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Hydro-Elastic Analysis of Marine Components Using MATLAB and Finite Element Analysis Techniques

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ABSTRACT

Balancing of the component is of main concern over the water surface and if it is controlled it is safer than travelling in airplanes where main the objective is higher speeds than carrying higher loads. In the present work, the analysis of a marine component (ship's hull) has been performed in order to facilitate the design of hull because its design plays a key role for the safe voyage of a ship. The uniqueness of this design is that does not involve complex geometries. First of all, a hull has been created using AutoCAD and Solid Edge. It was then analyzed assuming different loading condition like pressure and bending effects due to the ocean waves. Various possible movements i.e. rolling, yawing, pitching, heaving, slamming etc. of the hull in the marine environment have been mathematically formulated and then a detailed finite element analysis of resulting pressures and inertia forces due to the motion has been studied. As a result, the safe bending, shearing and normal stresses and strains were calculated by using Auto-FEM software. The importance of this work is that the method of analysis can be applied and extended to other marine components undergoing the same type of loading conditions.
Keywords: hull, bending, marine, analysis, roll.

Introduction

The work is related to the bending effect analysis of large length ships and marine structures when they pass over crests and troughs of sea waves. A hull is the main part of a ship and its bending depending upon the amplitude of the sea waves affects its safe performance and roll motion in particular which affects its metacenter. S. Parsons [1] provides a comprehensive literature about ships geometry and stability. SY Hong [2] provides hydrodynamic analysis of ships side by side in waves. S. Alimrazadeh [3] provides the analysis of a 3600 TEU container ship and its propeller using ANSYS. Matutat [4] has carried out numerical modeling and simulations of ship hull geometries with an objective to optimize the whole system (i.e. ship hull and V.S.P-Void Schneider Propeller) with respect to different target functions. Moreover, their results showed that with an increase in a number of mesh cells (i.e. a more refined mesh); more accurate predicted values can be obtained which are closer to the mathematical values.

Richard W. Garman [5] has studied the heat transfer analysis through a ship's hulls by mapping the hull geometries as the horizontal and vertical plates and strips dipped in water, with the help of ANSYS®. The results for both the forced convection and natural convection were found to be precisely comparable with the theory of heat transfer. Senjanovic [6] used the numerical procedure for the analysis of a ship. The modeling techniques formulated by the author consisted of structural models by employing the modal superposition method, determining the ship natural modes for a sophisticated beam model based on the advanced thin-wall girder theory. Michael and Sprague [7] performed the spectral or finite element analysis for the response of the ship-like structures against the explosions below the water surface, by examining the transient responses of a 31000-degree-of-freedom finite element model. The results indicated that useful simulations may be performed on a modern PC when all of the resource-conserving improvements are fully utilized.

Suresh Rajendran et. al [8]investigated the effect of the wave-induced motions and vertical bending moments induced by extreme sea on a Cruise Ship, numerically and experimentally. B. Gaspar et. al. [9] evaluated the present paper the effect of the nonlinear vertical wave-induced bending moments on the ship hull girder reliability. Guillermo Vasquez et. al [10] investigated the experimental and numerical vertical bending moments induced by abnormal waves on two ships, namely, a bulk carrier and a Roll-on/Roll-off. G.F. Clauss and M. Klein [11] performed an experimental investigation on the vertical bending moment in extreme sea states for different hulls. J. Juncher Jensen [12] gave stochastic procedures for extreme wave load predictions for the wave bending moment in ships. Suji Zhu and Torgeir Moan [13] presented the results Non-linear effects from the wave-induced maximum vertical bending moment on a flexible ultra-large containership model in severe head and oblique seas.

Jean Piquet and Michel Visonneau [14] performed a numerical procedure for the solution of the Reynolds-average Navier-Stokes equations in boundary-fitted coordinates and validated to predict ship stern flows. Mohammad Reza Khedmati and Ahmad Reza Rashedi [15]evaluated the ultimate hull girder strength using Non-linear finite element modelling and progressive collapse analysis of a product carrier under longitudinal bending. Preben Terndrup Pedersen and Yujie [16] presented an estimate of the elastic energy that can be stored in elastic hull vibrations during a ship collision. Dominique Beghin [17] gave a method for evaluation of the ultimate capacity of ships' hulls in combined bending. Hai Hong et. al.[18] studied the structural behavior of open deck ship hull structures subjected to bending, shearing and torsion by using analytic and finite element solutions. Timo Kukkanen [19] briefly discussed the hydrodynamic responses in waves for marine structures.

Materials and Methods

Work is related to analysis using software and the ship has assumed to be fixed beam at one end and applied hydrostatic pressure by water assuming the ship to standing statically in sea water and to see what happens when a wave with high amplitude passes below it. As the wave will pass under it, and the ship is stationary, wave amplitude will cause bending effect and the phenomenon will be just like a beam fixed at one end and undergone bending effect due to pressure applied by the wave. The simulation software used during the performance of the analysis of deformations caused by the hydro-elastic pressure was Auto-FEM. It can be downloaded from the official website of Auto-FEM [13]**Error! Reference source not found.**. This software can be used to perform the finite element analysis of the 3D models created within AutoCAD graphics environment. This software becomes the part of the menu toolbar of the AutoCAD.

Specifying the Material and Material Properties

Results obtained by the software were made a comparison with the results obtained by a research paper at [20]. Several steps were involved. The model was imported first into AutoFEM environment and then meshed as shown in Fig. 1(a).

Flow chart: Study Tree menu ⇒ Material ⇒Material Browser dialogue box ⇒ Library ⇒ Ductile Iron

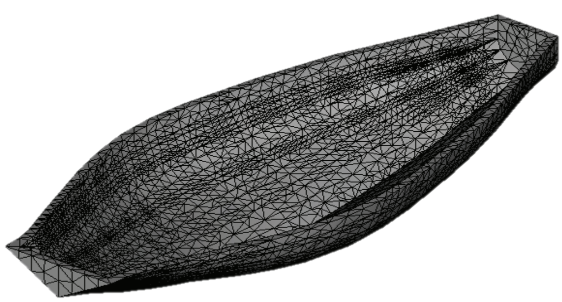

Fig 1(a): Mesh generation

Applying the Hydro-elastic Loads and Pressure on the Hull

Hydrostatic pressure is selected as the type of load because the ship hull model is assumed in contact with the sea water, as shown in Fig.1(b). Here an assumption was made because the hull is in motion, so the pressure on the stern or rear face of the ship can be assumed to be zero, or for the purpose of current analysis that face can be fixed. The bow or front face of the ship hull model is also applied pressure as shown in Figure 1(b).

Applying the Constraints (Boundary Conditions)

Fully fixed or rigid type of restraint is applied on the stern face of the hull model as shown in the Fig. 1(c).

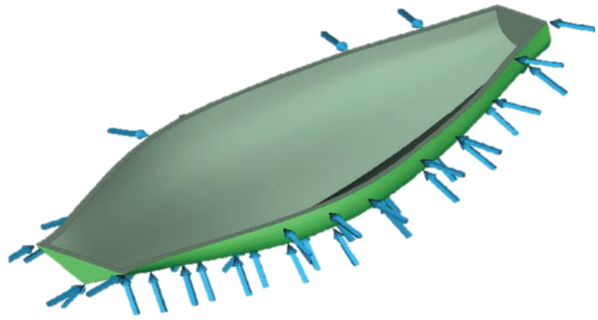

Fig 1(b): Applying the Hydro-elastic Loads and Pressure on the Hull

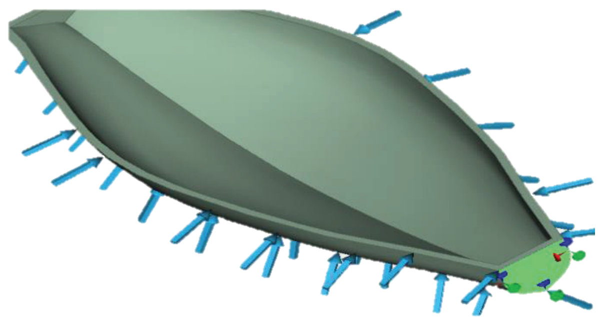

Fig 1(c): Applying the Constraints

Solving the Finite Element Model

Static structural FEM solver was used for analysis. This solver is used for steady state static analysis. The automatic method was selected in the solution control dialogue box. The solution was found successfully after 162 iterations. The mesh includes 57338 nodes and 29174 elements, with combined pre-processing and iterative calculation type. The calculations of strain were completed in 162 iterations which took in total 2 minutes and 29 seconds.

RESULTS AND DISCUSSION

Initially displacement under the applied loads (deformations), equivalent strains and equivalent stresses and factor of safety were added in the results folder as shown in Fig. 2.

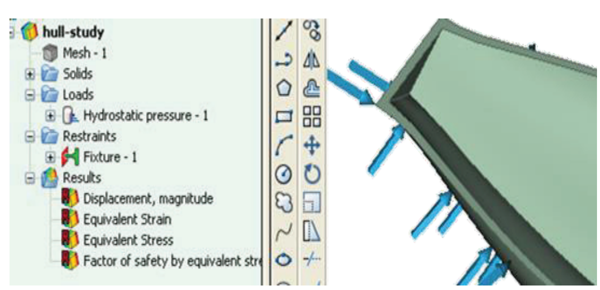

Fig. 2: Results pallet of Auto-FEM

Basic knowledge about the various types of stresses and strain was also studied [14].

Displacements

Maximum deformation or displacement occurs on the front face (as shown in red color. Its value is 0.432m (5.6E-27 times the Deformation scale) which is considerably accurate). As one moves along the longitudinal axis of the hull, the amount of deformation or displacement accordingly changes and is minimum at the fixed face (or zero in this case because the stern end was assumed fixed) as shown in Fig. 3(a).

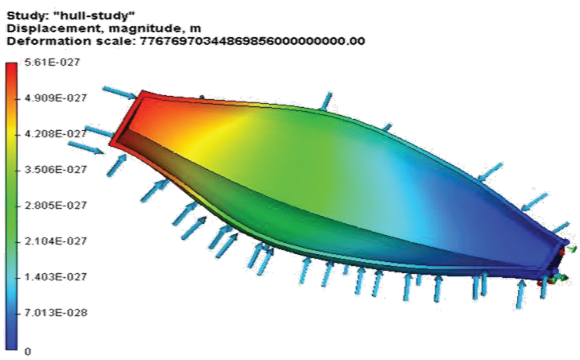

Fig. 3(a): Displacements Caused by the Applied Pressure

Equivalent Strains

In Fig. 3(b) the distribution of corresponding strains and its value is higher at the top edges and the fixed edge is shown. Because strain is the ratio of net change in dimensions to the original dimensions, there is not much fast distinctive color distribution as shown in Fig. 3(b).

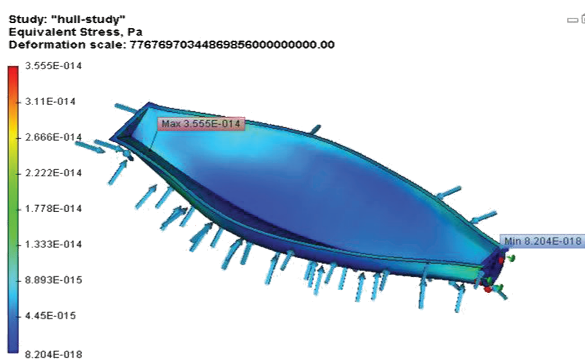

Fig. 3(b): Equivalent Strains Caused by the Applied Pressure

Displacement (OX, OY, OZ)

The spectrum represented in Fig. 4(a) shows the displacements caused by the pressure applied by the ocean waves on the hull. As OX is in the transverse direction and the waves strike side-wise against the both sides of the hull. But the side, towards which the ship is heading, undergoes more pressure (red spectrum on the left edges in Fig. 4(a)) as compared to the side the ship is heading away from (blue spectrum on the right edge in Figure 4(a)). Most of the spectral color is green that is a midway value between the highest and lowest values of displacements. Similarly, displacements along OY and OZ are shown Fig. 4(b) and Fig. 4(c).

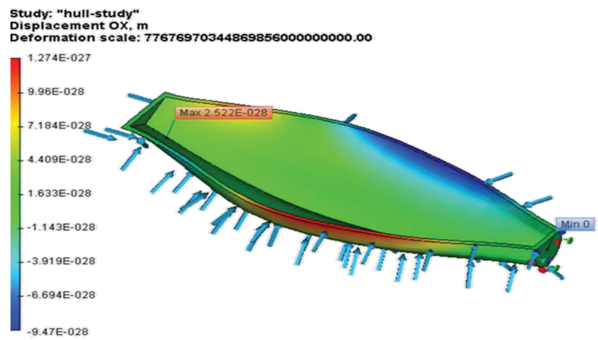

Fig. 4(a): Displacement, OX

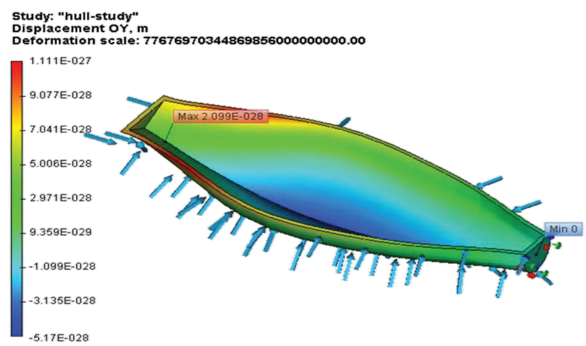

Fig. 4(b): Displacement, OY

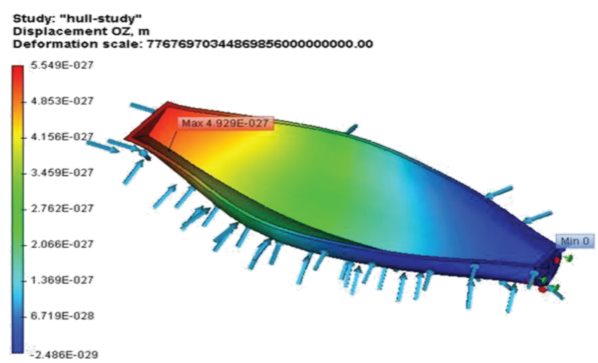

Fig. 4(c): Displacement, OZ

Normal Strains (OX, OY, OZ)

The behavior of normal strain shown in Fig. 5(a), in the OX direction, is clear from the colored variation of the spectrum that strain value mostly lies around the top of the spectrum and its value is 1.63. Maximum and minimum values are highlighted in Fig. 5(a). More area of the hull is in contact in x-direction whereas in y-direction is longitudinal and lesser area is in contact and average normal strain in the y-direction is in lower spectrum bar (blue and green color). Its value is 1.38 (Fig. 5(b)). OZ plane is vertical and strains are considerably lower. Its value calculated from the spectrum bar is 1.27 (Fig. 5(c)). General formula for calculation of strains from the spectrum bar is;

Strain= Value shown on the spectrum bar× Deformation scale (constant)

For example, in OZ direction value can be calculated using above formula

Strain in OZ direction= $1.635\times10^{26}\times$ *7767697034486985600000000=1.27*

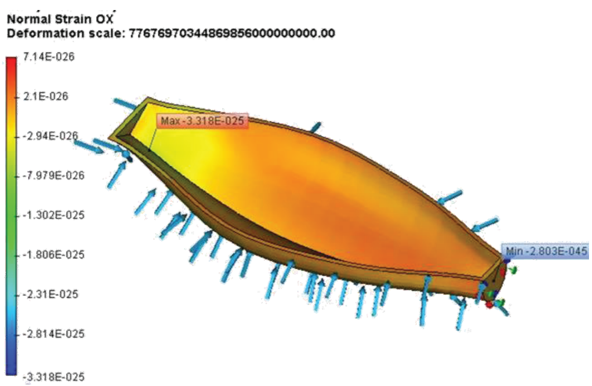

Fig. 5(a): Normal Strain, OX

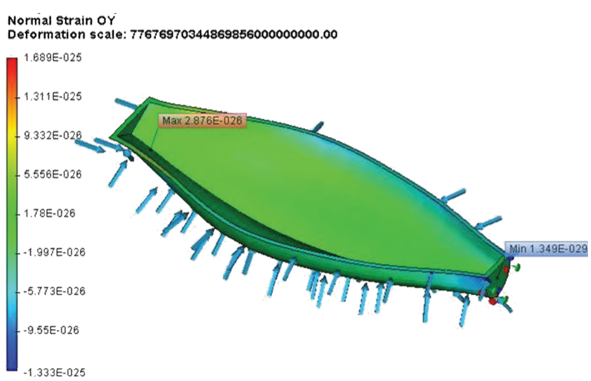

Fig. 5(b): Normal Strain, OY

Normal Stresses (OX, OY, OZ)

The behavior of normal stresses shown in Fig. 6(a), in the OX direction, is clear from the colored variation of the spectrum that stress value mostly lies around the top of the spectrum and maximum and minimum values are shown in the Fig. 6(b). The trend in OY (Fig. 6(b)) and OZ (Fig. 6(c)) direction is similar as in the case of normal strains in OY (Fig. 5(b)) and OZ (Fig. 5(c)), previously.

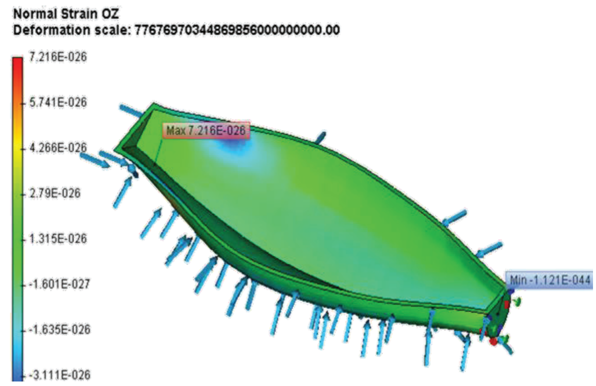

Fig 5(c): Normal Strain, OZ

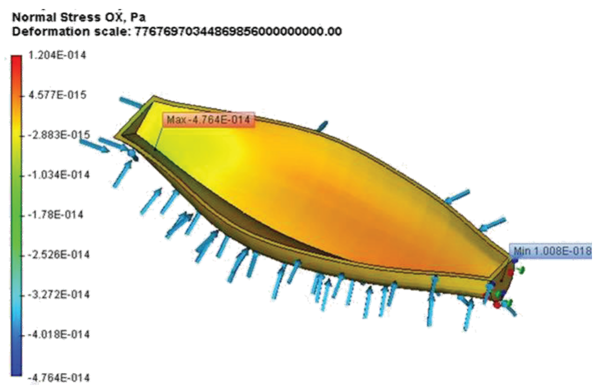

Fig. 6(a): Normal Stress, OX

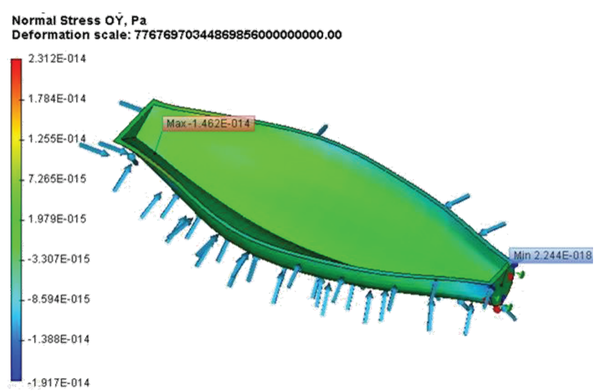

Fig. 6(b): Normal Stress, OY

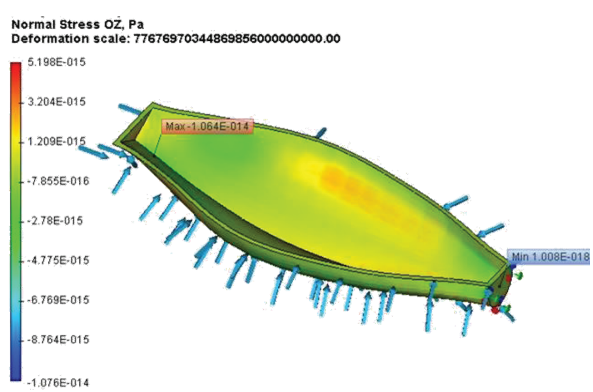

Fig. 6(c): Normal Stress, OZ

Shear Strains (Shear Strain in plane XOZ, XOY, YOZ)

The behavior of shear strains shown in Fig. 7(a), in the XOZ plane, is clear from the colored variation of the spectrum that strain value mostly lies around the middle of the spectrum and its value is .0321. Maximum and minimum values are highlighted in Fig. 7(a). More area of the hull is in contact in x-direction whereas XOY plane is horizontal average shear strain is in safe range as highlighted in green color (Fig. 7(b)). YOZ plane is vertical and shear strains are considerably lower as compared to normal strains and mostly lie in the middle of the spectrum bar (Fig. 7(b) and Fig. 7(c)).

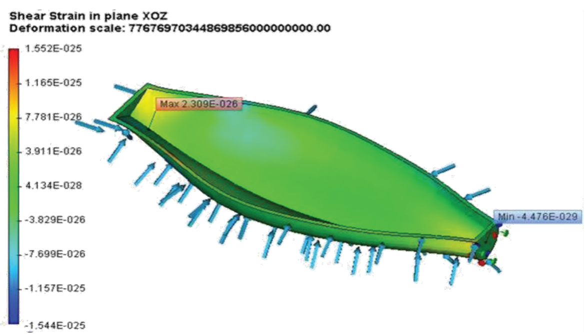

Fig. 7(a): Shear Strain in plane XOZ

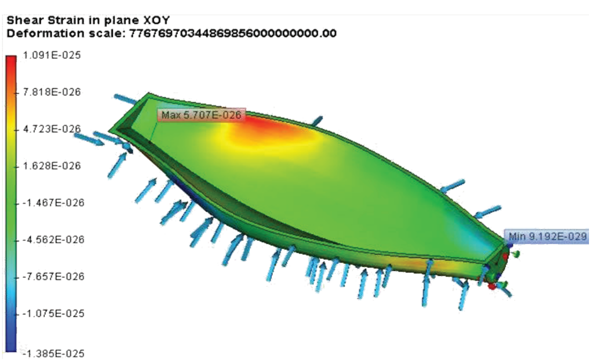

Fig. 7(b): Shear Strain in plane XOY

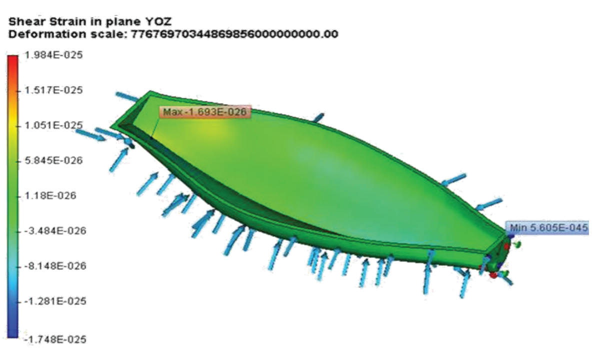

Fig. 7(c): Shear Strain in Plane YOZ

Shear Stresses (Shear Stresses in plane XOZ, XOY, YOZ)

The behavior of shear stresses shown in Fig. 8(a), in the XOZ plane.

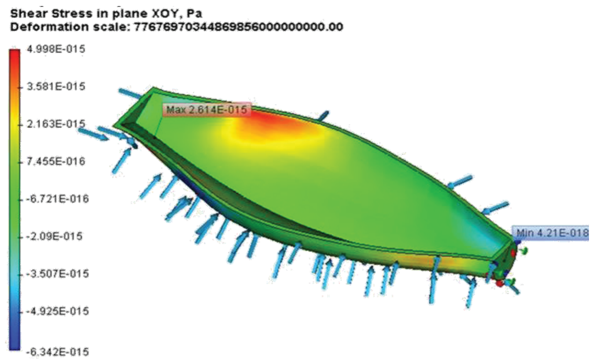

Fig. 8(a): Shear Stress in Plane XOY

It is clear from the colored variation of the spectrum that strain value mostly lies around the middle of the spectrum and its value is 1.63.

Maximum and minimum values are highlighted in Fig. 8(a). Maximum values are at the bow portion and minimum values are at the stern portion. Like shear strains these values are also in the safe region of the spectrum bar as highlighted from the green color (Fig 8(b) and Fig. 8(c)).

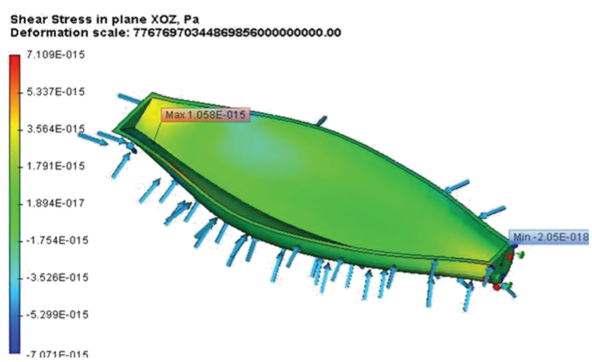

Fig. 8(b): Shear Stress in Plane XOZ

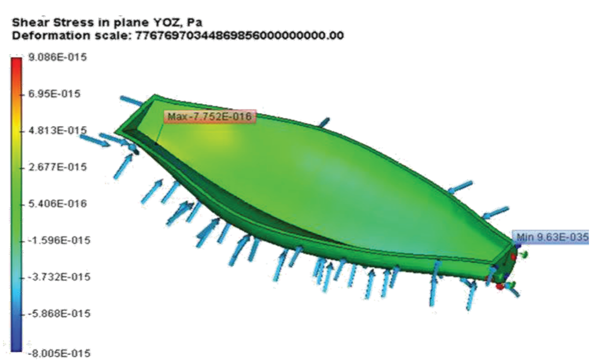

Fig. 8(c): Shear Stress in Plane YOZ

Bending Effect on Hull

Another analysis was performed to estimate the bending moment to the hull structure when the ships are sufficiently long so that at least greater than one wavelength. The hull may undergo sagging or hogging as the waves' crests or troughs pass underneath the hull.

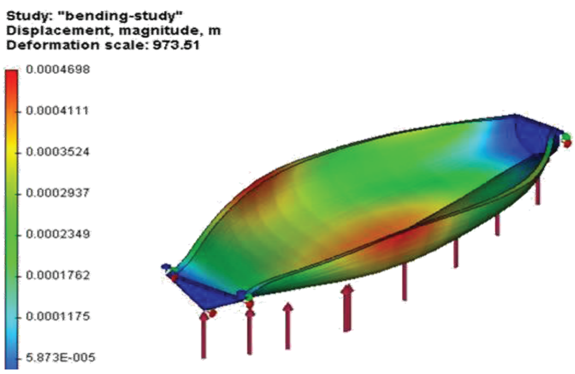

Fig. 9: Bending Effect

For the current analysis, it was assumed that hull undergoes hogging. This is the case when the crest of the wave passes through the middle portion of the hull. It was assumed that hull is fixed at both the stern and bow ends and the distributed force per unit length of the hull acts on the bottom central edges shown in Fig. 9.

Comparison with the Experimental Results

Though the spectral plots of the displacements or deformations created due to the bending effect of waves have been plotted and shown in Figure 10, it is necessary to analyze the results using the conventional method with help of a graph between the lengths of the ship hull on the x-axis and resulting displacements in the y-axis. The graph is shown in Figure 10. For the purpose of graph, the origin has been assumed at the mid-length of the ship hull and discrete points along the length have been sinusoidally plotted, i.e. the total length of the hull has been assumed to be π-radian or 180^o with 0^o -90^o corresponds the x-axis in the positive (right) direction from the origin and 90^o -180^o corresponds the x-axis in the negative (left) direction. The trend of the graph is almost similar, except for the ends, to the graph as a comparison from a research paper[20]. The graph [20] is actually for design vertical bending moments which have been calculated by DNV rules and direct calculations. From the comparison of the plots of Figure 10 and the graph **Error! Reference source not found.**[20], it can be seen that the displacements created in the vertical direction from the same reference line (water-line) are proportional to the bending moments at corresponding sections along the length of the hull. Maximum displacement will be where the bending moment is maximum.

LENGTH OF HULL IN RAD	DISPLACEMENT
0.999999619	0.057174242
0.974761194	0.114387425
0.900698239	0.171532462
0.781520472	0.228677499
0.623197354	0.285919887
0.433659085	0.343064924
0.222399391	0.400209961
0	0.457354998
-0.222399391	0.400209961
-0.433659085	0.343064924
-0.623197354	0.285919887
-0.781520472	0.228677499
-0.900698239	0.171532462
-0.974761194	0.114387425
-0.999999619	0.057174242

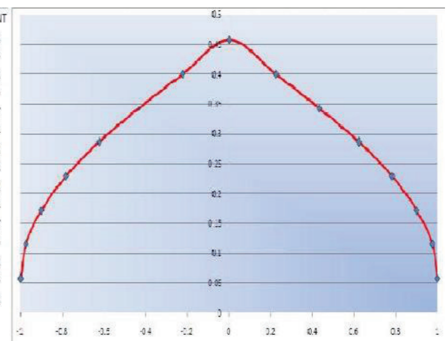

Fig. 10: Displacements or deformations created due to the bending effect of waves

Conclusions

Auto-FEM software has been used with AutoCAD building a simple hull model. The model of the ship has meshed and deformed under the bending forces and resulting stresses and strains automatically calculated in the form of spectral color variation and deformations have been presented. Shear stresses and strains in the horizontal plane are seen to be in safe range. Normal strain in the horizontal direction is much larger (value 1.63).Minimum values of any stress or strain parameter are usually at the rear or stern portion of the hull. Maximum values have been seen to occur mostly at the front or bow portion of the hull and at the bottom line where stress concentration is more likely to occur as compared to smoothly curving sides of the hull. Bending effect occurs on larger lengths of the hull where the length of the hull is greater than one wavelength of the sea wave so that when a crest passes underneath the hull bending effect is produced. There are various limitations for this analysis such it is entirely hydrostatic analysis. Hull geometry needs further to be modified and more accurate geometry can be modelled. In ANSYS workbench geometry can be modelled and fluent analysis can be done in future.

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