THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XI – SHIPBUILDING. ISSN 1221-4620
2017

COMPARATIVE STUDY OF FULL LENGTH AND TWO CARGO HOLDS 3D MODELS FOR STRENGTH ANALYSIS OF A TANKER SHIP STRUCTURE

Dan Sebastian Cioarec
University of Liege,
Faculty of Applied Sciences – ANAST, Liege
Place du 20 Août, 7 Bât.A1, 4000 Liegè, Belgium,
E-mail: dan.cioarec@yahoo.com

Elisabeta Burlacu
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati,
47 Domneasca Street, 800008, Romania,
E-mail: elisabeta.burlacu@ugal.ro

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

ABSTRACT

This study is focused on the sensitivity analysis of different structural models used for global and local strength assessment in the case of head equivalent design wave loads acting on the ship hull. Four types of structural models are considered: a 3D-FEM model full extended over the whole ship length, one sided, with coarse mesh shell elements; a 1D equivalent beam model, vertical bending and shearing behaviour, with the mass distribution and the external hull shape imported from the 3D-FEM model, with a coarse beam mesh; a 3D-FEM model extended over two cargo holds amidships, in two versions with coarse and fine mesh shell elements for structural details, with model characteristics and loads taken directly from the 3D-FEM extended model and the boundary displacements and rotations from the elastic 1D-equivalent beam model. In the case of 3D-FEM full extended model, the balance ship-EDW is obtained by user subroutines implemented directly in the FEM program. For 1D model an own program code is used in the case of head EDW waves, with a non-linear iterative approach. The stress post-processing of the 3D-FEM models is done by specific user subroutines. As numerical study case a chemical tanker with 3950.6 m^3 cargo capacity is considered. The study by the four structural models has revealed a good correlation of the numerical results, corresponding to the specific sensitivity ensured by each model.

Keywords: global and local strength, head equivalent design wave, 3D and 1D structural models.

1. INTRODUCTION

According to the rules [2] different types of structural models can be used for the global and local strength, the design stage.

The best method is based on 3D-FEM hull structure models whole extended over the ship length [4],[5]. The ship shape, rigidities and mass are modelled realistic, making possible to have simultaneously the global and local strength response. In the case of head EDW equivalent design waves [7],[10], with a quasi-static formulation, having one sided 3D model and centre line nodes symmetry condition, as the equilibrium ship-EDW is obtained by an iterative approach implemented in user subroutines directly into the FEM program [9]. The equilibrium approach requires two objective functions implemented by the vertical reaction forces at two nodes, aft and fore, with vertical simple support boundary conditions. This approach can be applied in the case of advanced design level of the whole ship, in order to have the details for structures and mass modelling. The overall mesh size is coarse, so that supplementary for any structural details local models with fine mesh size may be considered. For post-processing of the stress distributions user subroutines are used. The yielding stress limit and buckling criteria are used for ship strength assessment. The theoretical details of the 3D-FEM full extended models method are presented in references [4],[5].

Starting from the initial design stages, the global strength of the hull can be assessed by 1D equivalent beam models, full extended over the ship length [4]. The exact external ship shape is considered. The rigidities and the mass are idealized by the ship equivalent beam [4], making this method suitable only for global strength analysis, without any information for the local strength. The ship-EDW equilibrium is obtained by an iterative approach, implemented in own code P_ACASV [4].

Although the 1D model method has the smallest accuracy as compared to the 3D models, this approach requires a minimum of input data and is the fastest method for ship global strength assessment, being suitable for any design stage. In order to increase the accuracy of this method, besides the external shape a good correlation of the equivalent rigidities and masses to the 3D-FEM models must be ensured. The theoretical details of the 1D equivalent beam models method are presented in reference [4].

As a third option, the 3D-FEM partial extended models amidships, over several cargo-holds (at least two), can be used for the global and local strength assessment [6]. This kind of models represent the ships centre part, where the shape, rigidities and mass are realistic modelled. This models are recommended by rules [2], being the easy way to have also local strength results by 3D-FEM, even if the whole ship is not modelled. The equilibrium ship-EDW with this models cannot be obtained directly, as the 1D model results are required. By user subroutines with ship-EDW balance parameters the external wave pressure is applied. At both model extremities the boundary conditions, displacement and rotations, bending moments and shear forces, using a master-slave nodes technique and rigid bar elements connections, are modelling the global influence from the removed aft and fore parts structural blocks. In the case of head EDW waves the model is one sided, so that the centre line nodes symmetry boundary condition must be applied. The mesh size for this 3D partial extended models can be coarse but also fine. In the case of fine mesh size no other supplementary local models are necessary. The theoretical details of the 3D-FEM models extend over several cargo-holds amidships are presented in reference [6].

The numerical study, using all three structural models for global and local ship strength assessment with different mesh sizes, is developed for the chemical tanker, with 3950.6 m^3 cargo capacity, from a design concept from Ship Design Group Galati Company [3].

2. THE CHEMICAL TANKER DATA

The chemical tanker main data are:
-the chemical tanker characteristics (Table 1) [3];
-the chemical tanker offset-lines (Fig.1) [3];
-the chemical tanker mass diagram (Fig.2)[3].

Table 1. The chemical tanker characteristics [3]

LOA [m]	109.62	Steel AH 40	390
LBP [m]	106.20	N_{ND} (1D)	165
B [m]	13.50	N_{EL} (1D)	164
H [m]	8.60	Type (1D)	Beam
T [m]	5.45	δx [m] (1D)	0.3÷0.7
ρ [t/m^3]	1.025	N_{ND} (3D-full)	49508
g [m/s^2]	9.81	N_{EL} (3D-full)	110558
Δ [t]	5380.18	Type (3D)	Shell
E [N/m^2]	2.1e+11	Size(3D)[m]	0.3÷1.2
ν	0.3	h_w [m]	0÷8.123
ρ_m [t/m^3]	7.7	EDW length	λ=*L*
Steel A	235	EDW angle	head

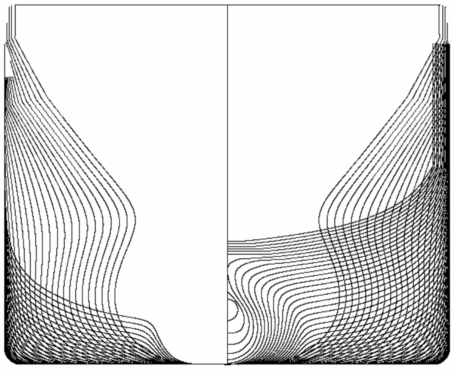

Fig.1 Chemical tanker offset-lines [3].

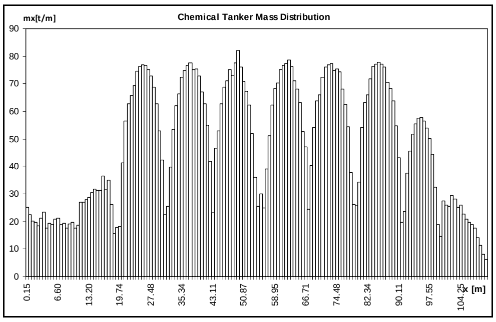

Fig.2 Chemical tanker mass distribution [3].

3. THE 3D-FEM FULL EXTENDED MODEL, LOAD HEAD EDW WAVE, STRENGTH ANALYSIS

The 3D-FEM model full extended for the chemical tanker (CTK), with coarse mesh is presented with details in Figs. 5.1-4 with 3D-CAD model from Figs. 4.1-4, considering the blocks division from Fig. 3 [3].

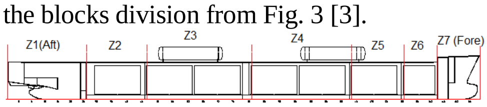

Fig.3 Chemical tanker hull blocks division[3]

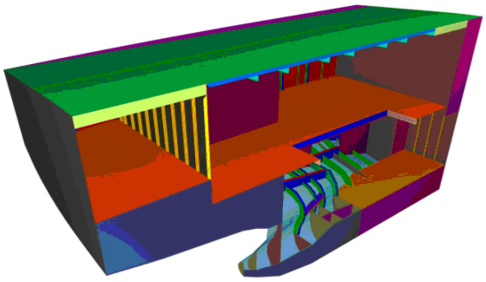

Fig.4.1 3D-CAD, CTK, aft block (1)

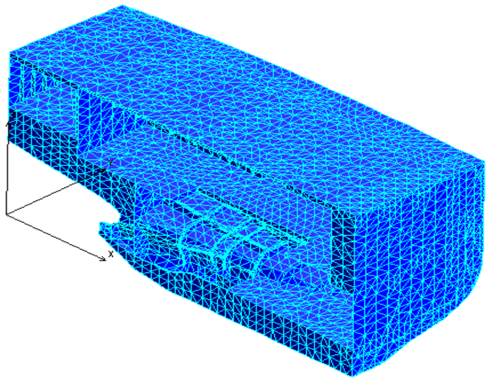

Fig.5.1 3D-FEM, CTK, aft block (1)

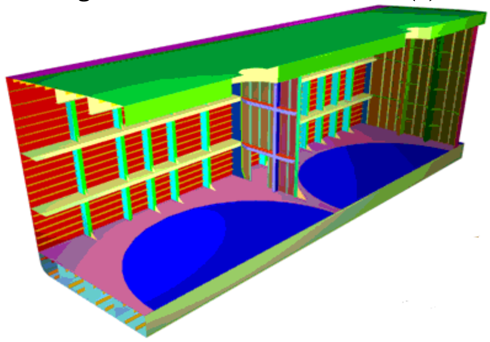

Fig.4.2 3D-CAD, CTK, amidships block (4)

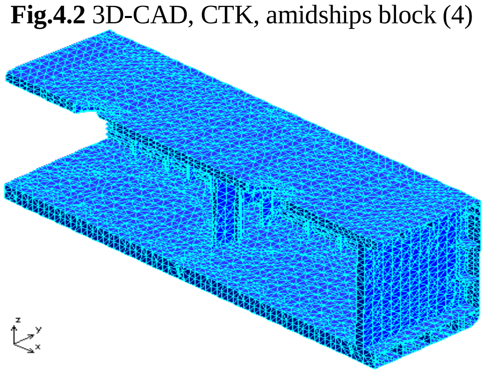

Fig.5.2 3D-FEM, CTK, amidships block (4)

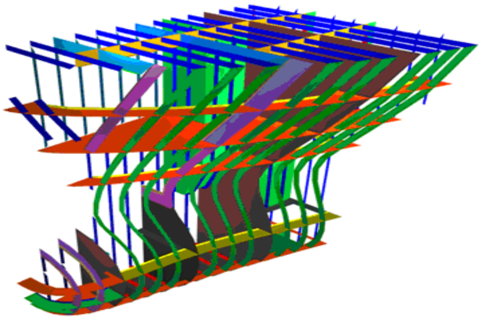

Fig.4.3 3D-CAD, CTK, fore block (7)

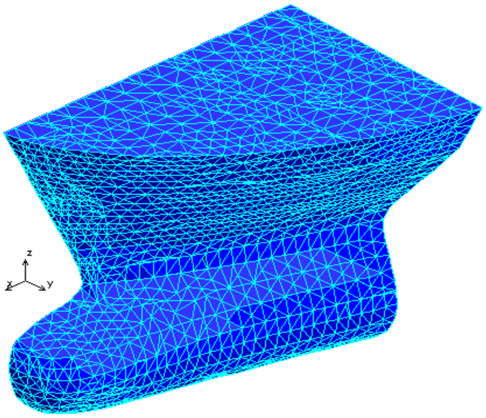

Fig.5.3 3D-FEM, CTK, fore block (7)

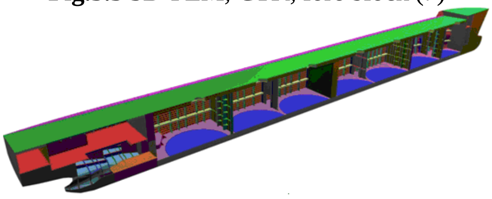

Fig.4.4 3D-CAD, CTK, full extended model

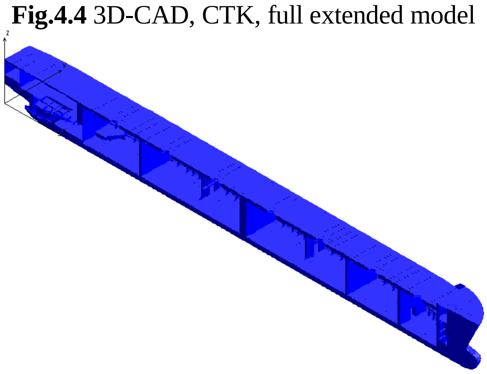

Fig.5.4 3D-FEM, CTK, full extended model

In the case of the 3D-FEM model full extended for the chemical tanker, using the iterative algorithm and the user subroutines from reference [4], results:

-Figs.6.1-5 the water pressure, 3D full model;
-Figs.7.1-5 the von Mises equivalent stress on the whole chemical tanker structure;
-Figs.8.1-2 maximum deck normal stress;
-Figs.9.1-2 maximum bottom normal stress;
-Figs.10.1-2 maximum side tangential stress;
-Tabs.2.1-2 equilibrium parameters of chemical tanker - EDW and maximum deflection;
-Tabs.3.1-2 maximum and admissible stresses at deck, bottom and side panels.

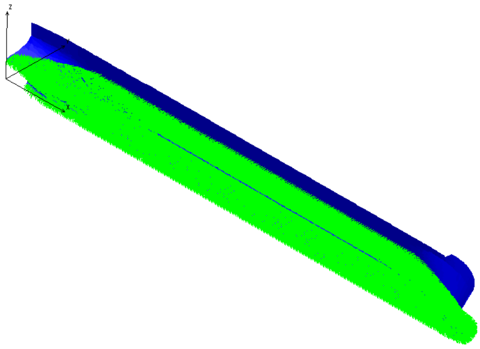

Fig.6.1 3D full, water pressure, h_w=0, sw.

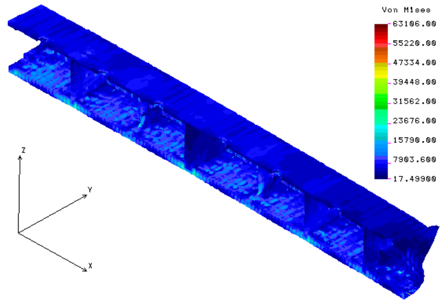

Fig.7.1 3D full,σ_{vM} [kN/m^2],h_w=0,still water.

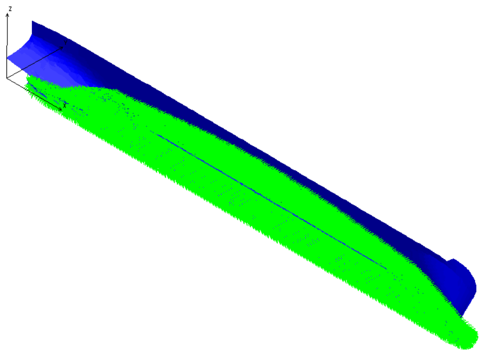

Fig.6.2 3D full, water pressure, h_w=4, hogg.

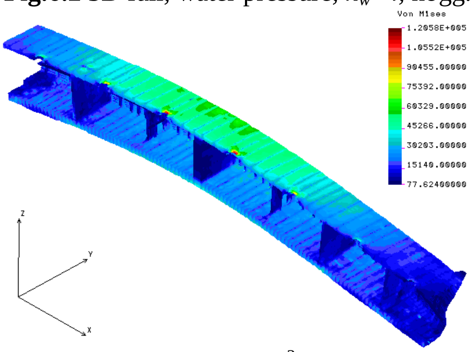

Fig.7.2 3D full, σ_{vM} [kN/m^2], h_w=4, hogging.

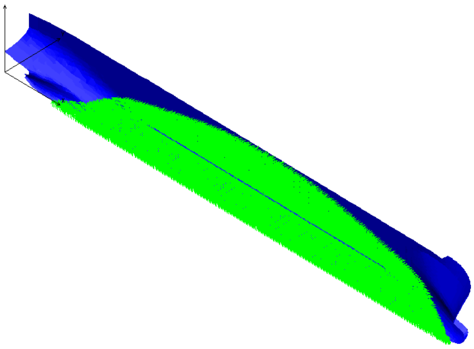

Fig.6.3 3D full, water press., h_w=8.123, hogg.

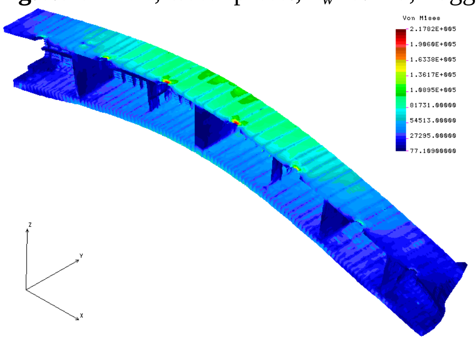

Fig.7.3 3D full,σ_{vM} [kN/m^2], h_w=8.123, hogg.

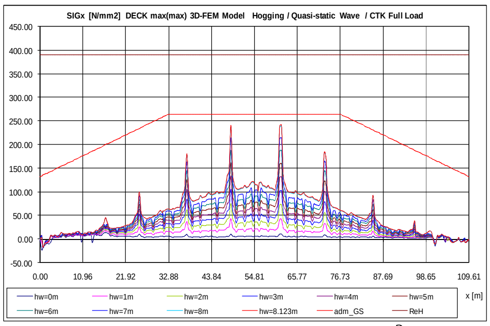

Fig.8.1 3D full, deck max. σ_x [kN/m^2], hogg.

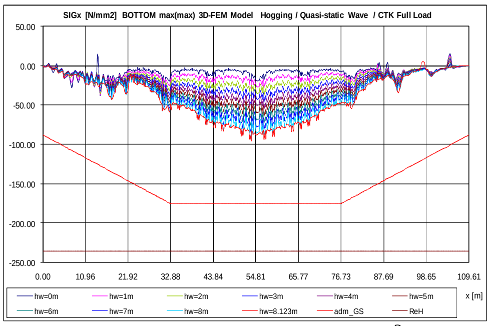

Fig.9.1 3D full, bott. max. σ_x [kN/m^2], hogg.

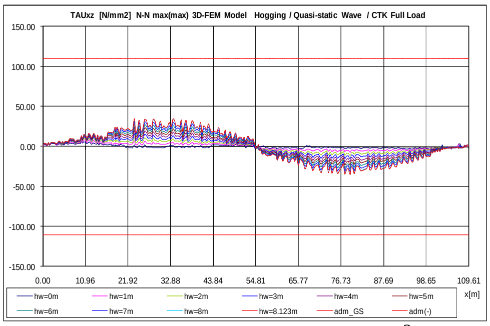

Fig.10.1 3D full, side max. τ_{xz} [kN/m^2],hogg.

Table 2.1 3D-FEM full, ship-EDW equilibrium parameters (d_m, *trim*), maximum vertical deflection (w_{adm} =L/500=0.219 m), hogging

h_w[m]	d_m[m]	*trim*[rad]	w_{max}[m]	$\|w_{max}\|/w_{adm}$
0	4.412	0.003188	-0.0459	0.209
1	4.344	0.001416	-0.0412	0.188
2	4.263	0.000254	0.0403	0.184
3	4.172	0.000471	0.0538	0.245
4	4.075	0.001381	0.0669	0.305
5	3.973	0.002635	0.0797	0.364
6	3.864	0.004060	0.0921	0.420
7	3.746	0.005676	0.1039	0.474
8	3.613	0.007612	0.1145	0.522
8.123	3.595	0.007874	0.1156	0.527

Table 3.1 3D-FEM full, maximum stresses, deck, bottom and side, reference h_w=8.123 m, hogging EDW wave case

Panel stress	Stress 3D [MPa]	ReH [MPa]	Cs= ReH/ Stress_3D	Stress 1D [MPa]	3D/1D
Max. σ_x deck	241.20	390	1.617	98.25	2.45
Max. σ_{vonM} deck	217.80	390	1.791	98.25	2.21
Max. σ_x bottom	94.89	235	2.477	71.27	1.33
Max. σ_{vonM} bottom	85.62	235	2.745	71.27	1.20
Panel stress	τ_{3D} [MPa]	τ_{adm} [MPa]	3D/adm	τ_{1D} [MPa]	3D/1D
Max. τ_{xz} side	34.70	110	0.315	40.09	0.86

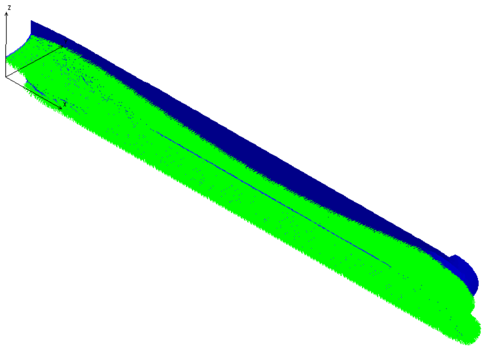

Fig.6.4 3D full, water press., h_w=4, sagging.

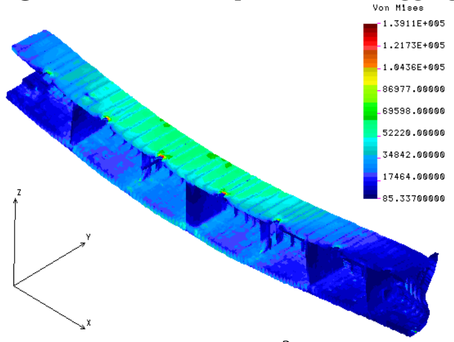

Fig.7.4 3D full, σ_{vM} [kN/m^2], h_w=4, sagging.

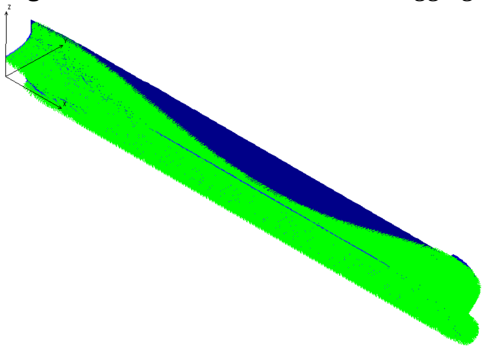

Fig.6.5 3D full, water press., h_w=8.123, sagg.

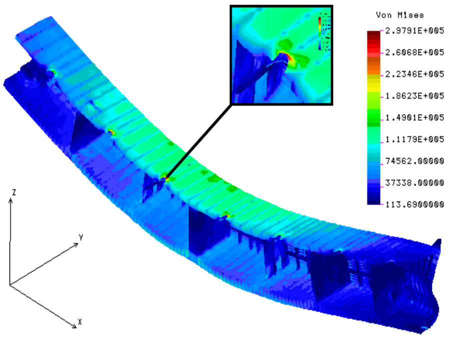

Fig.7.5 3D full, σ_{vM} [kN/m^2], h_w=8.123,sagg.

Table 2.2 3D-FEM full, ship-EDW equilibrium parameters (d_m, *trim*), maximum vertical deflection (w_{adm} =L/500=0.219 m), sagging

h_w[m]	d_m[m]	*trim*[rad]	w_{max}[m]	$\|w_{max}\|/w_{adm}$
0	4.412	0.003	-0.0459	0.209
1	4.469	0.007	-0.0539	0.246
2	4.518	0.010	-0.0608	0.277
3	4.562	0.013	-0.0678	0.309
4	4.602	0.015	-0.0746	0.340
5	4.638	0.016	-0.0886	0.404
6	4.671	0.017	-0.1081	0.493
7	4.700	0.018	-0.1279	0.583
8	4.726	0.019	-0.1482	0.676
8.123	4.729	0.019	-0.1507	0.687

Table 3.2 3D-FEM full, maximum stresses, deck, bottom and side, reference h_w=8.123 m, sagging EDW wave case

Panel stress	Stress 3D [MPa]	ReH [MPa]	Cs= ReH/ Stress_3D	Stress 1D [MPa]	3D/1D
Max. σ_x deck	329.90	390	1.18	121.17	2.72
Max. σ_{vonM} deck	297.90	390	1.30	121.17	2.46
Max. σ_x bottom	111.30	235	2.11	87.90	1.27
Max. σ_{vonM} bottom	106.50	235	2.207	87.90	1.21
Panel stress	τ_{3D} [MPa]	τ_{adm} [MPa]	3D/adm	τ_{1D} [MPa]	3D/1D
Max. τ_{xz} side	47.85	110	0.435	48.27	0.99

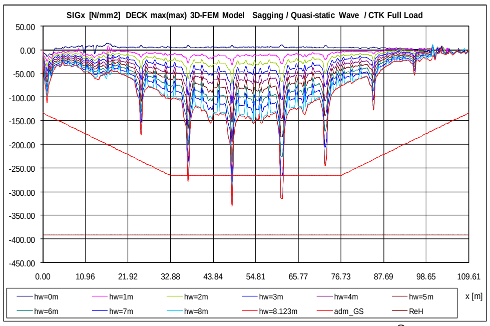

Fig.8.2 3D full, deck max. σ_x [kN/m^2], sagg.

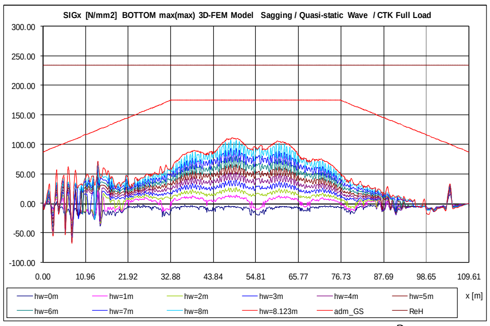

Fig.9.2 3D full, bott. max. σ_x [kN/m^2], sagg.

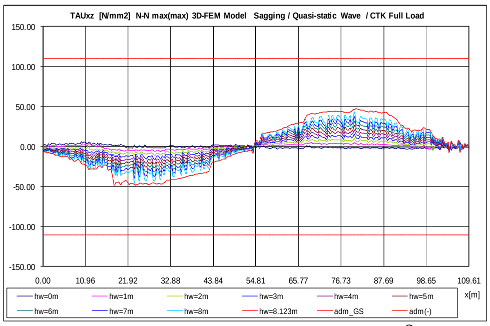

Fig.10.2 3D full, side max. τ_{xz} [kN/m^2],sagg.

4.THE 1D MODEL CTK HEAD EDW WAVE STRENGTH ANALYSIS

For the chemical tanker, by 1D model and the iterative procedure [4], results:
-Table 4 equilibrium parameters of chemical tanker - EDW, hogging and sagging;
-Table 5 maximum and admissible stresses;
-Figs.11.1-2 deck normal stress;
-Figs.12.1-2 bottom normal stress;
-Figs.13.1-2 side tangential stress.

Table 4. Equilibrium parameters by 1D model

1D	hogging		sagging	
h_w[m]	d_m[m]	*trim*[rad]	d_m[m]	*trim*[rad]
0	4.412	0.002800	4.412	0.002800
1	4.344	0.000930	4.469	0.005080
2	4.266	0.000050	4.518	0.007330
3	4.177	0.000090	4.559	0.009420
4	4.074	0.001210	4.594	0.011290
5	3.964	0.002730	4.625	0.012920
6	3.846	0.004480	4.651	0.014280
7	3.718	0.006450	4.673	0.015420
8	3.575	0.008700	4.693	0.016370
8.123	3.556	0.009000	4.695	0.016480

Table 5. Maximum and adm stress, 1D model

Panel stress	Stress max 1D [MPa]	Stress adm_GS [MPa]	max/ adm_GS
Hogging EDW wave			
Maximum σ_x deck	98.25	265	0.37
Maximum σ_x bottom	71.27	175	0.41
Maximum τ_{xz} side	40.9	110	0.37
Sagging EDW wave			
Maximum σ_x deck	121.17	265	0.46
Maximum σ_x bottom	87.90	175	0.50
Maximum τ_{xz} side	48.27	110	0.44

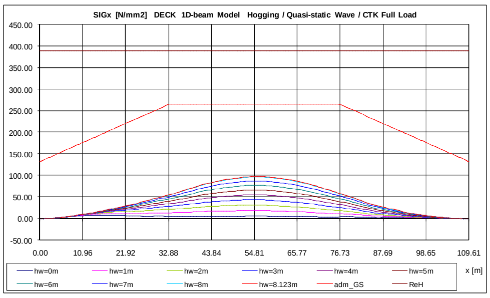

Fig.11.1 1D CTK, deck σ_x [MPa], hogg.

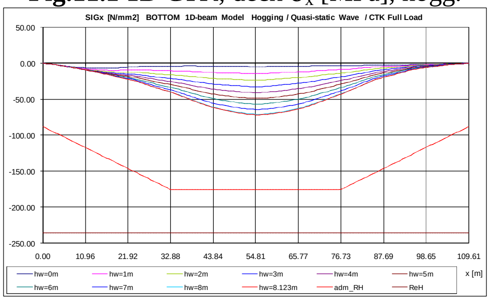

Fig.12.1 1D CTK, bottom σ_x [MPa], hogg.

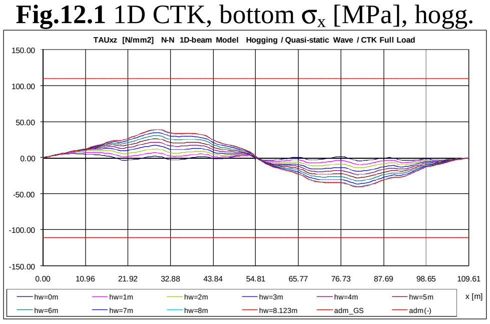

Fig.13.1 1D CTK, side τ_{xz} [MPa], hogg.

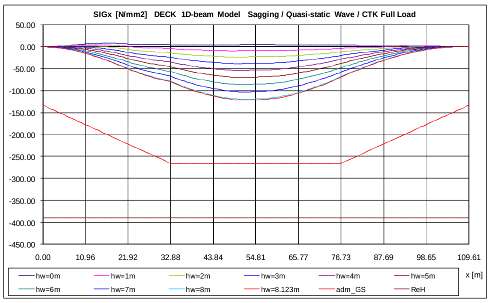

Fig.11.2 1D CTK, deck σ_x [MPa], sagg.

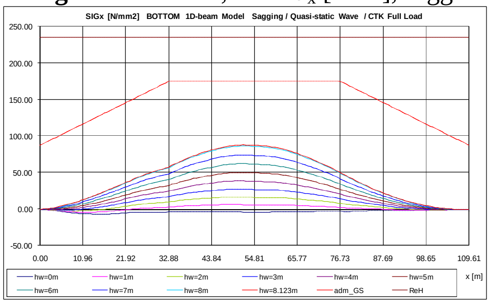

Fig.12.2 1D CTK, bottom σ_x [MPa], sagg.

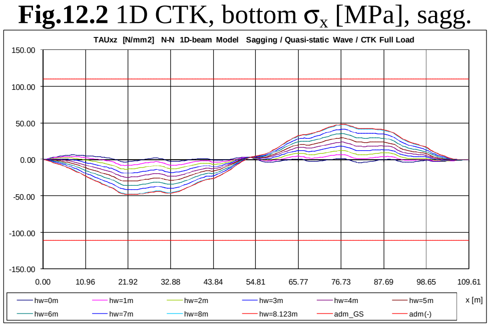

Fig.13.2 1D CTK, side τ_{xz} [MPa], sagg.

5. THE 3D-FEM TWO CARGO HOLDS MODEL, LOAD HEAD EDW WAVE, STRENGTH ANALYSIS

For the 3D-FEM two cargo holds model of the chemical tanker, extended for 31.772m to 80.224m (Fig.14, blocks 3-4), with coarse and fine mesh, by the method from [6], results:
-Table 6 global boundary conditions;
-Figs.15.1,2 water pressure, h_w=8.123;
-Figs.16.1,2 von Mises stress, h_w=8.123;
-Figs.17.1,2 and Figs.18.1,2 normal deck stress, in the case of coarse and fine mesh;
-Table 7.1-3 and Table 8.1-3 stress maximum values compared to the other two structural models of chemical tanker.

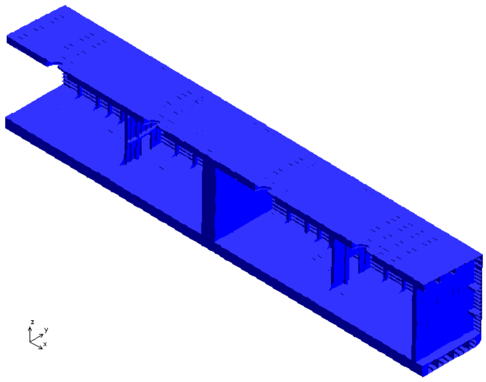

Fig.14 3D-FEM model of two cargo-holds

Table 6. Global boundary conditions, aft and fore node, two cargo holds 3D model, with 1D model equilibrium parameters

G.S.	Still water		Hogging h_w=8.123m		Sagging h_w=8.123m	
Node	aft	fore	aft	fore	aft	fore
x[m]	31.712	80.224	31.712	80.224	31.712	80.224
Uz[m]	0.00658	0.00536	0.07217	0.06761	-0.09600	-0.08476
Ry[rad]	0.00009	0.00015	-0.00189	0.00205	0.00237	-0.00260

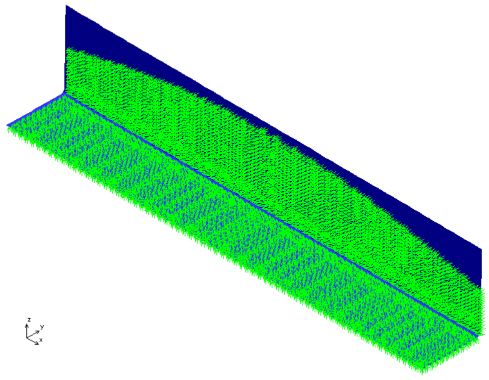

Fig.15.1 3D, water press., h_w=8.123, hogg.

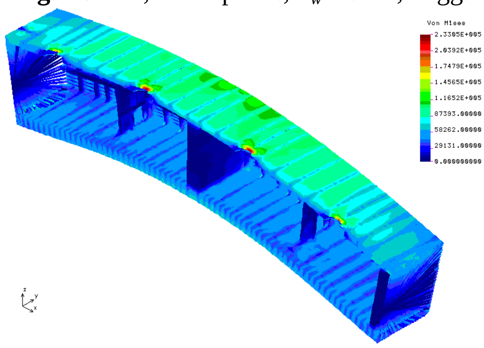

Fig.16.1 3D, σ_{vM} [kN/m^2], h_w=8.123, hogg.

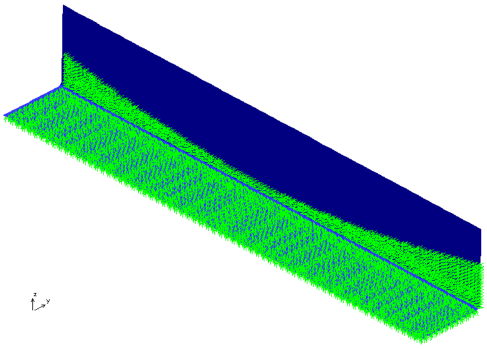

Fig.15.2 3D, water press., h_w=8.123, sagg.

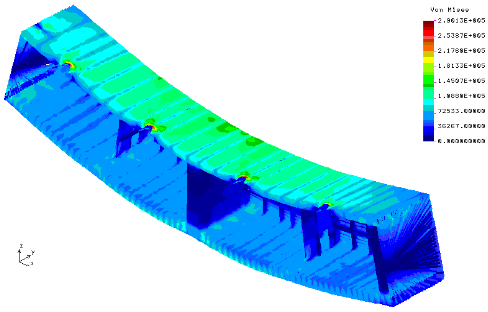

Fig.16.2 3D, σ_{vM} [kN/m^2], h_w=8.123, sagg.

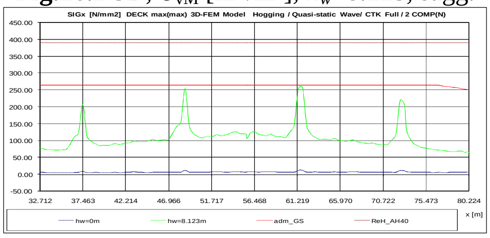

Fig.17.1 3D-2C,coarse, deck σ_x[MPa], hogg.

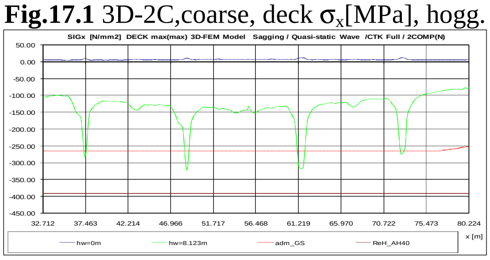

Fig.17.2 3D-2C,coarse, deck σ_x[MPa], sagg.

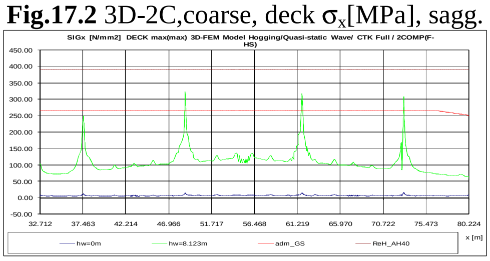

Fig.18.1 3D-2C,fine, deck σ_x[MPa], hogg.

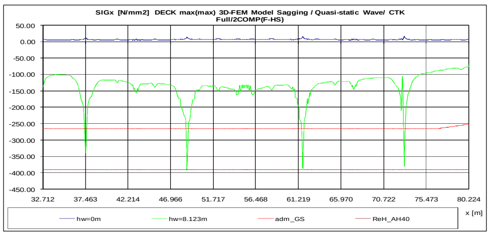

Fig.18.2 3D-2C,fine, deck σ_x[MPa], sagg.

Table 7.1 3D-2C, coarse, stresses [MPa], hogg.

D & B	σ_{3D}	ReH	Cs=R_{eH}/σ_{3D}	σ_{1D}	3D/1D
$\sigma_{x\ max\ D}$	257.90	390	1.512	98.25	2.625
$\sigma_{vM\ max\ D}$	233.00	390	1.674	98.25	2.372
$\sigma_{x\ max\ B}$	98.01	235	2.398	71.27	1.375
$\sigma_{vM\ max\ B}$	88.60	235	2.652	71.27	1.243
Side	τ_{3D}	τ_{adm}	3D/adm	τ_{1D}	3D/1D
$\tau_{xz\ max}$	35.78	110	0.325	40.09	0.892

Table 7.2 3D-2C, coarse, stresses [MPa], sagg.

D & B	σ_{3D}	ReH	Cs=R_{eH}/σ_{3D}	σ_{1D}	3D/1D
$\sigma_{x\ max\ D}$	321.30	390	1.214	121.17	2.650
$\sigma_{vM\ max\ D}$	290.10	390	1.344	121.17	2.390
$\sigma_{x\ max\ B}$	118.90	235	1.976	87.90	1.350
$\sigma_{vM\ max\ B}$	105.46	235	2.230	87.90	1.200
Side	τ_{3D}	τ_{adm}	3D/adm	τ_{1D}	3D/1D
$\tau_{xz\ max}$	42.36	110	0.385	48.27	0.870

Table 7.3 3D-Full & 2C-coarse, stresses [MPa]

h_w[m] 8.123	σ_{x3D} Full	σ_{x3D} 2C	σ_{x3D} F/2C	σ_{vM3D} Full	σ_{vM3D} 2C	σ_{vM3D} F/2C
D_{hogg}	241.20	257.90	0.94	217.80	233.00	0.93
D_{sagg}	329.90	321.30	1.03	297.90	290.10	1.03
B_{hogg}	94.89	98.01	0.97	85.62	88.60	0.97
B_{sagg}	111.30	118.90	0.94	106.50	105.46	1.01
side	τ_{xz3D} Full		τ_{xz3D} 2C		τ_{xz3D} Full /2C	
S_{hogg}	34.70		35.78		0.97	
S_{sagg}	47.85		42.36		1.13	

Table 8.1 3D-2C, fine, stresses [MPa], hogg.

D & B	σ_{3D}	ReH	Cs=R_{eH}/σ_{3D}	σ_{1D}	3D/1D
$\sigma_{x\ max\ D}$	321.57	390	1.213	98.25	3.27
$\sigma_{vM\ max\ D}$	294.76	390	1.323	98.25	3.00
$\sigma_{x\ max\ B}$	109.30	235	2.150	71.27	1.53
$\sigma_{vM\ max\ B}$	100.40	235	2.341	71.27	1.41
Side	τ_{3D}	τ_{adm}	3D/adm	τ_{1D}	3D/1D
$\tau_{xz\ max}$	36.52	110	0.332	40.09	0.91

Table 8.2 3D-2C, fine, stresses [MPa], sagg.

D & B	σ_{3D}	ReH	Cs=R_{eH}/σ_{3D}	σ_{1D}	3D/1D
$\sigma_{x\ max\ D}$	389.90	390	1.000	121.17	3.22
$\sigma_{vM\ max\ D}$	371.64	390	1.049	121.17	3.07
$\sigma_{x\ max\ B}$	120.70	235	1.947	87.90	1.37
$\sigma_{vM\ max\ B}$	107.80	235	2.180	87.90	1.23
Side	τ_{3D}	τ_{adm}	3D/adm	τ_{1D}	3D/1D
$\tau_{xz\ max}$	42.41	110	0.386	48.27	0.87

Table 8.3 3D-Full & 2C-fine, stresses [MPa]

h_w[m] 8.123	σ_{x3D} Full	σ_{x3D} 2C	σ_{x3D} F/2C	σ_{vM3D} Full	σ_{vM3D} 2C	σ_{vM3D} F/2C
D_{hogg}	241.20	321.57	1.33	217.80	294.76	1.35
D_{sagg}	329.90	389.90	1.18	297.90	371.64	1.25
B_{hogg}	94.89	109.30	1.15	85.62	100.40	1.17
B_{sagg}	111.30	120.70	1.08	106.50	107.80	1.01
side	τ_{xz3D} Full		τ_{xz3D} 2C		τ_{xz3D} Full /2C	
S_{hogg}	34.70		36.52		1.05	
S_{sagg}	47.85		42.41		0.89	

6. CONCLUSIONS

Combining the results from sections 3, 4, 5, in synthesize are presented in Tables 9.

Table 9.1 Maximum stress CTK, hogging

Hogg. stress	1D	3D-F full	3D-C_C coarse	3D-C_F fine	3D-F/ 1D	3D-C_C /1D	3D-C_F /1D
σ_{xD}	98.25	241.20	257.90	321.57	2.45	2.62	3.27
$\sigma_{vM\,D}$	98.25	217.80	233.00	294.76	2.21	2.37	3.00
σ_{xB}	71.27	94.89	98.01	109.30	1.33	1.38	1.53
$\sigma_{vM\,B}$	71.27	85.62	88.60	100.40	1.20	1.24	1.41
τ_{xzS}	40.09	34.70	35.78	36.52	0.86	0.89	0.91

Table 9.2 Maximum stress CTK, sagging

Sagg. stress	1D	3D-F full	3D-C_C coarse	3D-C_F fine	3D-F/ 1D	3D-C_C /1D	3D-C_F /1D
σ_{xD}	121.17	329.90	321.30	389.90	2.72	2.65	3.22
$\sigma_{vM\,D}$	121.17	297.90	290.10	371.64	2.46	2.39	3.07
σ_{xB}	87.90	111.30	118.90	120.70	1.27	1.35	1.37
$\sigma_{vM\,B}$	87.90	106.50	105.46	107.80	1.21	1.20	1.23
τ_{xzS}	48.27	47.85	42.36	42.41	0.99	0.88	0.88

At the hogging condition (Table 9.1), the stress ratio 3D-C_{coarse}/3D-F is: 2.21 - 2.62 (deck), 1.20-1.38 (bottom), pointing out the hotspots, and the side tangential stress ratio is 0.86-0.89≈1. In the case of fine mesh model 3D-C_{fine} results that the stresses are higher with 24.8-26.6% (deck),10.8-13.7% (bottom) and with smaller changes 2.2 % around side neutral axis.

At the sagging condition (Table 9.2), the stress ratio 3D-C_{coarse}/3D-F is: 2.39-2.72 (deck), 1.20-1.35 (bottom), pointing out the hotspots, and the side tangential stress ratio is 0.88-0.99≈1. In the case of fine mesh model 3D-C_{fine} results that the stresses are higher with 21.5-28.4% (deck), 1.5-2.5% (bottom) and without changes around side neutral axis.

In conclusion, depending on sensitivity, a good correlation can result between the three structural models.

Acknowledgements

This study has been accomplished in the frame of the EMSHIP - European Masters Course in Advanced Ship and Offshore Design Ref. 159652-1-2009-1-BE-ERA MUNDUS-EMMC, coordinator University of Liege, at Research Centre of the Naval Architecture Faculty from "Dunarea de Jos" University of Galati and Ship Design Group Galati.

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Paper received on December 11th, 2017