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GLOBAL STRENGTH ANALYSIS FOR A SPLIT HOPPER BARGE SUBJECT TO HEAD EQUIVALENT DESIGN WAVE

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ABSTRACT

Due to the Classification Societies' regulations, in the preliminary design stage for new ship constructions it is necessary to prove with calculations that the stress and deformation distributions in the ship structure do not exceed the stress limit values, regardless the sea state such as calm water, sagging or hogging wave conditions. Normally, it is considered that the hogging and sagging conditions are the worst head wave conditions, when the vertical shear forces and bending moments can reach high values and the risk of ship structure collapse can be high. The main purpose of this study is to assess, using the Finite Element Method (FEM), the global strength for a split hopper barge in three sea state conditions: calm water, hogging and sagging head design waves.

Keywords: hogging and sagging waves, global strength analysis, design waves, stress assessment.

1. INTRODUCTION

A split hopper barge is a special vessel, usually towed by a tug or with self propulsion which is used for hydro-technical, fluvial or maritime works, especially for dredges, the main purpose being to transport the dredged material.

The main purpose of this study is to determine the global stress and deformation distribution for such a vessel in the cases of calm water, hogging and sagging waves [1], [2],[3],[5]. To do this analysis we chose to use a vessel that is already built and fully functional. The main particulars of the split hopper barge are presented in Table 1.

Table 1. Main particulars of the barge

Length over all, L_{OA} [m]	54
Length of waterline, L_{WL} [m]	52
Beam, B [m]	10
Depth, H [m]	3
Draft, T [m]	2
Volumetric displacement, ∇[m^3]	780

Based on the construction plans, the 3D model of the ship was generated in Rhinoceros [9] from surfaces (Fig.1). To obtain accurate results from the analysis, every part of the barge structure was modelled. In order to reduce the amount of time that would take to generate the whole 3D model of the barge, only the fore pick up to the first strengthened

frame was modelled. In this way, once the 3D model is ready, it can be imported in the finite element analysis software [4] where the mesh will be generated. Then the mesh elements and nodes for the rest of the structure are copied until we obtain the full 3D model. For this analysis FEMAP/NX Nastran [4] software is used.

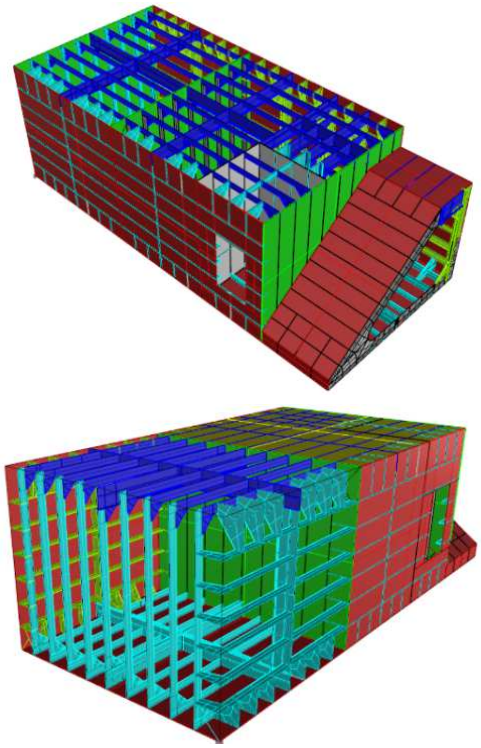


Fig.1. 3D-CAD model of the ship structure

In Fig.1 it is presented the 3D-CAD model of the ship structure (using only surfaces) that was generated using Rhinoceros [9]. With the 3D-CAD model done, the .sat file is exported from Rhinoceros [9] and imported in FEMAP/NX Nastran [4]. The finite element analysis software allows us to generate the mesh directly on the surfaces. Because the model is very complex and the software does not recognise the intersection between two surfaces the mesh cannot be done automatically by the FEM software and needs to be made manually.

2. EQUIVALENT DESIGN WAVE

For a head design wave defined by height h_w from rules [1],[2],[5] and length λ=L, equal with the ship's length L for maximum structural response, the quasi-static wave free-surface elevation is [3]:

$$\zeta_w(x) = d_{pp} + (d_{pv} - d_{pp})\frac{x}{L} \pm \frac{h_w}{2} \cdot \cos\left(\frac{2\pi x}{\lambda}\right) \quad (1)$$

where: $x \in [0, L]$; d_{pp}, d_{pv} are the barge – design wave equilibrium parameters obtained by an iterative procedure [3]; ± sagging or hogging wave condition.

The pressure from head design wave acting over the external shell of the 3D-FEM barge hull model has the expression [3]:

$$p_w(x,z) = \rho \cdot g \cdot [\zeta_w(x) - z];\ z \in [0, H] \quad (2)$$

where: ρ, g are the water density and the gravity acceleration.

3. BOUNDARY CONDITIONS

The barge hull is symmetrical at the longitudinal central plane and including the control nodes at both extremities; the boundary conditions applied on the 3D-FEM model are presented in Table 2 and Fig.2.

Table 2. 3D-FEM boundary conditions [3]

DOF	Ux	Uy	Uz	Rx	Ry	Rz
Symm. plane	-	X	-	X	-	X
Fore node	-	X	X	X	-	X
Aft node	X	X	X	X	-	X

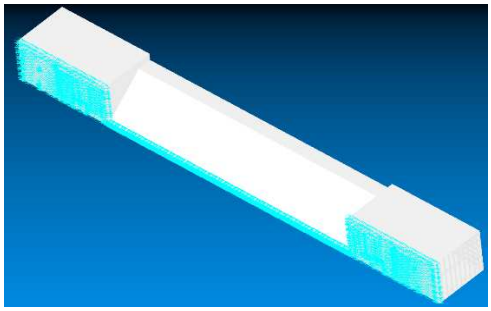


Fig.2. 3D-FEM model boundary conditions

4. THE 3D-FEM MESH

The 3D-FEM model is developed using membrane and thick plate (Mindlin), triangle and quad, finite elements [6],[7],[8],[10]. The resulting FEM-mesh consists in 162400 finite elements and 149326 nodes (Fig.3).

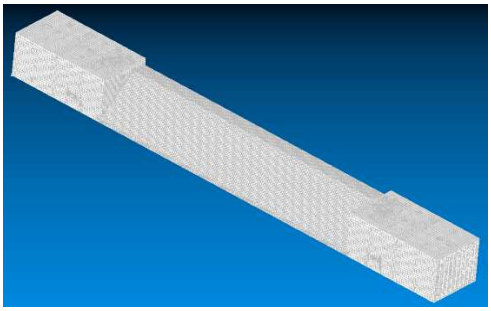


Fig.3. The 3D-FEM mesh model

5. LOADS ON 3D-FEM MODEL

To obtain a better perspective of the results we ran three different cases, i.e. when the ship is in calm water, in hogging and sagging conditions. For the analysis it is necessary to take into account the gravity load from all the model masses and to apply the external load induced by waves [3]. To apply the pressure correctly, the external shell finite elements have to be checked and oriented so that the normal vector on face 1 is going from the outside to the inside of the barge hull [4]. To apply the pressure on the external shell of the barge, the following expression was used [3]:

max(0.000;(1.05525e-5(-ZEL(!EL)+*
*!DPP+(!DPV-!DPP)*XEL(!EL)/!L±* (3)
*±!HW/2*COS((2*180*XEL(!EL)/!L)))))*

where: *EL* are the immerse elements; *HW*= 0, 1.8 m is the wave height; *DPP* =*DPV* = 0.9611 m are the barge – wave equilibrium parameters; *L*=54 m is the barge overall length.

All the variables from equation (3) have been previous defined in FEMAP/NX Nastran [4]. Also for the entire 3D-FEM model the body gravity load is defined $a_z = -g = 9.81\, m/s^2$ for weight modelling.

Case 1.

For the first case we have the external pressure distribution (3) when the ship is in the most frequent position, that is when the ship is on calm water (h_w=0).

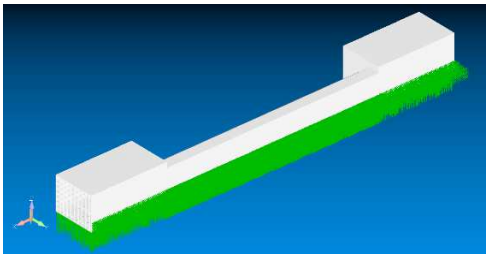


Fig.4. Calm water – pressure distribution

Case 2.

For the second case we have the external pressure distribution (3) when the ship is on hogging condition (h_w=-1.8m) and the deck is subjected to stretch and the bottom to compression.

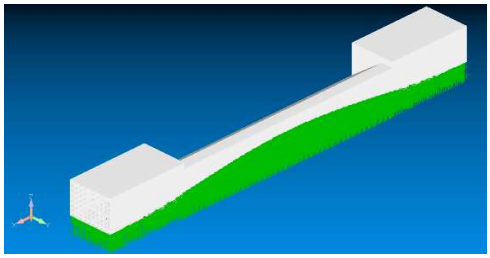


Fig.5. Hogging – pressure distribution

Case 3.

And for the third case we have the external pressure distribution (3) when the ship is on sagging condition (h_w=+1.8m) and the deck is subjected to compression and the bottom to stretch.

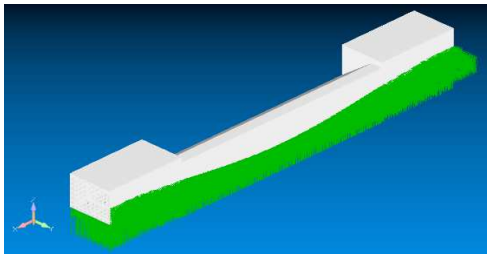


Fig.6. Sagging – pressure distribution

6. NUMERICAL RESULTS

Case 1.

The maximum value for von Mises stress is around 200 MPa for the full model (Fig.7). If we look just at the cargo area the values are much lower, somewhere around 55 MPa (Fig.8). That high value is due to the transition to inclined deck where the structural elements of the barge structure are very complex.

Regarding the vertical displacement, we have a maximum value of 27 mm for the full model (Fig.9) and 27 mm for the cargo area (Fig.10), which means that the displacement remains constant and that the high value of the stress does not affect the barge deformation.

As we can see the maximum value of the vertical displacement is located somewhere around the central line of the ship, as it was expected. The most affected part is the shell of the barge bottom, due to the water pressure acting on the barge's shell.

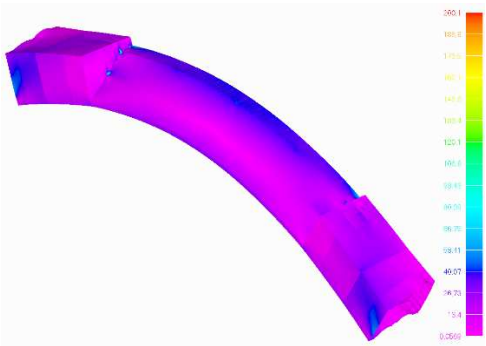


Fig.7. Case 1-Stress distribution - full model

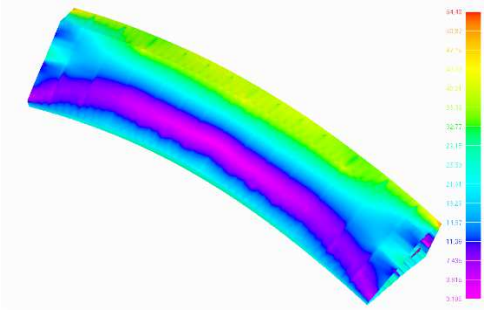


Fig.8.a Case 1-Stress distribution - cargo area

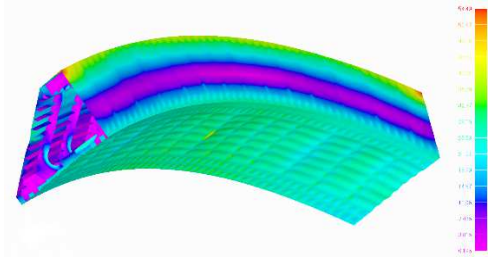


Fig.8.b Case 1-Stress distribution - cargo area

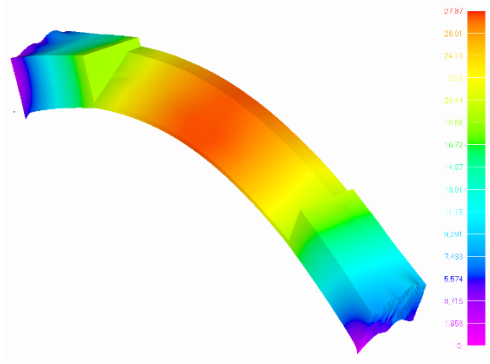
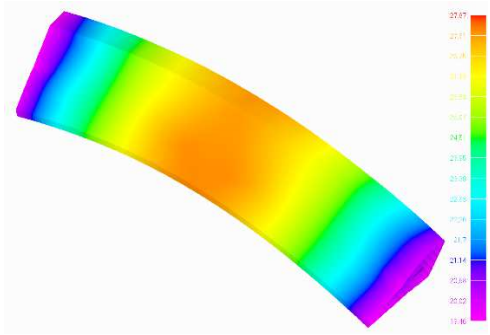


Fig.9. Case 1-Vertical displacement - full model



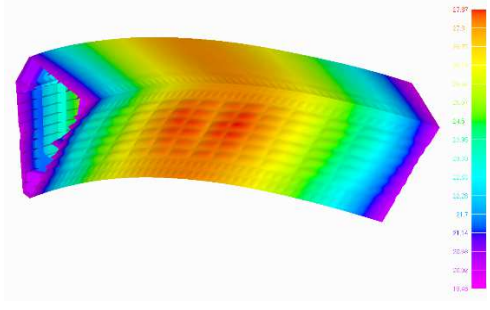


Fig.10. Case 1-Vertical displacement-cargo area

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Case 2.

As it was expected, the vertical maximum displacement is located within the same area, but the values are a little higher this time, some-where around 42 mm (Figs.13,14).

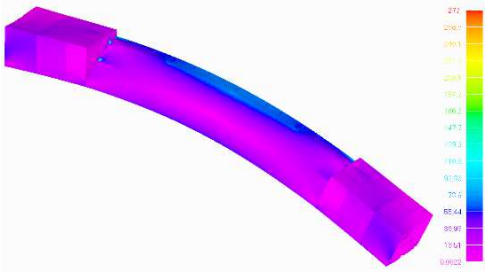


Fig.11. Case 2 - Stress distribution - full model

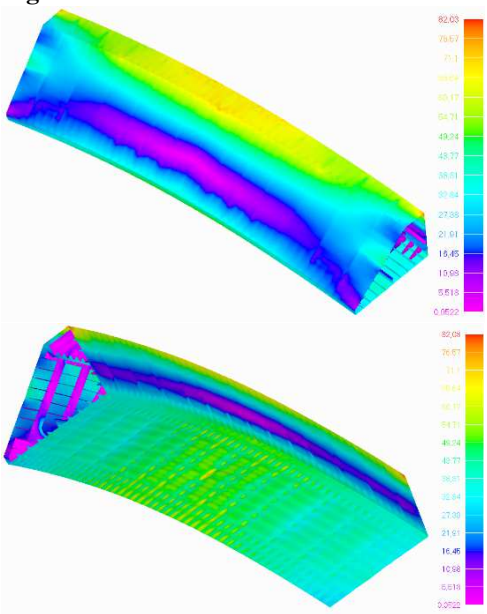


Fig.12 Case 2 - Stress distribution - cargo area

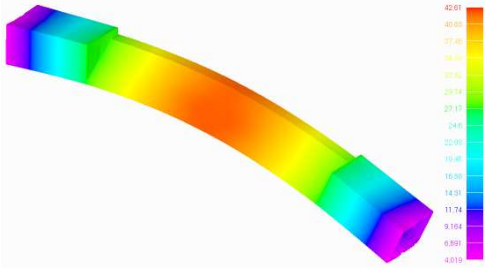
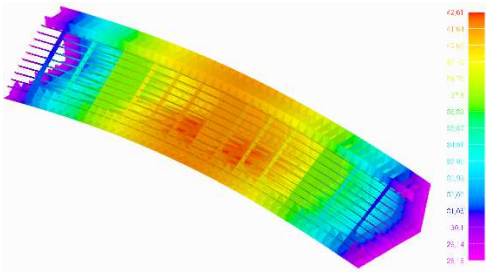


Fig.13. Case 2 - Vertical displacement-full model

For the hogging condition the structure behaviour is similar to the calm water condition, but for this case the maximum stress value is around 277 MPa (Figs.11,12). This is also due to some stress concentrators.



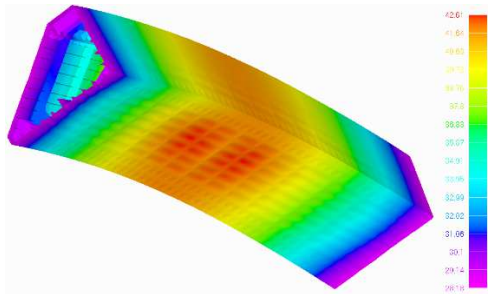


Fig.14. Case 2 -Vertical displacement - cargo area

Case 3.

For the third case the maximum value for Von Mises stress is 123 MPa (Fig.15). This means that the structure response for sagging condition is better than in the other two cases. Also, for the cargo area, the stress value is 29 MPa (Fig.16).

Similarly, the vertical displacement for the sagging condition has the lowest value, somewhere around 13 mm (Figs.17.18).

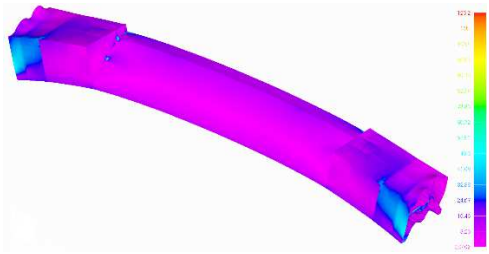


Fig.15 Case 3 - Stress distribution - full model

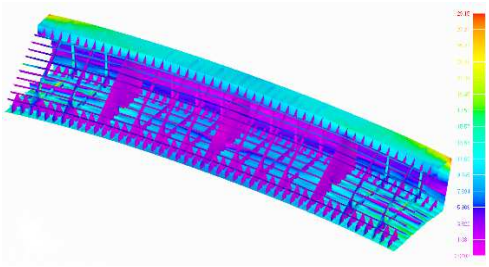


Fig.16. Case 3 - Stress distribution - cargo area

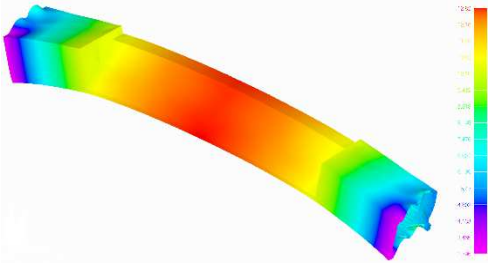


Fig.17. Case 3 - Vertical displacement-full model

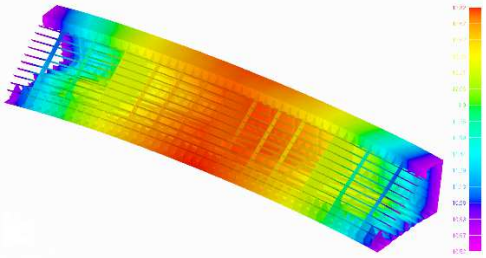


Fig.18. Case 3 - Vertical displacement-cargo area

5. CONCLUSIONS

Using the FEM finite element method, the global strength for a split hopper barge in the design stage has been performed. As it was shown in this study, we can analyse the structural behaviour of the barge in terms of equivalent von Mises stress and the maximum displacement distributions, so we can assess the integrity of the barge by the rules criteria [1],[2].

Taking into account that the von Mises stress does not exceed the rules' admissible value in the central area, and the highest value corresponds to a local effect, we can conclude that the structure is overall well-dimensioned, and some local redesign is required to reduce the stress hot spots.

Table 3. 3D-FEM numerical results

Full model results			
Case	Calm water	Hogging	Sagging
VonMises stress [MPa]	200.1	277	132.2
Displacement [mm]	28.87	42.61	12.82

Central area results			
Case	Calm Water	Hogging	Sagging
VonMises stress [MPa]	54.49	82.03	29.15
Displacement [mm]	27.87	42.61	12.82

Acknowledgements

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