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Determination of deformations and stress states in the double bottom by MEF

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Abstract: This paper aims to conduct a study on the determination of stress states in a more precise double bottom structure of a 55000 tdw chemical tank, in order to ensure optimal safety and efficiency in operation and methods of using the resistance of structures.
This study was performed entirely in FEMAP/NX Nastran. FEMAP/NX Nastran is a simulation software program, with the help of which models can be created to analyze the finite elements of the complex system and display solution results. FEMAP/NX Nastran can model a component, assemblies or systems and determine the behavioral response for a particular operating environment [1].
In order to carry out this study, 3 cases of static positioning of the ship were required: on still water, on sagging and hogging.
Keywords: hydrostatic water pressure, stress calculation, mechanical structural, finite element

I. INTRODUCTION

FEMAP/NX Nastran software was used to generate the FEM model. The program consists of two parts. Generating the finite element model is performed by FEMAP, and the solution of the resulting system of linear equations is performed by the NX Nastran solver [1]. The program was developed by Siemens and is a combination of two independent programs.

The FEM models extended over a piece of the vessel length, with vessel-wave balancing parameters, calculated using the equivalent beam model, are suitable for analyzing the hull resistance on areas where global demands are dominant, respectively for the central areas of cargo compartments.

Usually, the hull of commercial vessels has trapezoidal shapes in the central area, so that, for the model to be analyzed, it is sufficient to know the shape of the cross section in the master couple [3].

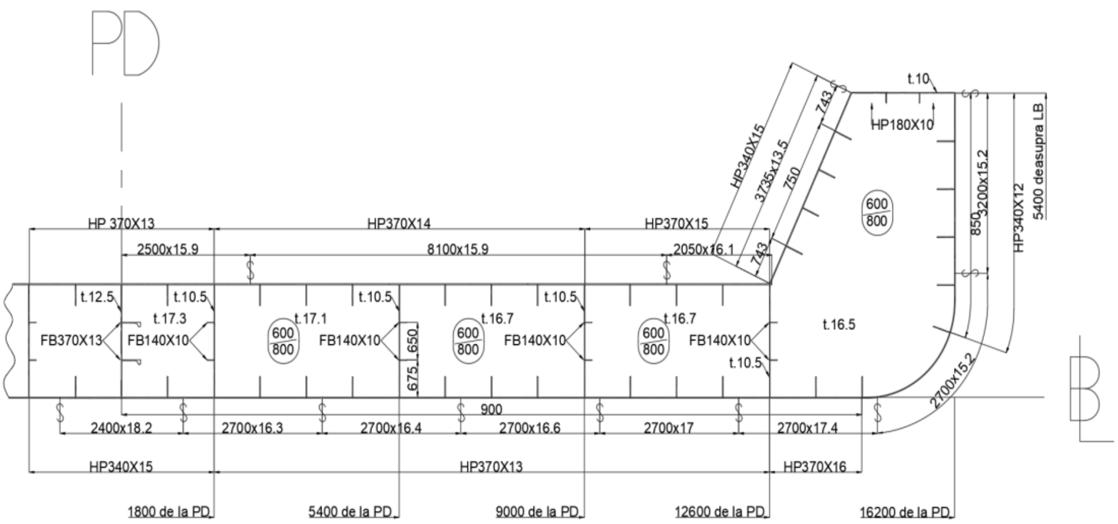


Figure 1 Simplified double bottom structure of the chemical tanker

The geometry and thicknesses of each element are according to the sampling and are illustrated in **Figure 1**. For this calculation, an extended 3D model was made along a warehouse in the central area, located between the C106 and C134 frames [3].

The used material for this structural analysis is the steel with high resistance, for which the voltage at which the flow starts is $\sigma_c = 315$ MPa and the voltage at which the breakage starts is 440 MPa, elasticity longitudinal module (Young modulus) is $E = 210\ GPA$ and coefficient of Poisson is $\nu = 0.3$. The density of material was defined $\rho = 7800\ kg/m^3$.

II. REALIZATION OF 3D-FEM MODEL OF DOUBLE BOTTOM STRUCTURE

Based on the 3D-CAD model [5], the 3D-FEM MODEL is further generated. In order to be able to highlight the voltage concentrators in all structural elements, it is necessary to use the membrane and plate elements, implemented in the FEM program.

The structure is divided in elements of approximately 150 mm^2, being different in certain cases. The discretization was done manually, which resulted in a number of 75592 nodes and 78510 QUAD elements (**Figure 2** and **Figure 3**).

Table 1 Main characteristics of the chemical tanker (simplified structure)

L = 194040 mm	aL = 900 mm	E = 2.1E+5N/mm^2	No. CR = 14915
B = 32400 mm	aF = 2700 mm	ν = 0.3	No. SF = 2911
D = 17900 mm	Elsize = 150 mm	ρ = 7800 kg/m^3	No. ND = 75592
L_{mag} =1magX25200 mm	h_{wmax} = 7230 mm	No. PT = 12414	No. EL = 78510

Table 2 Balancing parameters from simplified 1D analysis

LOA = 194040 mm	XPP = 89000 mm	DPP = 12700 mm
h_w = 7230 mm	HHC = 17900 mm	DPV = 12700 mm

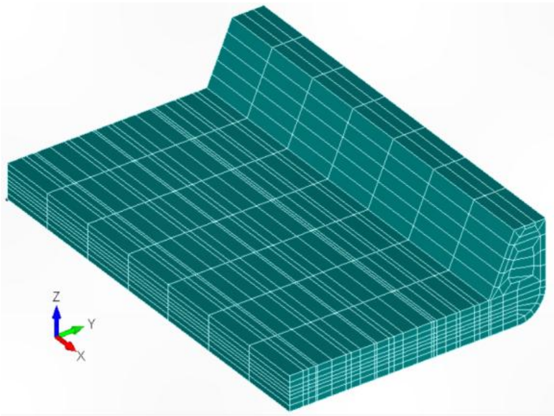


Figure 2 3D-CAD model

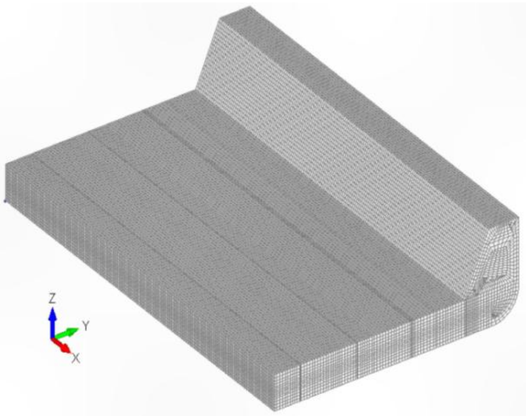


Figure 3 3D-FEM model

The edge conditions recommended by DNV-GL for this model are:

a) Symmetry conditions in PD of the vessel, representing the blocking of the movement on the lateral direction, respectively the blocking of the rotations around the vertical and longitudinal axes.

b) Blocking the vertical movement near the board and double-board walls.

c) Blocking the movements in vertical direction, at the aft and fore ends of the double bottom plates, representing the simple bearing condition.

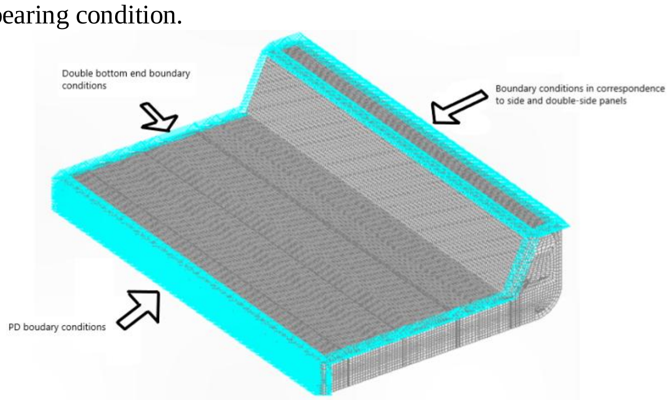


Figure 4 Edge conditions applied to the 3D-FEM model

2.1 The case of static placement on still water

The 3D-FEM model corresponding to the double bottom structure in the central area of the vessel is subject to the following types of loading in still water:

a. Gravitational load given by the net weight of the structural elements of the vessel: $g = 9.81\, m/s^2$, $\rho = 7.8$ t/m^3.

b. The load given by the cargo, idealized on the double bottom shell and on the inclined roof of the bilge, that the hydrostatic pressure in the cargo ($\rho = 0.9$ t/m^3), for a reference quota HHC ($D = 17900$ mm).

The hydrostatic pressure will be $p = \rho g z$ [kN/m^2], where:

ρ – density of transported goods [t/m^3]

g – gravitational acceleration [m/s^2]

z – vertical distance to the highest point the goods reach inside the warehouse [m]

c. The load given by the sea water in which the hull of the vessel is immersed, idealized on the outer shell, as the hydrostatic pressure in the water ($\rho = 1.025$ t/m^3), for a full load draught of $T = 12700$ mm.

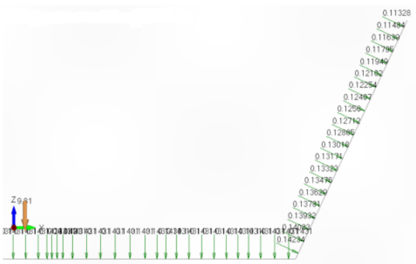


Figure 5 Distribution of the hydrostatic pressure of the goods on the double shell

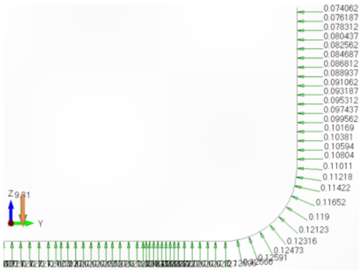


Figure 6 Distribution of hydrostatic water pressure on the outer shell

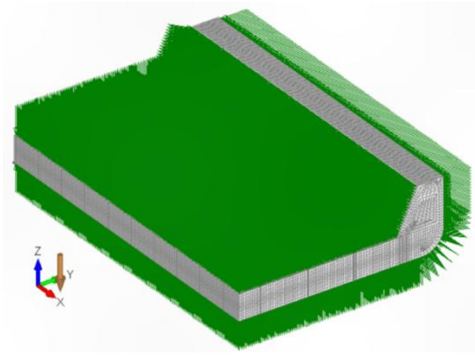


Figure 7 Distribution of hydrostatic pressure of the goods and water on the inner and outer shell

2.2 The case of static placement on the wave

In the case of static vessel placement on the wave, the 3D-FEM model shall be subjected to the following types of loads:

a) Gravitational loading (same as in the case of placement on still water);

b) the load given by the goods (the same as in the case of placement on still water);

c) the load in the equivalent quasi-static meeting wave, with Smith correction, with the equivalent hydrostatic pressure [N/mm^2], with the elongation relative to the basic plane of the vessel from the relations (1.1) and (1.2), taking into account the balancing parameters, calculated on the basis equivalent beam model, depending on the wave height (h_w).

The height of the wave h_w is calculated according to the rules of the DNV GL register with the formula (1.3):

$$\zeta_w(x) = d_{pp} + (d_{pv} - d_{pp}) \cdot \frac{x}{L} \pm \frac{h_w}{2} \cdot \cos\left(\frac{2\pi x}{L}\right), x \in [0, L], x \in [x_{mpp}, x_{mpv}] \tag{1.1}$$

$$p_w(x) = \rho \cdot g \cdot \zeta_w, x \in [0, L], \rho = 1.025\, t/m^3 \tag{1.2}$$

$$h_w = 1.25 \cdot \sqrt[3]{\lambda} \tag{1.3}$$

III. RESULTS OBTAINED FROM THE FINITE ELEMENT ANALYSIS

Following the analysis, maximum stresses were found at the level of the stiffening elements of the structure. Next, the hypothesis was developed according to which the preponderance of stress in these framing elements is due to the absence of certain geometric details and additional stiffening elements, the model considered for analysis being a simplified one. Thus, for a partial compensation of these shortcomings, a 3 mm increase in the thickness of the longitudinal bottoms, double bottom and bilge was used to fill the absence of the bulb.

The following figures illustrate the comparative studies between the results obtained on the analyzed model, before adjusting the longitudinal thickness (**Figure 9a**) and after adjusting the longitudinal thickness (**Figure 9b**).

In order to check the results, it will be taken into account that the maximum stresses recorded do not exceed the flow limit of the used steel.

In the case of average stresses per element, the verification is made by comparing the results with the values accepted by IACS of the stresses according to the Common Structural Rules, rules that apply to tank type vessels and bulk carriers with L = 150 m.

According to **Figure 8** the allowable stress will be calculated for the bottom and double bottom plates that are part of the structure, at a static analysis, multiplying the flow limit of the material by the factor λ_{yperm} = 0.65. For the rest of the elements, the material flow limit will be multiplied by λ_{yperm} = 0.81. Therefore, the average stress limit per element for the bottom and double bottom cover is 204.75 MPa, and for the rest of the elements it is 255.15 MPa.

Structural component	Coarse mesh permissible yield utilisation factor, λ_{yperm}
Plating of all longitudinal hull girder structural members, primary supporting structural members and bulkheads. Face plate of primary supporting members modelled using shell or rod elements. Dummy rod of corrugated bulkhead	1.0 (load combination S+D) 0.8 (load combination S)
Corrugation of vertically corrugated bulkheads with lower stool and horizontally corrugated bulkhead, under lateral pressure from liquid loads, for shell elements only. Supporting structure in way of lower end of corrugated bulkheads without lower stool (1).	0.90 (load combination S+D) 0.72 (load combination S)
Corrugation of vertically corrugated bulkheads without lower stool under lateral pressure from liquid loads and without lower stool, for shell elements only.	0.81 (load combination S+D) 0.65 (load combination S)
(1) Supporting structure for a transverse corrugated bulkhead refers to the structure in the longitudinal direction within half a web frame space forward and aft of the bulkhead, and within a vertical extent equal to the corrugation depth. Supporting structure for a longitudinal corrugated bulkhead refers to the structure in transverse direction within 3 longitudinal stiffener spacings from each side of the bulkhead, and within a vertical extent equal to the corrugation depth.	

Figure 8 CSR rules, Maximum allowable stresses following an EMF analysis [4]

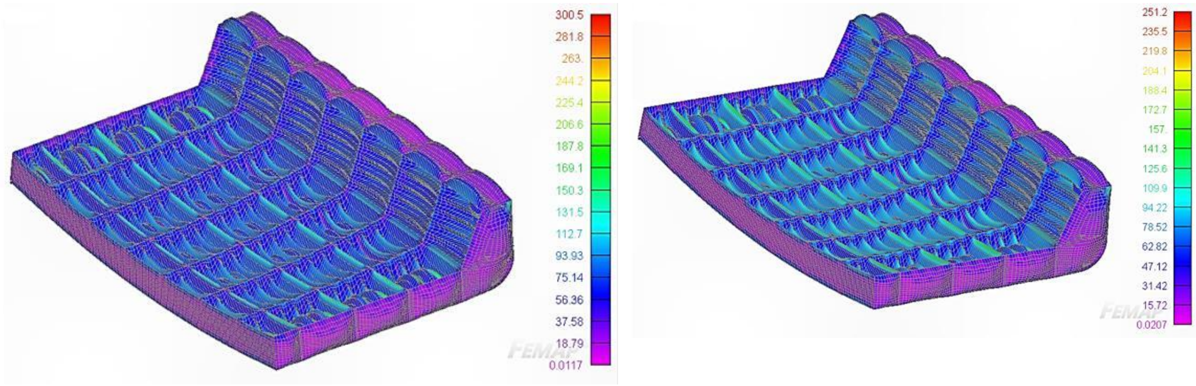
3.1 Results obtained in still water

In this case there is a decrease of voltage of up to 49.3 MPa in the most stressed areas (longitudinal of double bottom **- Figure 9**) where, following the increase of thicknesses, values of maximum 251.2 MPa are recorded in area with concentrators. These areas with concentrated stresses appear at the aft and fore extremities of the model, at the passages through reinforced floors.

The maximum stresses obtained after adjustment of thicknesses are within the limits allowed by the material flow limit.

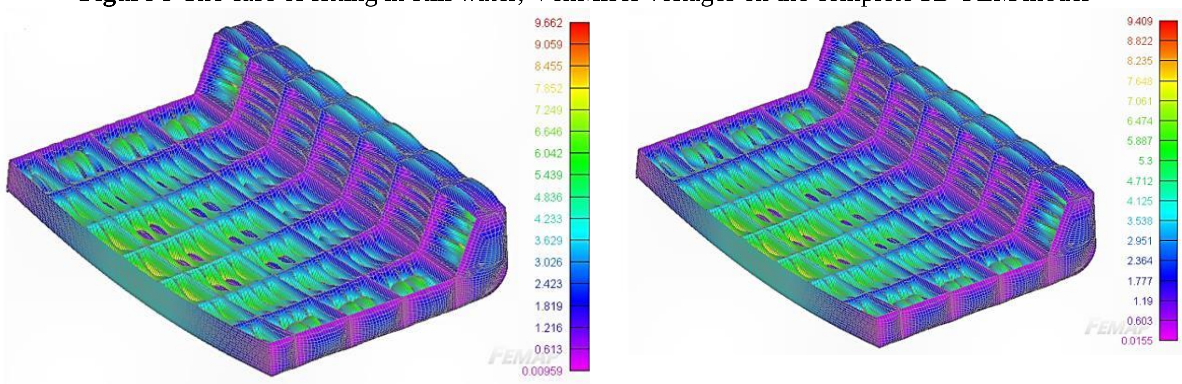
The average stresses per element do not exceed the allowable prescribed by CSR, reaching up to 176 MPa for the double bottom plating, respectively 173 MPa for the longitudinal double bottom.

The movements with the greatest results from the static analysis in still water are taken place at the level of double bottom floor, in the central area of the bowlocker, where the bending phenomenon is predominant.



a) b)

Figure 9 The case of sitting in still water, VonMises voltages on the complete 3D-FEM model



a) b)

Figure 10 The case of settling in still water, the displacements that appear in the complete 3D-FEM model

3.2 Results obtained on the wave.

3.2.1 The case of static placement of the vessel on the sagging

In the case of placement of the vessel on the sagging there is a decrease of voltage of up to 50.5 MPa in the most stressed areas (longitudinal of double bottom) where, following the increase of thicknesses, values of maximum 258.2 MPa are recorded in area with concentrators. Similar to case of placement of vessel in still water, these areas with concentrated stresses appear at the aft and fore extremities of the model, at the passages through reinforced floors.

The bottom plating, as can be seen in **Figure 11** is subject to stretching, and the stresses are between 19 **-** 72 MPa, in the area without concentrators.

The maximum stresses obtained after adjustment of thicknesses are within the limits allowed by the material flow limit.

The average stresses per element do not exceed the allowable prescribed by CSR, reaching up to 170 MPa for the double bottom plating, 130 MPa for bottom plating and 182 MPa for the longitudinal double bottom.

The movements with the greatest results from the static analysis in sagging are taken place at the level of double bottom floor, in the central area of the bowlocker, similar to case of static placement on still water.

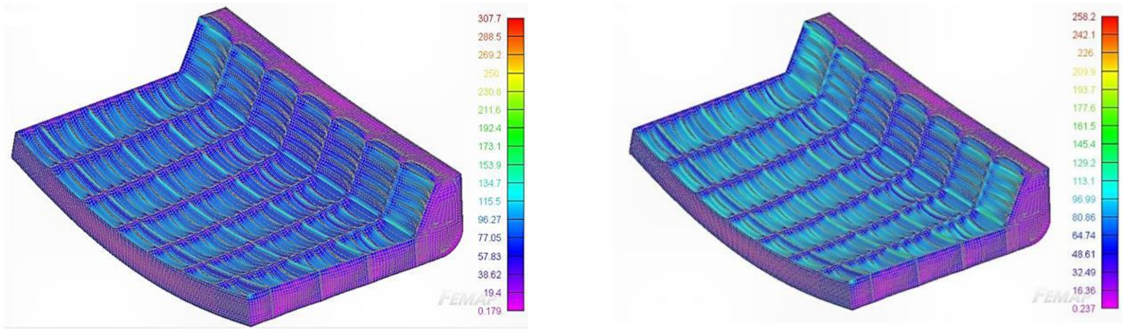


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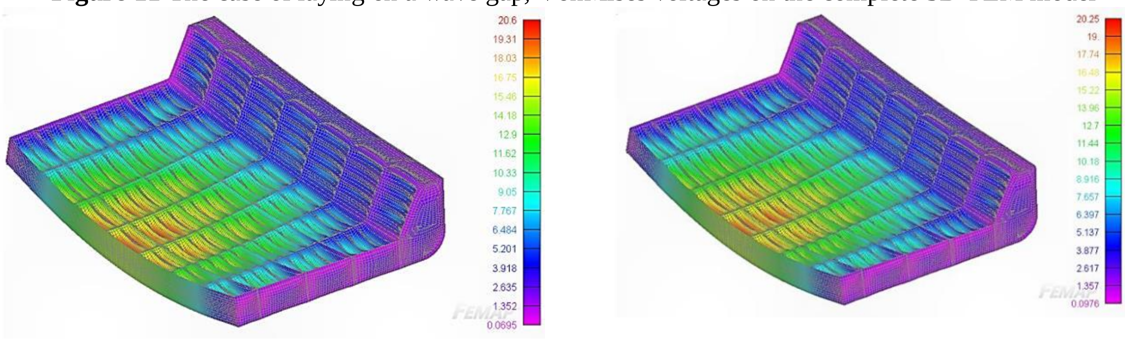
Figure 11 The case of laying on a wave gap, VonMises voltages on the complete 3D-FEM model



a) b)

Figure 12 The case of placing on a wave gap, the displacements that appear in the complete 3D-FEM model

3.2.2 The case of static placement of the vessel on hogging

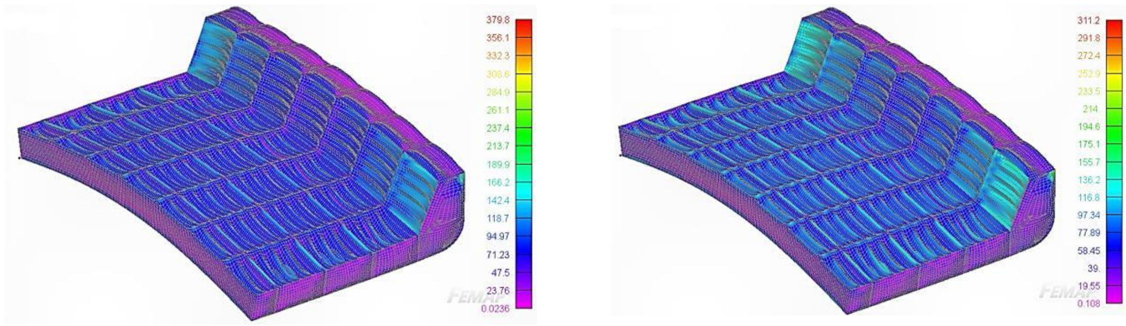
In the case of placement of the vessel on the hogging, the compensation of absence of bulb by increasing longitudinal thicknesses has the effect of decrease of voltages in the most stressed areas (longitudinal bilge plating) of up to 68.6 MPa, so that at the level of voltage concentrators at the extremities of the model maximum values of 311.2 MPa are registered.

Analyzing **Figure 13**, it can be seen how the stresses in the outer plating vary between 31 MPa and 93 MPa, in areas without concentrators, reaching up to 261.9 MPa when extending the bilge plating to the planking for reasons of discontinuity. The bottom plating, in this case, is subjected to compression.

The maximum stresses obtained after adjustment of thicknesses are within the limits allowed by the material flow limit.

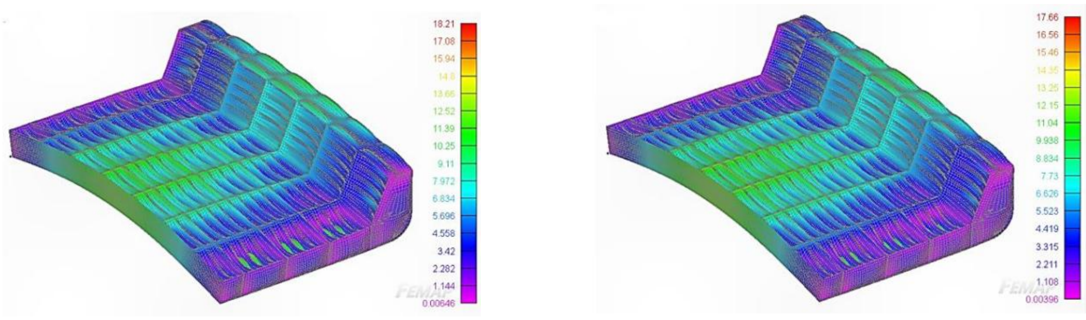
For this loading case, the average stresses per element do not exceed the allowable values prescribed by the CSR, reaching up to 185 MPa for the double bottom plating, 225 MPa for the bottom plating and 219 MPa for the longitudinal elements of bilge.

The movements are manifested predominantly, this time, on the board of the outer plating of the bottom, in the central area of the bowlocker, for the previous stated reasons for the other cases of loading.



a) b)

Figure 13 The case of sitting on the wave ridge, VonMises voltages on the complete 3D-FEM model



a) b)

Figure 14 The case of settling on the wave ridge, the displacements that appear in the complete 3D-FEM model

IV. CONCLUSION

As a result of the FEM analysis, the areas with voltage concentrators that could not be highlighted after pre-dimensioning in POSEIDON were highlighted.

Based on the above obtained results, a series of conclusions can be drawn regarding the structural resistance of the vessel for the studied cases: still water, wave, sagging and hogging.

In areas where stress concentrators exceed the allowable flow value of steel ReH = 315 N/mm^2, it is possible to choose a steel with a higher quality, AH36 or A420, with flow limit ReH = 355 N/mm^2 and ReH = 420 N/mm^2 having tested the resistance to shock at a temperature of ± 0oC, or thicknesses of sheets and profiles larger than those dimensioned in the sample shall be adopted.

In order to reduce the tensions in the extreme fibers, it is possible to use the welding of flat strips around the technological cuts, these having the role of taking over from the loads of the stiffening elements.

Another way to eliminate areas with stress concentrators is to add stiffening ribs between the profiles.

The results obtained using this method can be used to optimize the structural resistance of naval structures.

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