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ON THE STRUCTURAL ANALYSIS BY A MIDSHIP CARGO-HOLDS MODEL OF AN OIL TANKER 105930 DWT

Bilea-Pricop Andreea
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati, 47
Domneasca Street, 800008, Romania,
Email: bileaandreea@yahoo.com

Leonard Domnisoru
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati, 47
Domneasca Street, 800008, Romania,
Email: leonard.domnisoru@ugal.ro

ABSTRACT

This paper aims to analyze global-local structural analysis using a model with three tanks in the central area of an oil tanker. Taking into account the negative effects of petroleum cargo on marine fauna and flora, regulations have been imposed to reduce pollution in the marine environment. As a result, the stresses and deformations state of tanker vessels is an aspect of great interest in the design phase. Also, the paper captures the influence of the navigation conditions on the structure of the ship's hull and the effect that sloshing in cargo tanks has on the inner hull.

Keywords: oil tank structure, FEM analysis, sloshing effect.

1. INTRODUCTION

In this study, the global and local strength of a 105930 DWT oil tanker is analyzed, using 3D-FEM models developed with the Femap/NX Nastran program [6]. The ship's main dimensions were taken from the JSEA catalog [3]. Based on this data, a series of evaluations were made regarding the ship's main dimensions [2], being requested in the preliminary dimensioning of the ship's structure, by the DNV rules [4], [5].

Table 1 The main dimensions of the ship [3].

Dimension	Value	Unit
L_{oa}	243	m
L_{pp}	233	m
B	42	m
D	20.7	m
T	14.7	m
Dwt	105 930	tdw

The amidships model of the three cargo tanks is shown in Figure 1.

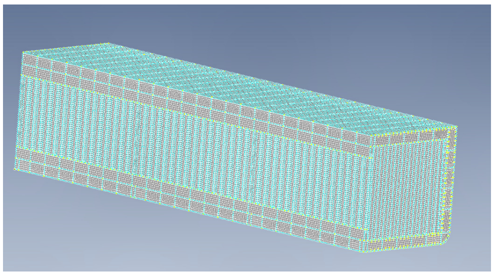

Fig.1 Amidships model of cargo-holds.

1.1. Boundary conditions

To integrate the structure composed of the three cargo tanks, extended into a single board, into the ship's hull, two master nodes were generated at the extremities of the FEM model, in which the specific constraints were applied (Table 2) [1]. The model is characterized by symmetry towards the diametral plane, which restrains translation after the transversal direction (y) and the rotation after the longitudinal axis (x) in the nodes located in the diametral plane of the ship [1].

Table 2. Boundary restrained conditions [1].

Boundary conditions	Degrees of freedom					
	U_x	U_y	U_z	R_x	R_y	R_z
Diametral plan	-	×	-	×	-	-
AFT master node	×	×	×	×	-	×
FORE master node	-	×	×	×	-	×

1.2. Loads

The model is subjected to the following types of loads: the gravitational load, generated by the ship's weight, the load from the quasi-static equivalent wave that acts on the outer shell, the cargo load pressure on the inner hull, as well as the global loads from the bending moments at the bow master node, respectively at the stern master node that corresponds to the global analysis of the model. Considering the navigation conditions, the wave pressure changes accordingly, and the most favorable case is the navigation in calm water conditions, as well as the most unfavorable is the navigation without restrictions when the height of the wave reaches the maximum design value of 10.3 m [4],[5], but also the intermediate cases of the two extreme situations are presented.

2. NUMERICAL RESULTS FROM THE GLOBAL-LOCAL STRENGTH ANALYSIS

Taking into account the stress state of the initial FEM model, it was decided to improve it by increasing the thickness of the shells whose stress state exceeded the allowed limits and also by choosing larger profile structural elements.

The values of stress, as well as the differences between the two generated FEM models, are centralized in Table 3.

Table 3. The percentage difference between the two structural variants

Condition	Improved structure [MPa]	Initial structure [MPa]	Difference [%]
Hogging, Still Water	172.76	203.45	-15%
Hogging, RE 50%	169.83	180.71	-6%
Hogging, R4 60%	188.8	199.66	-5%
Hogging, R3 70%	208.17	218.71	-5%
Hogging, R2 80 %	227.65	237.88	-4%
Hogging, R1 90%	247.24	257.16	-4%
Hogging, R0 100%	266.83	276.71	-4%
Sagging, Still Water	166.98	168.58	-1%
Sagging, RE 50%	189.51	258.13	-27%
Sagging. R4 60%	199.47	272.16	-27%
Sagging, R3 70%	209.07	285.47	-27%
Sagging, R2 80%	221.79	298.22	-26%
Sagging, R1 90%	234.32	310.38	-25%
Sagging, R0 100%	250	321.82	-22%

3. THE SLOSHING EFFECT ON THE OIL-TANKER STRUCTURE STRENGTH

Since cargo tanks can be loaded at various percentages of their capacity, the additional pressure given by the sloshing effect was also taken into account. Therefore, using the DNV-GL [4] rules, the additional sloshing pressure for two cases was calculated: full tanks and half-loaded tanks. As expected, in the case of loading tanks at 98% of their capacity (full load), the sloshing phenomenon does not occur. In the other case, considerable values are obtained for the additional sloshing pressure. Thus, the longitudinal component of the additional sloshing pressure has a value of 0.0627 N/mm^2, and in the transverse direction, 0.027 N/mm^2.

The following results are for the case of the tanks loaded at 50% of their capacity. Given the roll and pitch oscillations of the ship, the pressures are applied in the corresponding directions of action.

So, for the roll oscillation, the additional pressure acts on the inner hull and the longitudinal corrugated bulkhead, and in the case of the pitch oscillation, the pressure acts on the transverse bulkheads.

To apply the supplementary sloshing pressures, it is necessary to extend the FEM model on both sides.

In the hogging condition, as shown in Table 4, differences in stress values are observed between the model extended on one side and the model extended on both sides, attributed to variations in the formulation of boundary conditions.

Table 4. Differences between stress values, design equivalent wave h_w=10.3, navigation class R0(100%), by the two FEM models

Stress values [MPa]	Both sides model	One sided model	Difference [%]
3D-FEM Model	280.72	266.83	5%
Bottom and bilge	272.36	266.83	2%
Double bottom	198.59	197.31	1%
Outer and inner shell	251.3	234.11	7%
Deck	259.54	240.89	8%
Longitudinal bulkhead	185.16	173.66	7%
Transversal bulkhead	**133.27**	**78.815**	**69%**
Transversal elements	102.27	105.96	-3%
Longitudinal elements	280.72	260.39	8%

According to the presented results (Table 4), at the transversal bulkheads, the stress increases by 69%. This is caused by the initial boundary conditions in the diametrical plane that provided increased rigidity to those transversal bulkheads.

The other differences are minimal and there are no structural issues.

In the case of roll oscillations, a local increase in stress values is observed due to the additional sloshing pressure, as shown in Table 5.

Table 5. Differences between stress values, design equivalent wave h_w=10.3 m, navigation class R0 (100%), by the FEM extended model in both sides and model with supplementary sloshing pressure, roll oscillations

Stress values [MPa]	No sloshing effect	Model with sloshing	Difference [%]
Model 3D-FEM	280.72	283.4	1%
Bottom&bilge	272.36	273.3	0%
Double bottom	198.59	198.73	0%
Outer& inner shell	251.3	255.6	2%
Deck	259.54	263.85	2%
Longitudinal bulkhead	185.16	192.14	4%
Transversal bulkhead	133.27	139.11	4%
Transversal elements	**102.27**	119.07	16%
Longitudinal elements	**280.72**	283.43	1%

Table 6. FEM model with roll oscillations effect, inner hull stress

Case Stress values	Loads from wave and cargo [MPa]	Loads from wave, cargo and sloshing [MPa]	Difference
Max global stress	240.18	244.02	1.6%
Local stress in the area of sloshing effect	165.78	199.31	20.2%

Also, in the case of the pitch oscillation, the transversal bulkheads are additionally loaded with sloshing pressure. In this case, both a local and global increase in the state of stress of the bulkheads can be observed, as shown in Table 7.

Table 7. Differences between stress values, design equivalent wave h_w=10.3 m, navigation class R0 (100%), model extended in both sides and model with supplementary longitudinal pressures due to sloshing

Stress values [MPa]	Model extended in both sides	One side model	Difference [%]
3D-FEM Model	280.72	280.83	0%
Bottom&bilge	272.36	271.71	0%
Double bottom	198.59	197.57	-1%
Outer& inner shell	251.3	252.56	1%
Deck	259.54	260.67	0%
Longitudinal bulkhead	185.16	190.65	3%
Transversal bulkhead	133.27	161.67	21%
Transversal elements	102.27	102.6	0%
Longitudinal elements	280.72	280.83	0%

Tabel 8. FEM model with pitch oscillations, transversal corrugated bulkheads

Case Stress values	Loads from wave and cargo [MPa]	Loads from wave, cargo and sloshing [MPa]	Difference [%]
Max. global stress	133.27	161.67	21.3%
Local stress in the area of sloshing effect	16.742	30.792	83.9%

According to the numerical results, the sloshing phenomenon does not present a significant danger to the structure of the oil tanker.

4. VERISTAR HULL ANALYSIS OF THE OIL-TANKER HULL STRUCTURE

Unlike the quasi-static equivalent design wave at following / head design wave used in the first part of the study to analyze the oil-tanker structure, this section considers the ship subjected to oblique, beam, and following / head equivalent design waves, analyzed using the BV Veristar Hull Analysis program [7],[8].

The wave pressure applied by user procedures in the Femap/NX Nastran model [6] in the first part of the study is now generated by the BV program [7],[8]. The analyzed conditions are according to Figs 2, 3, and 4. The final numerical maximal stresses are presented in Table 9.

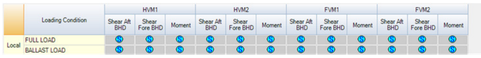

Fig.2 Sea going (Head & Following Seas)

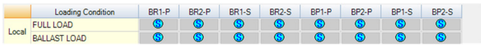

Fig.3 Sea going (Beam Seas)

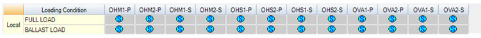

Fig 4. Sea going (Oblique Seas)

Table 9. FEM model, VeristarHull Analysis, maximal stresses

Elements	Stress [MPa]
3D-FEM Model	483.36
Bottom&bilge	251.1
Double bottom	245.37
Shell	265.47
Inner hull	247.32
Deck	271.9
Long bulkhead	197.14
Transverse bulkhead	360.71
Transversal elements	483.36
Double bottom girders	218.68
Deck girders	209.81
Low&upper stool	197.14
Double hull platforms	226.83

Analyzing the FEM results, a significant state of stress is observed at the level of the transversal bulkheads and the intersection of the transversal elements.

To better understand the distribution of stress in the areas of interest, new FEM analyses are made with finer mesh in the structural zones exceeding the admissible limits.

The intersection of the transversal bulkhead with the shell of the double hull, but also with the shell of the double bottom, has stress values above the admissible limit. The hot-spot stress phenomenon was locally analyzed, constituting an area of interest, and thus the transition to a finer mesh of 50x50 mm was made.

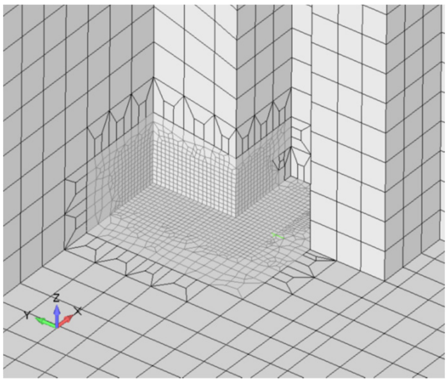

Fig 5. The transition from coarse mesh to finer mesh

The welded elements are illustrated in Fig.6 and they are required for the check of the stress state values. The stress values in the area of interest are highlighted in Figs. 8 and 9, reaching the maximum value of 758.31MPa in the hot-spot stress area. To verify the stress state of the model, the values obtained were compared with the admissible values, illustrated in Fig 7.

Allowable VM stress			
	-	welded elements	not welded elements
R_{eh} [mPa]	coarse mesh	50x50 - steel ships	
315	281.3	377.0	430.4

Fig 7. Allowable von Misses Stress [7],[8].

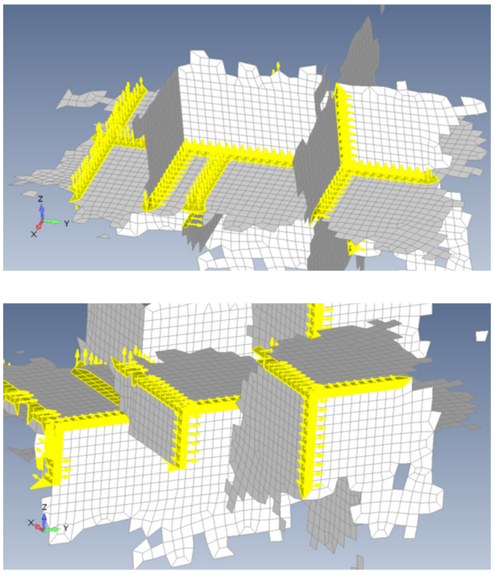

Fig 6 a, b. Welded elements

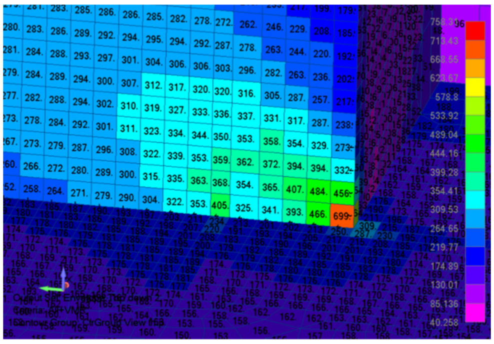

Fig 8. Stress values above double bottom

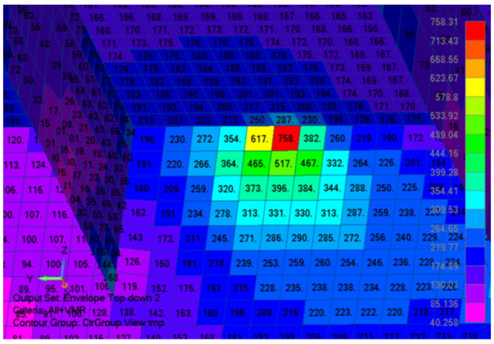

Fig 9. Stress values below double bottom

Comparing the values of the stress state obtained using a fine mesh (50x50) with the maximum allowed values, it is observed that in the case of some elements around interest, the stress state exceeds the imposed limit. Thus, the structural model will need improvement by design to eliminate these stress hot spots at the structural elements' joints.

5. CONCLUSIONS

Based on the first analysis performed with Femap/NX Nastran [6], it can be stated that:

• The stress state of the model is within the permissible limits, from cargo and design wave pressures, acting on the ship in the head / following sea condition.

• The extension of the FEM model on both sides and the removal of the symmetry conditions in the diametrical plane, denotes the existence of higher stresses at the level of the transversal bulkheads, compared to the FEM model extended only on a single side.

• The sloshing phenomenon does not affect the structure globally, but locally. A significant increase in the stress state of the shells in question can be noticed.

Based on the second analysis by the VeriStar Hull [8], it can be stated that:

• The FEM model subjected to oblique, beam, and following / head equivalent design waves presents certain hot-spot stress areas (well delimited and highlighted) in which the stress values significantly exceed the admissible stress limits, due to the lack of additional stiffening elements.

• Overall, analyzing the stress state of the FEM model, it is observed that it is moderate, withstanding the imposed design navigation conditions [4],[7].

Recommendations: placing stools at the level of the transversal bulkheads, placing brackets at the joints of the transversal elements, and reinforcing the double bottom area in correspondence with the intersection of the transversal bulkheads.

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