N/mm^2 and I is the suffix which denotes the selected predominant load case of loading condition'k'

Hot spot stress range

The hot spot stress range in N/mm^2, in load case 'i of loading condition 'k' is obtained from the following formula

$\Delta\sigma_{W,\ i(k)} = |\Delta\sigma_{W,\ i1(k)} - \Delta\sigma_{W,\ i2(k)}|$ (2)

Where $\Delta\sigma_{W,\ i1(k)}$, $\Delta\sigma_{W,\ i2(k)}$ are the hot spot stress in N/mm^2 in load case 'i1' and 'i2' of loading condition 'k', obtained by direct FEM analysis using fine mesh model.

From the hot spot stress range, equivalent hot spot stress range is calculated using the formula given in [2.3.2] and equivalent notch stress is calculated based on the formula given in [2.3.1] of Ch.8,Sec.2, IACS,2010 [3]. Correction of equivalent stress range is carried out based on [3.1.1]. Finally cumulative damage ratio is found out based on [4.1.1], Ch.8, Sec.2, IACS, 2010 and also the fatigue life is estimated subsequently.

Cumulative fatigue damage

The cumulative fatigue damage, D is calculated for the combined equivalent stress based on the formula given in [3.3.1] of Ch.8, Sec.2, IACS, 2010 [3]

The expected fatigue life, in years, is given by

Fatigue life = Design life / D (3)

Fatigue life estimation

For the problem studied herein the hot spot stress obtained for the ship structure is 210.5 Mpa and cumulative fatigue damage (D) is 0.81. Fatigue life corresponding to a design life of 25 years has been estimated as 31 years.

5 CONCLUSION

Linear static analysis of the three cargo hold model of ship structure has been carried out and the maximum hot spot stress is found out. The fatigue life has been estimated for a unit bending moment at midship section.

6 REFERENCES

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