“EMSHIP” Erasmus Mundus Master Course in “Integrated Advanced Ship Design”

Global and Local Strength Analysis in Equivalent Quasi-static Head Waves, for a Tanker Ship Structure, Based on Full Length and 2-3 Cargo Holds 3D-FEM Models

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Galati, February 2013

Chemical Tanker 4000 t Ship Hull Structure Input Data, granted by Ship Design Group, Galati

3D-CAD/FEM full extended model on the ship length, using coarse mesh

- development of the 3D-CAD model and 3D-FEM model
- boundary conditions
- equivalent quasi-static loads and ship-wave vertical inplane equilibrium

1D - equivalent beam model

- ship hull equilibrium parameters under head quasi-static wave
- bending moments and shear forces

3D-FEM two cargo holds model, using coarse mesh

- model used to validate the boundary conditions

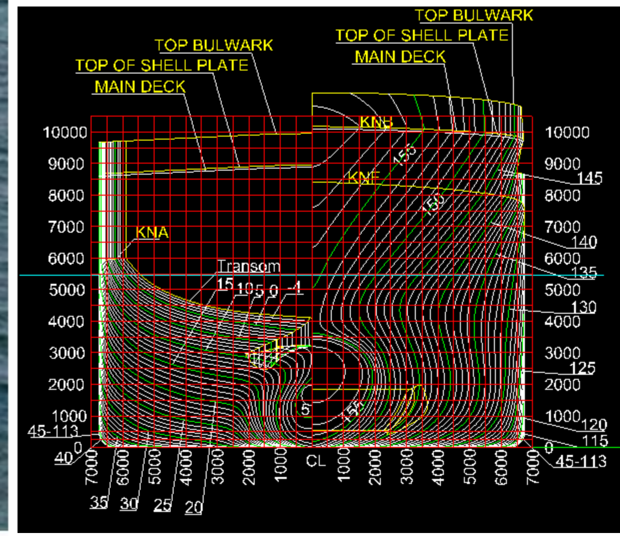
3D-FEM two cargo holds model , using fine mesh

Results:

- deformation and stress
- hot-spot stress evaluation

Ship Hull Structure Input Data

Chemical Tanker 4000 Tones prototype ship
(granted by Ship Design Group 2007)

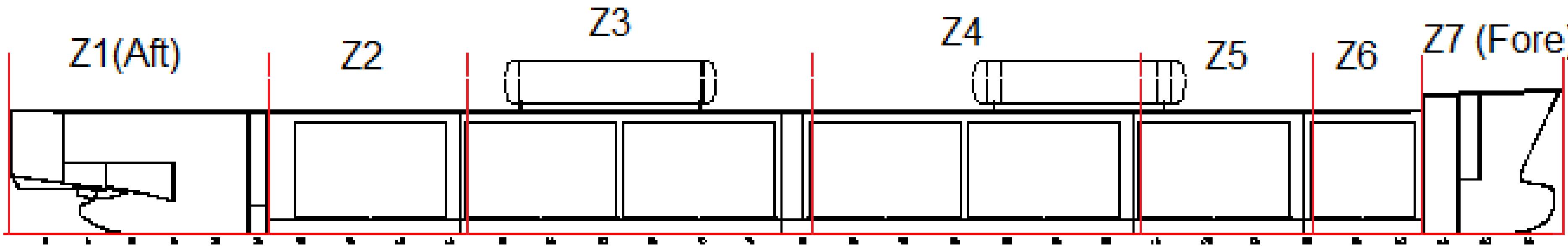


The 2D - Offset Lines
(granted by Ship Design
Group Galati, 2007)

Main dimensions:

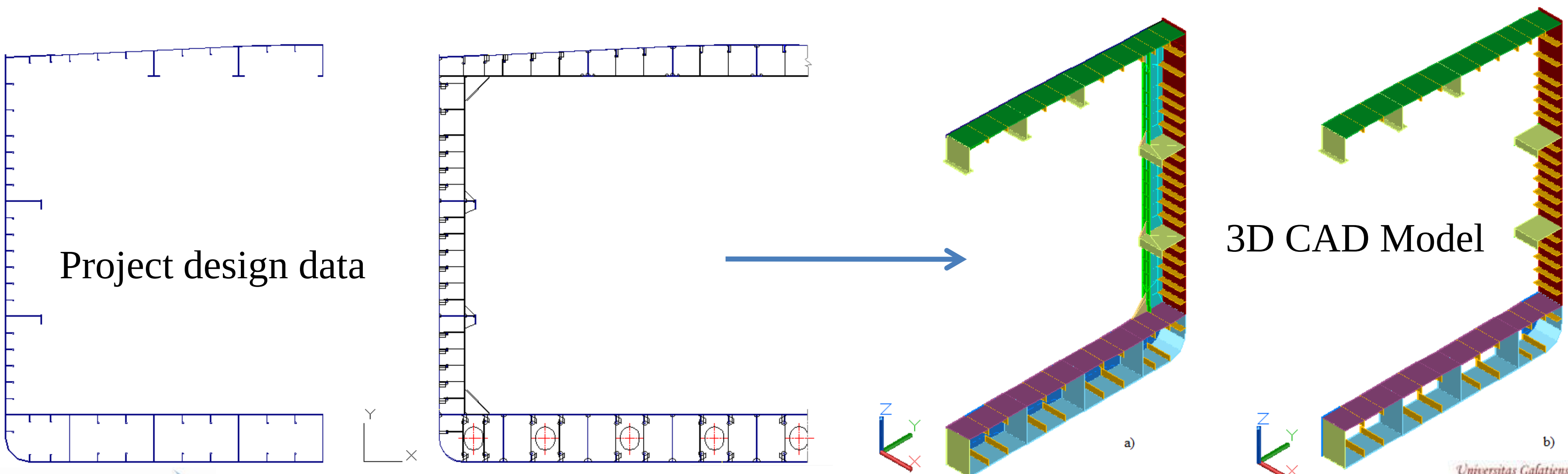
Length Over All : 109.62 m
Length Between Perpendiculars: 106.20 m
Breadth moulded: 13.50 m
Design draught: 5.45 m
Depth at side (moulded): 8.60 m

3D-CAD/FEM Full Extended Model on the Ship Length

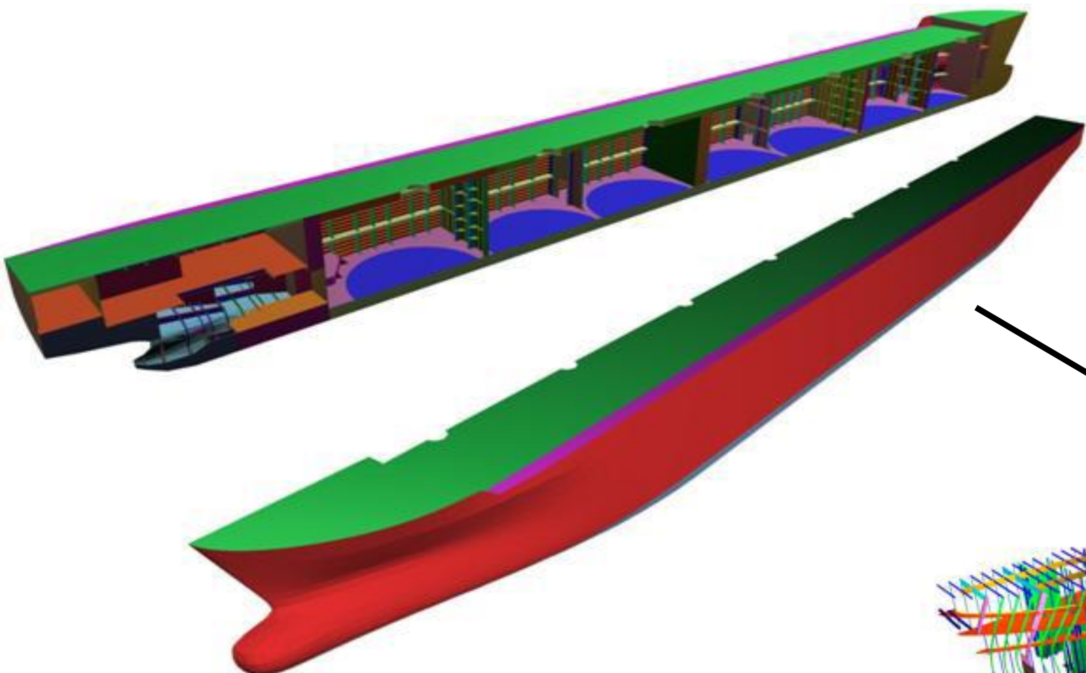


Dividing the ship to blocks (Ship Design Group 2007)

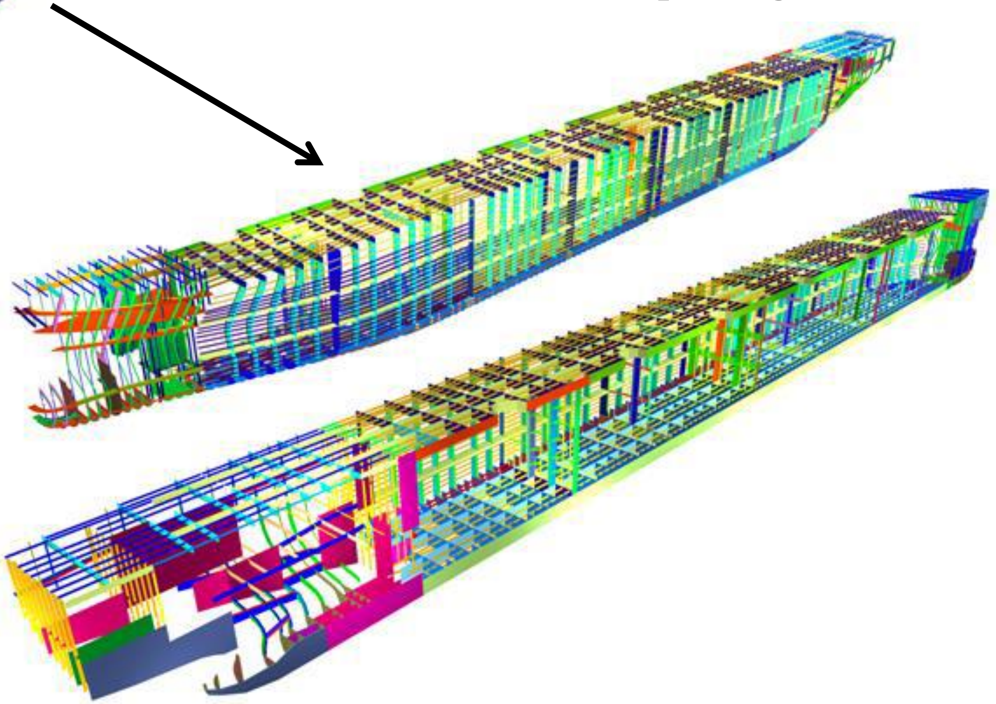
In order to develop the 3D-CAD model, the entire length of the ship was divided into 7 main blocks.

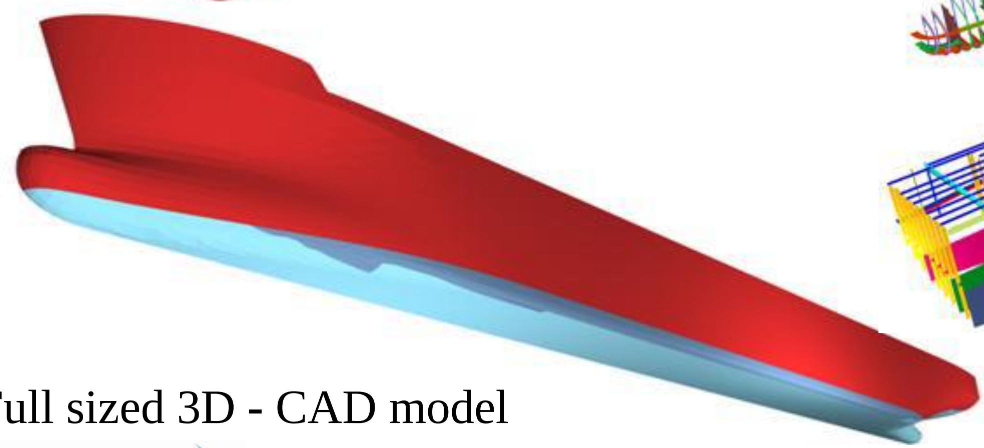


3D-CAD/FEM Full Extended Model on the Ship Length



Full sized 3D - CAD model without shell plating

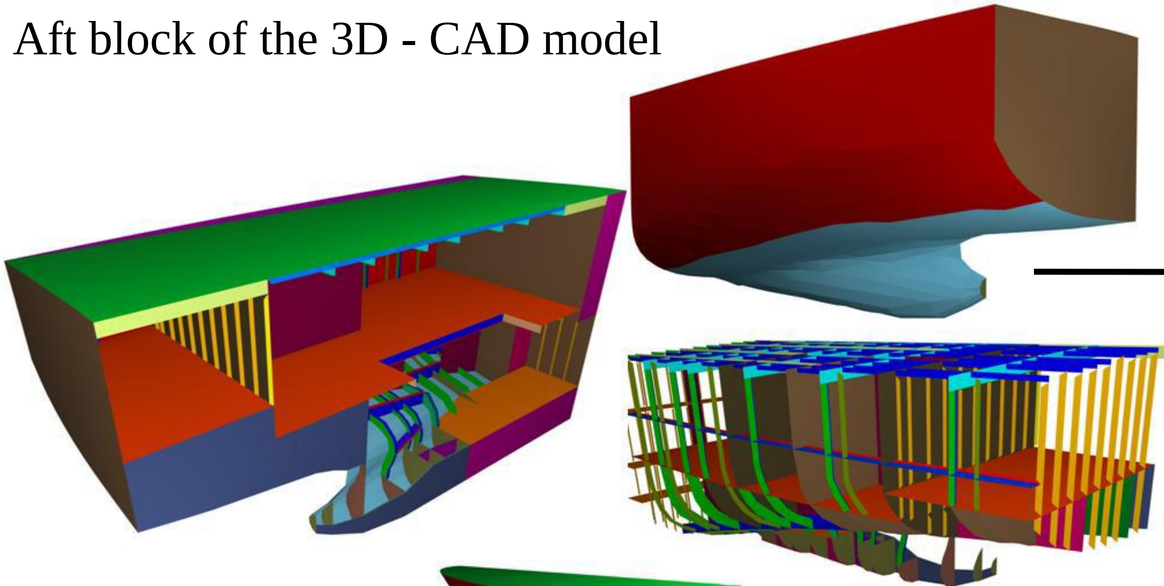


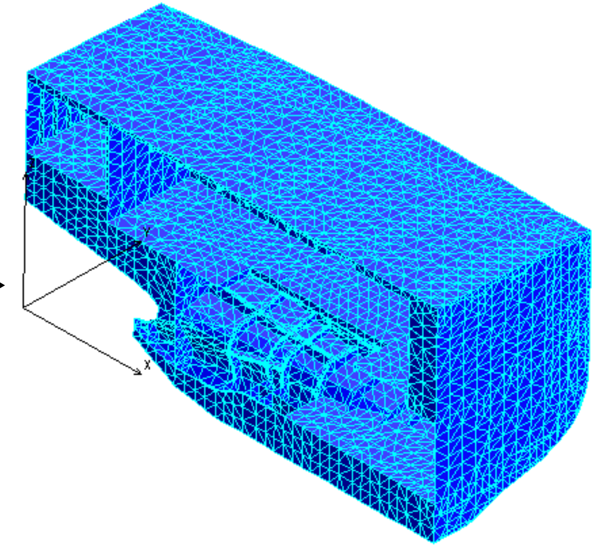


Full sized 3D - CAD model

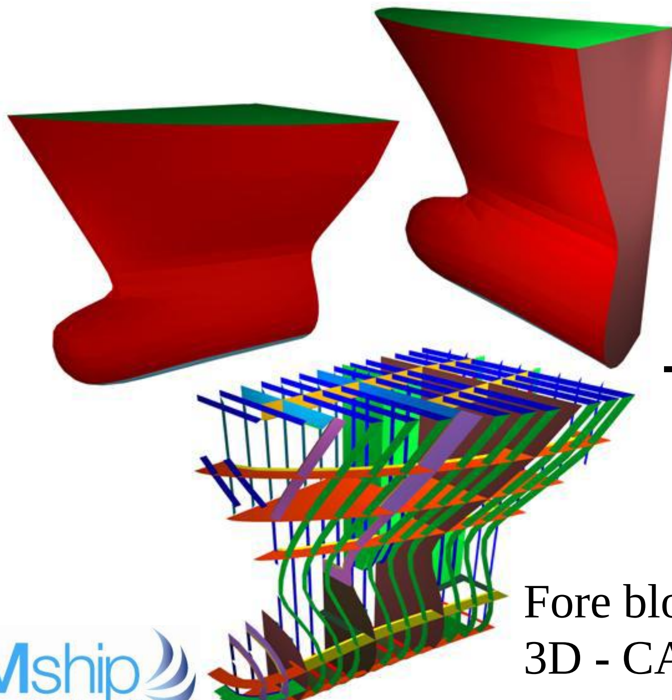
3D-CAD/FEM Full Extended Model on the Ship Length

Aft block of the 3D - CAD model

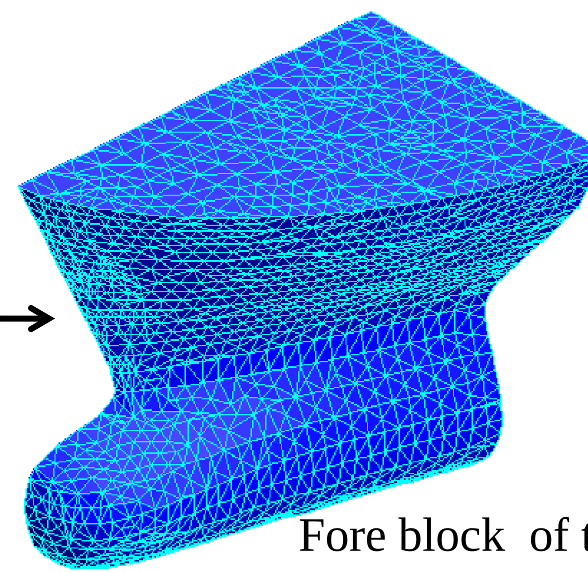




Aft block of the 3D - FEM model



Fore block of the 3D - CAD model



Fore block of the 3D - FEM model

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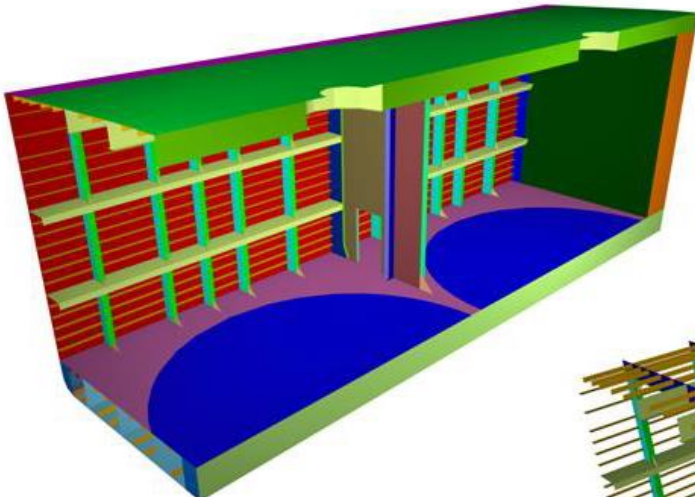
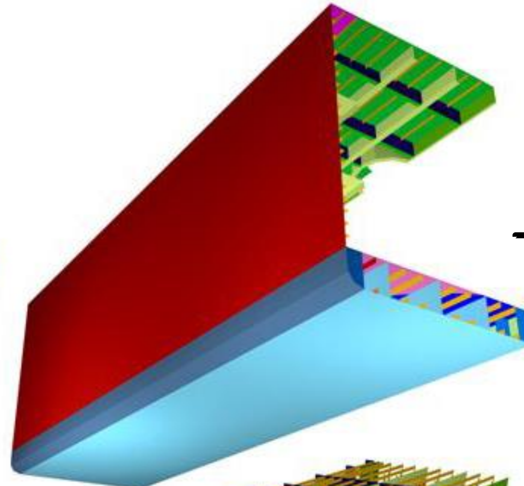
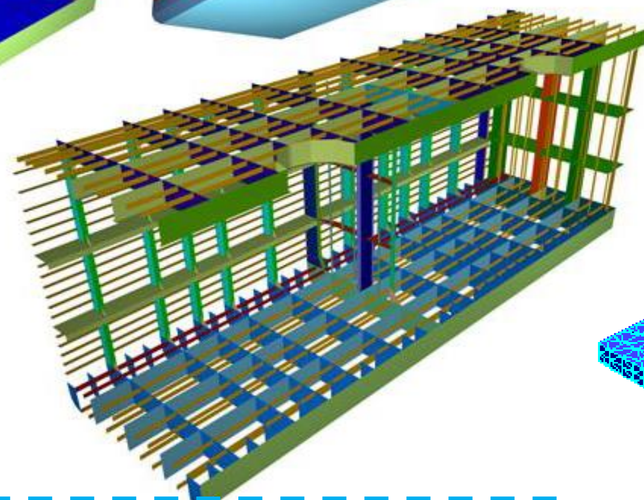
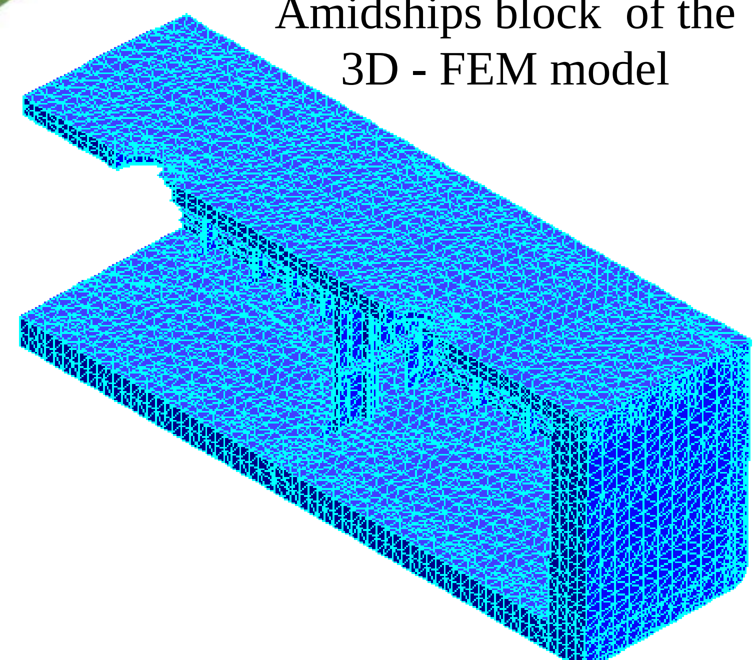
3D-CAD/FEM Full Extended Model on the Ship Length







Amidships block of the 3D - CAD model



Amidships block of the 3D - FEM model

The 3D-FEM full extended model is obtained in the Solid Works Cosmos/M 2007 program, by assembling all the GFM files corresponding to the block model FEM objects presented above.

The Global Ship Strength Analysis Based on 1D-Equivalent Beam Model

The 1D equivalent beam model for the ship hull is selected for an evaluation of the global strength at the initial design stage, without the possibility to include the local hot-spots stress domains.

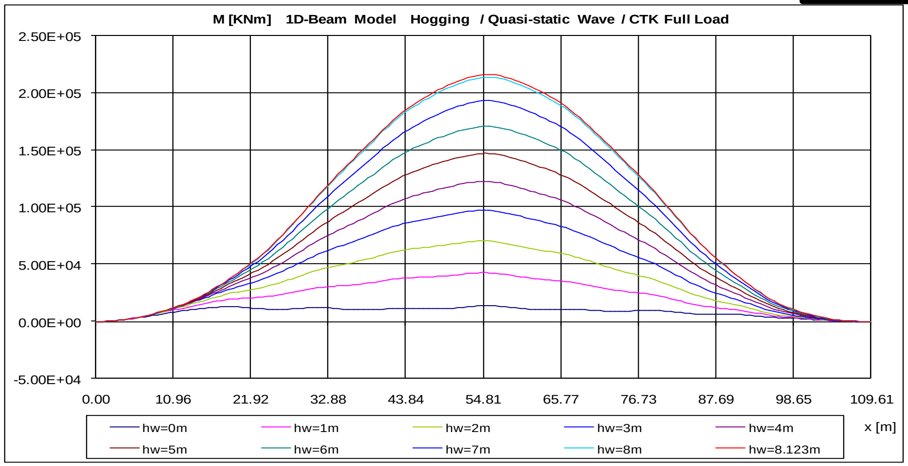
In order to obtain the equilibrium conditions of the ship hull girder under equivalent head waves, it is used a nonlinear iterative procedure for the free floating and trim condition, making possible to take into account the ship hull shape geometrical nonlinearities.

The 1D equivalent beam model numerical analysis is performed by P_ACASV program, developed at the Galati Naval Architecture Department. The input data for the 1D analysis contains the mass distribution diagram along the ship's length and the equivalent beam transversal sections strength characteristics. The height of the equivalent quasi-static head wave is considered to be in the range $h_w = 0 – 8.123$ m, with the step increment $\Delta h_w = 1$ m.

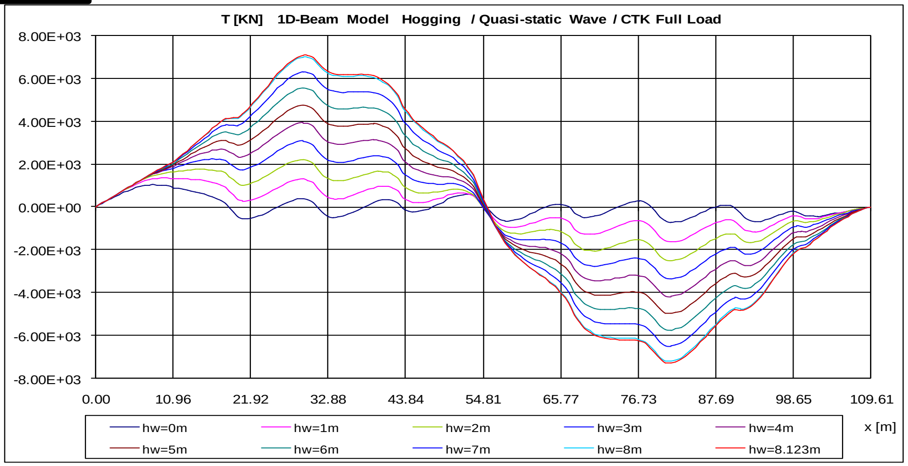
The Global Ship Strength Analysis Based on 1D-Equivalent Beam Model

Results

Hogging

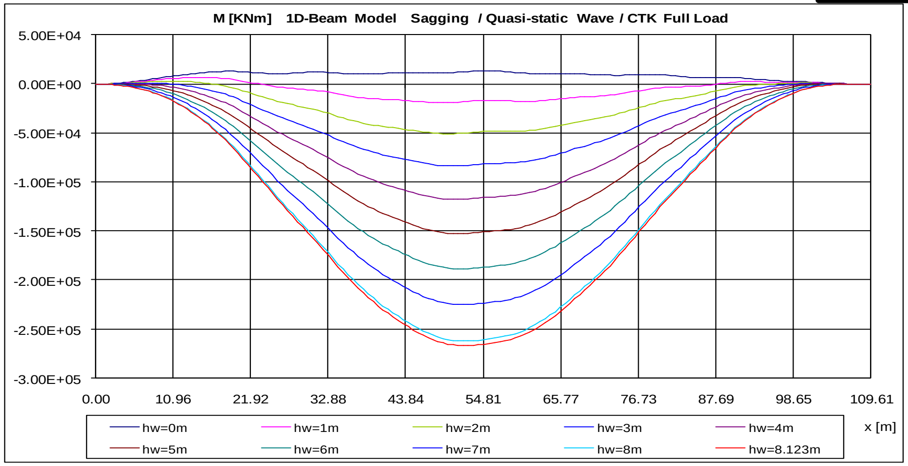


Bending moment M [kNm] for 1D computation

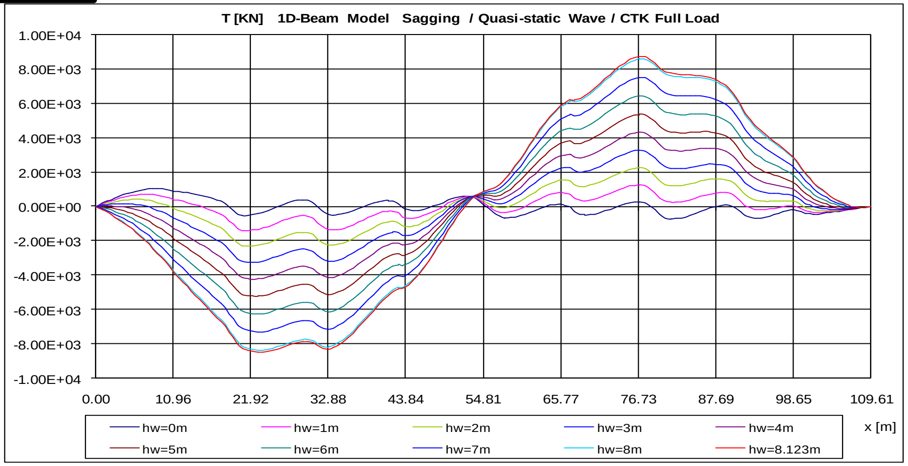


Shear force T [kN] for 1D computation

Sagging



Bending moment M [kNm] for 1D computation



Shear force T [kN] for 1D computation

The Global Ship Strength Analysis Based on 1D-Equivalent Beam Model

Results

Maximum hogging stresses based on 1D-equivalent beam model, h_w=8.123 m

Panel stress	Stress max 1D [MPa]	Stress adm_GS [MPa]	max/adm_GS
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

Maximum sagging stresses based on 1D-equivalent beam model, h_w=8.123 m

Panel stress	Stress max 1D [MPa]	Stress adm_GS [MPa]	max/adm_GS
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

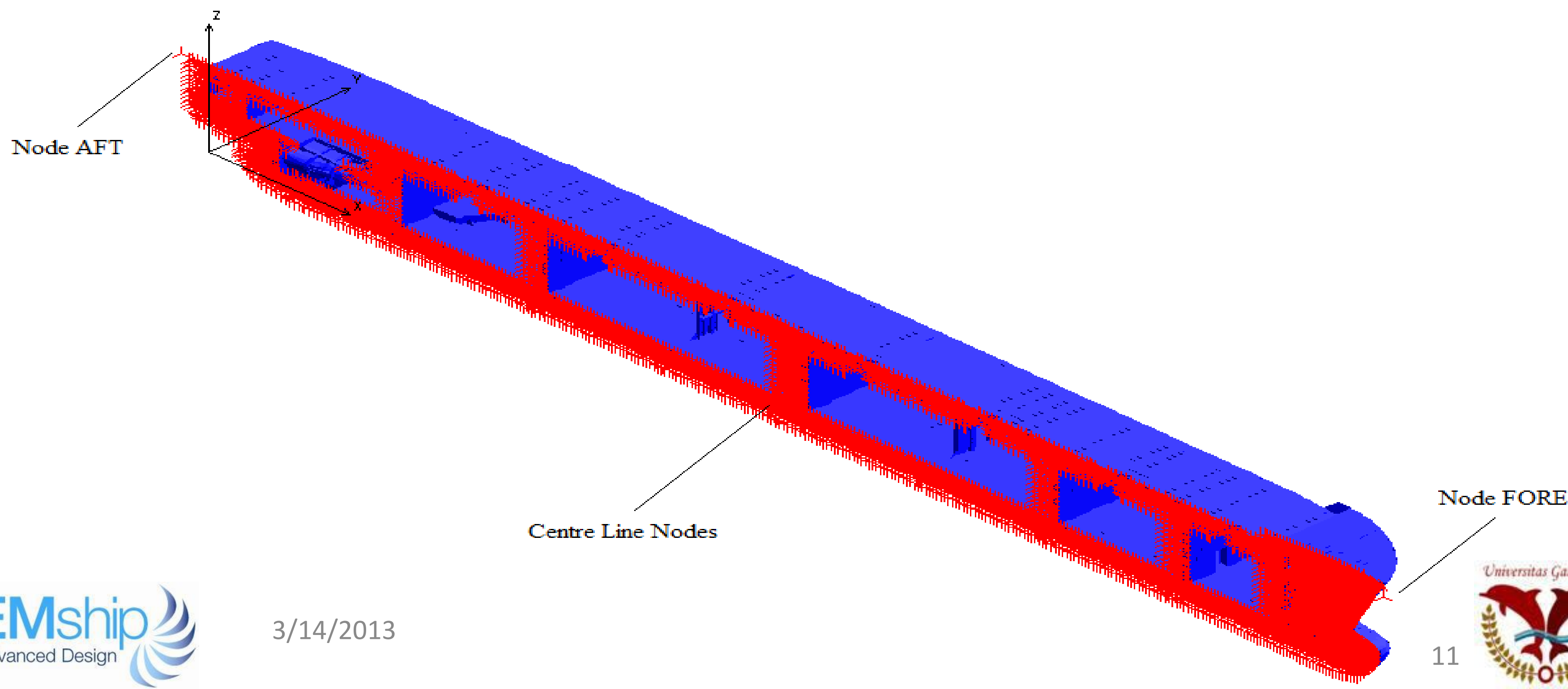
- The maximum stresses are smaller than the admissible values, the highest ratio being recorded for the bottom, max/adm_{GS}=0.41 in hogging and 0.50 in sagging conditions.

- The 1D model results will be used for further comparison with the 3D FEM models

The Numerical Analysis of Global-Local Ship Hull Strength, Based on the 3D-FEM Full Extended Model

Boundary conditions

Nodes	Constraints	Type
ND_AFT	U_X	Neutral
	U_Z	Forced, for equilibrium objective function definition
ND_FORE	U_Z	Forced, for equilibrium objective function definition
CENTRE PLANE	U_Y; R_X	Symmetry, natural



The Numerical Analysis of Global-Local Ship Hull Strength, Based on the 3D-FEM Full Extended Model

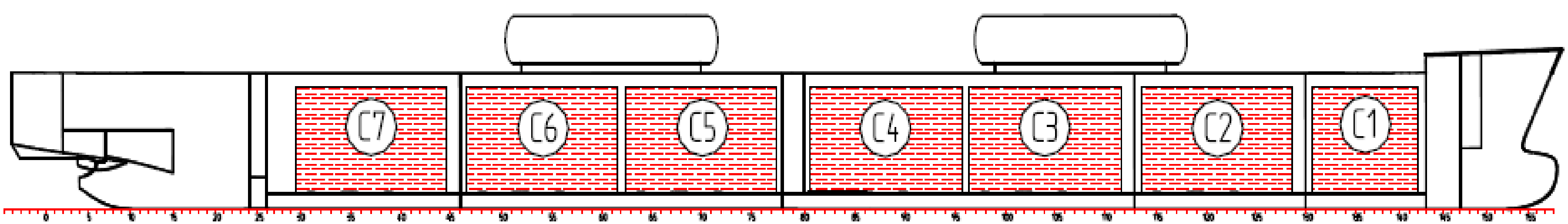
Loading conditions

Onboard mass components

Chapter	Mass [t]	Pressure P (kN/m^2)
Steel	1017.282	
Cargo tanks	271.3	6.79
Miscellaneous	64.3	
Outfitting	121.8	13.49
Machinery	68.1	22.31
Accommodation	85.7	5
Systems	71.1	5.5
Electrical	27.7	6.04
TOTAL	**1727.282**	

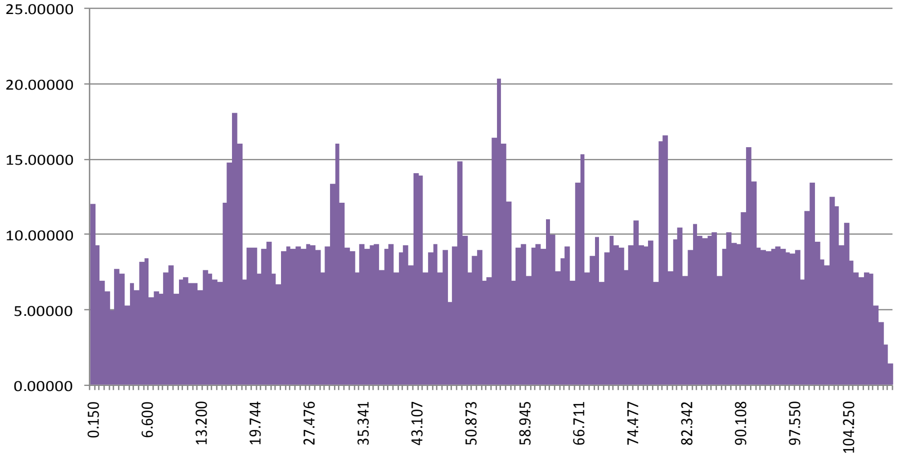
Independent filled up structural cargo tanks

Position	Mass (t)	Pressure P (kN/m^2)
CARGO Tank 1	326	62.6
CARGO Tank 2	679	61.1
CARGO Tank 3	679	
CARGO Tank 4	679	
CARGO Tank 5	679	
CARGO Tank 6	679	
CARGO Tank 7	679	

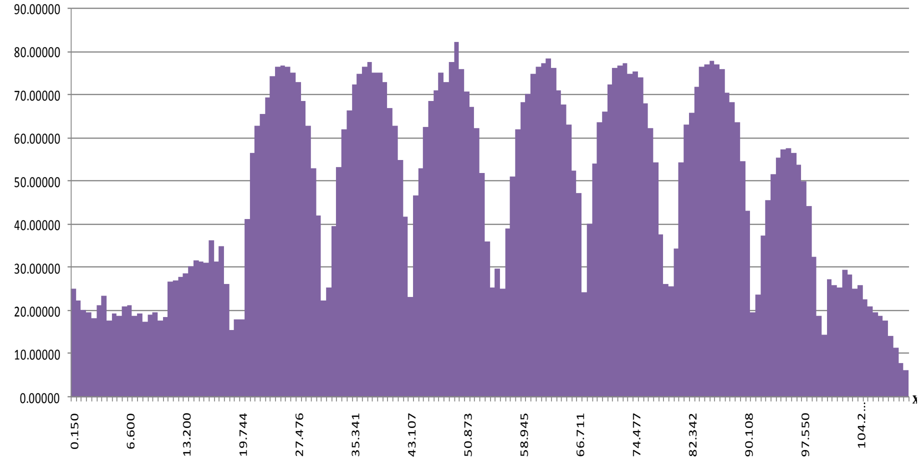


The Numerical Analysis of Global-Local Ship Hull Strength, Based on the 3D-FEM Full Extended Model

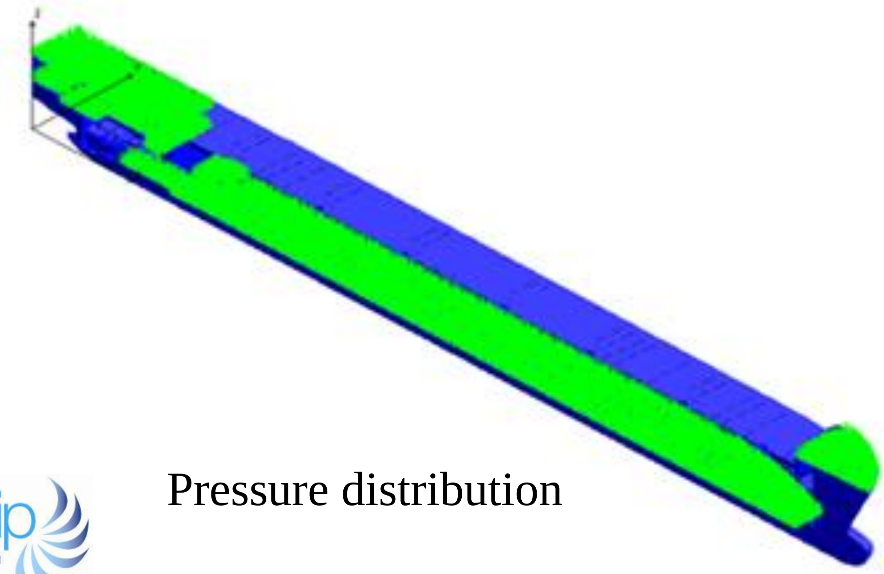
Mass distribution



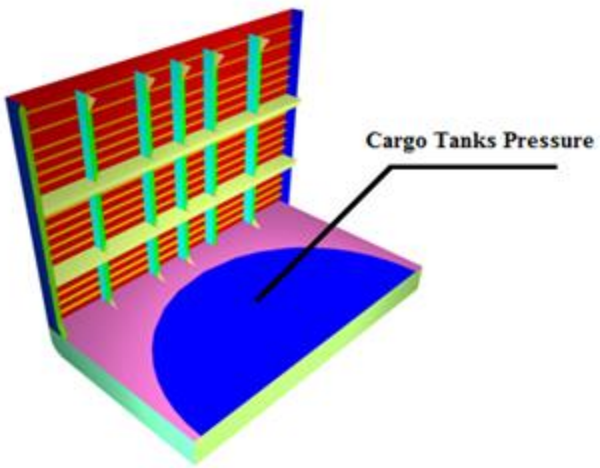
Lightship mass distribution



Mass distribution in full cargo loading case

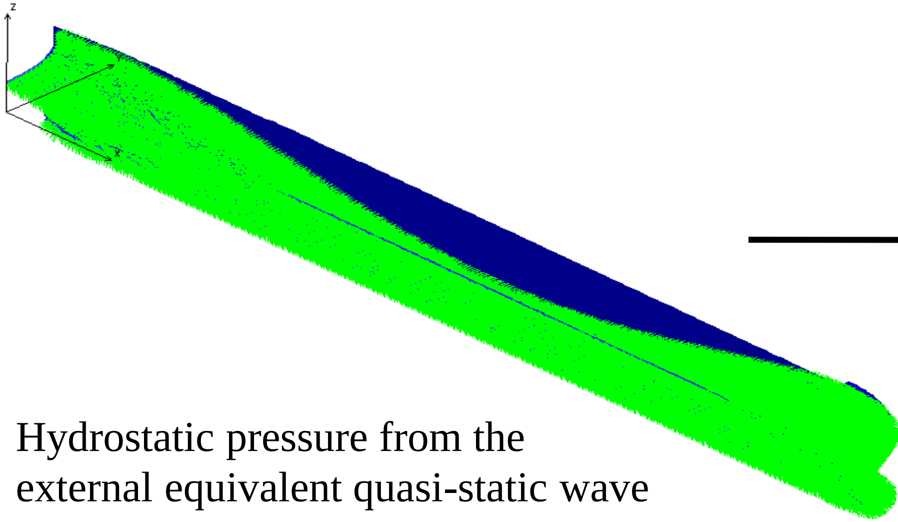


Pressure distribution

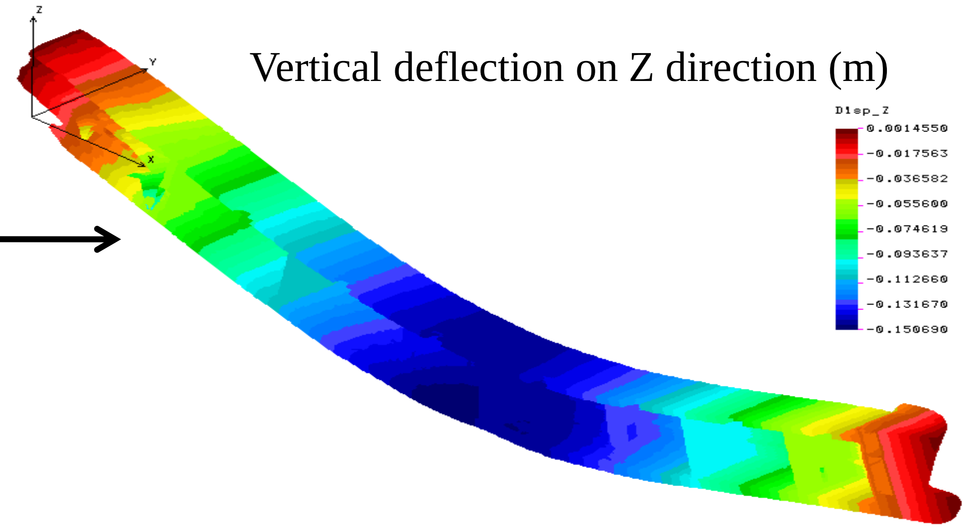


The Numerical Analysis of Global-Local Ship Hull Strength, Based on the 3D-FEM Full Extended Model

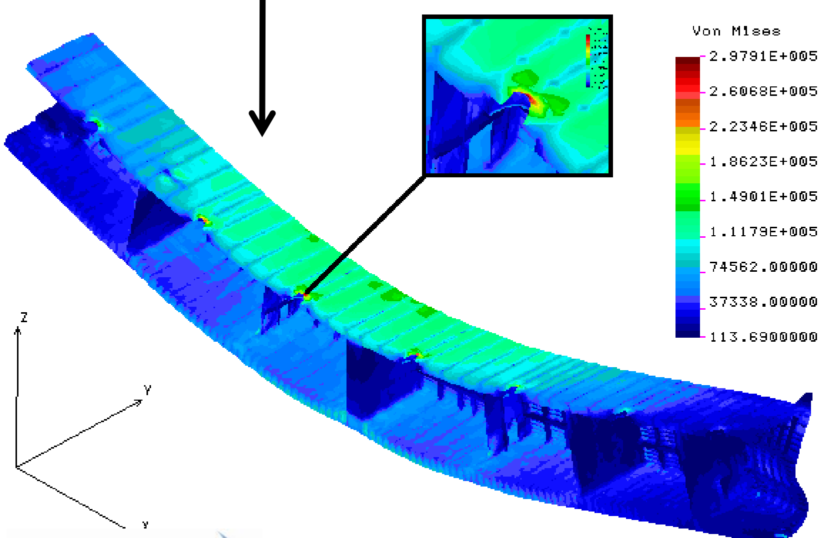
Results – wave sagging conditions (h_w = 8.123m)



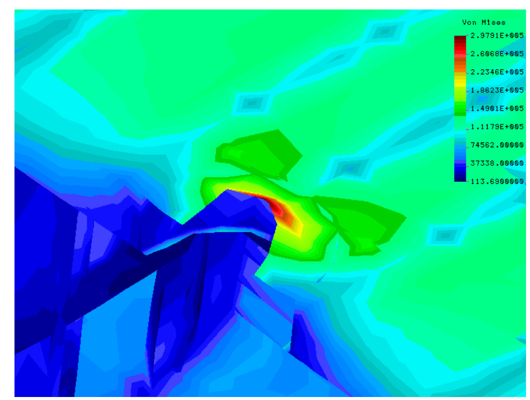
Hydrostatic pressure from the external equivalent quasi-static wave



Vertical deflection on Z direction (m)



Equivalent vonMises stress distribution [kN/m^2]

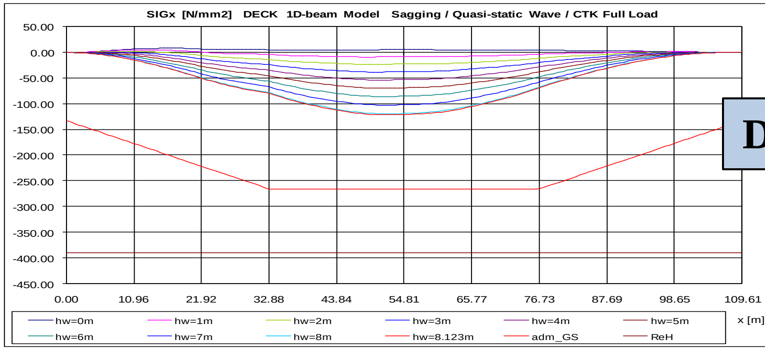


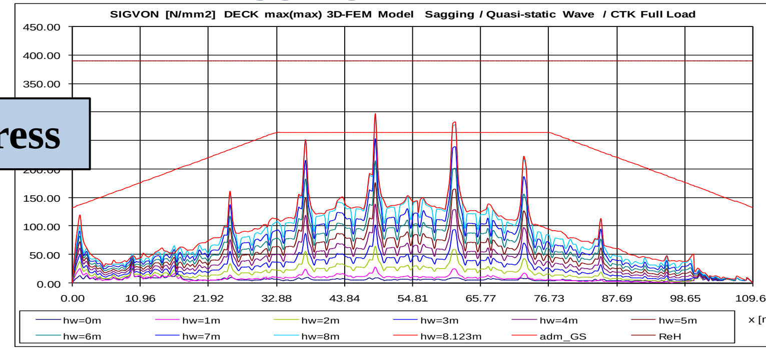
Equivalent vonMises stress distribution detail [kN/m^2]

The Numerical Analysis of Global-Local Ship Hull Strength, Based on the 3D-FEM Full Extended Model

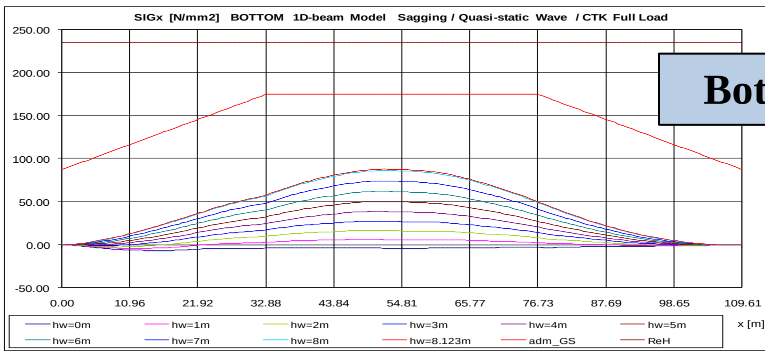
Results – wave sagging conditions (h_w = 8.123m)

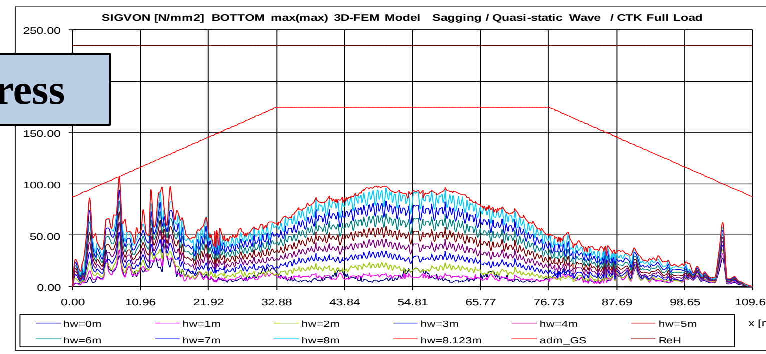
Deck stress





Bottom stress

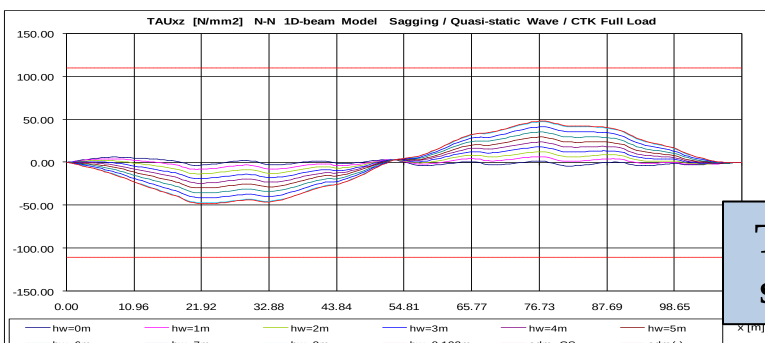


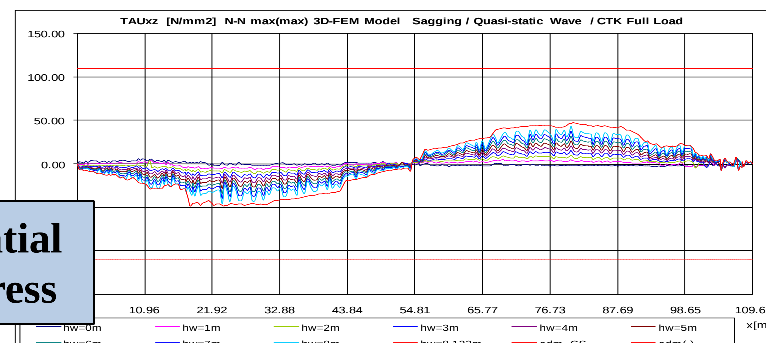


σ_X [MPa], 1D model

σ_{von} [Mpa] 3D-FEM full extended model

Tangential side stress





τ_{xz} [Mpa] 1D model

τ_{xz} [MPa] 3D-FEM full extended model

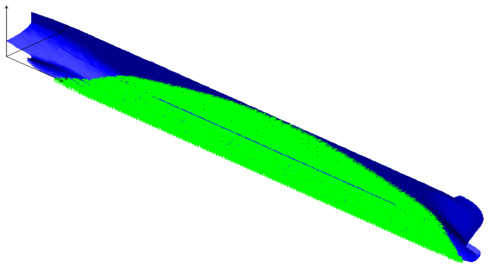
Results – wave sagging conditions (h_w = 8.123m)

Maximum sagging stresses based on 3D-FEM full extended model

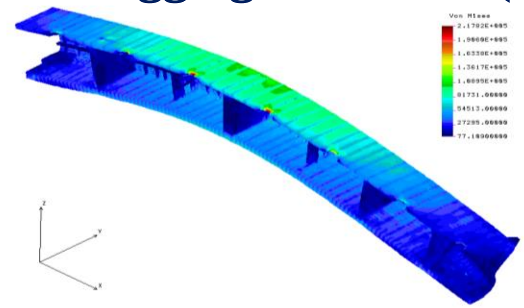
Panel stress	Stress 3D [MPa]	ReH [MPa]	Cs=ReH/Stress_3D	Stress 1D [MPa]	3D/1D
Maximum σ_x deck	329.90	390	1.18	121.17	2.72
Maximum σ_{vonM} deck	297.90	390	1.30	121.17	2.46
Maximum σ_x bottom	111.30	235	2.11	87.90	1.27
Maximum σ_{vonM} bottom	106.50	235	2.207	87.90	1.21
Panel stress	**τ_{3D} [MPa]**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

The maximum stresses results in the deck panel, with significant hot spots around the liquid cargo tank hatch. More accurate hotspots stress factors will be computed based on finer mesh model.

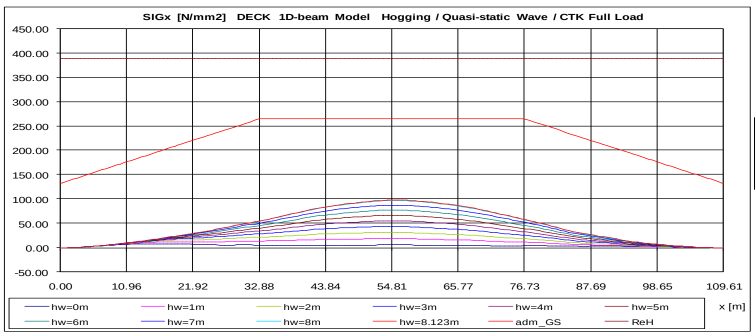
The Numerical Analysis of Global-Local Ship Hull Strength, Based on the 3D-FEM Full Extended Model **Results – wave hogging conditions (h_w = 8.123m)**



Hydrostatic pressure from the external equivalent quasi-static wave

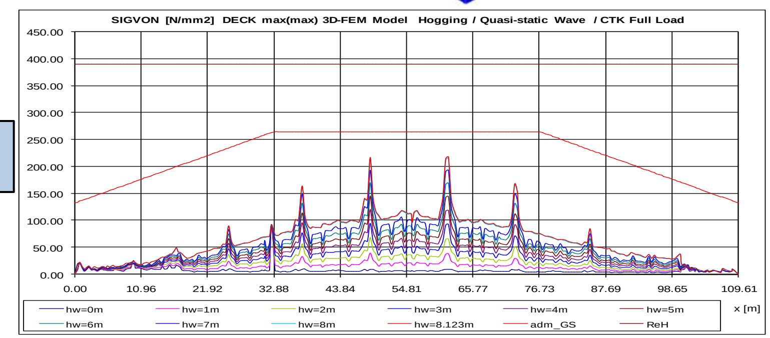


Equivalent vonMises stress distribution [kN/m^2]



σ_X [MPa] , 1D model

Deck stress

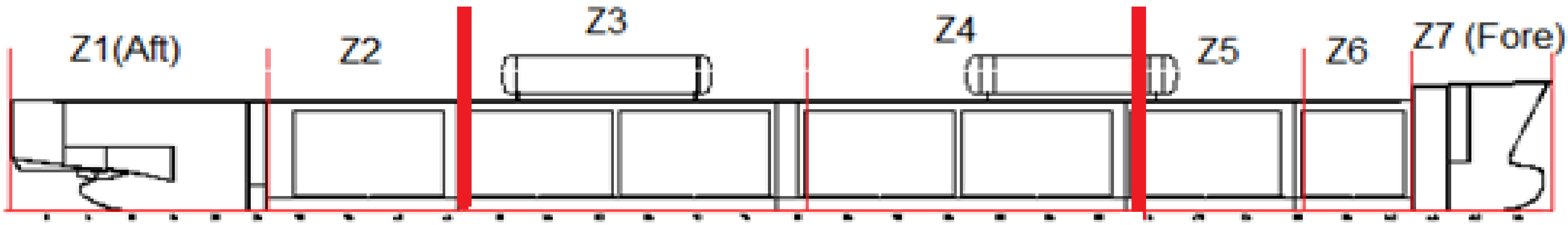


σ_{von} [MPa], 3D-FEM full extended model

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

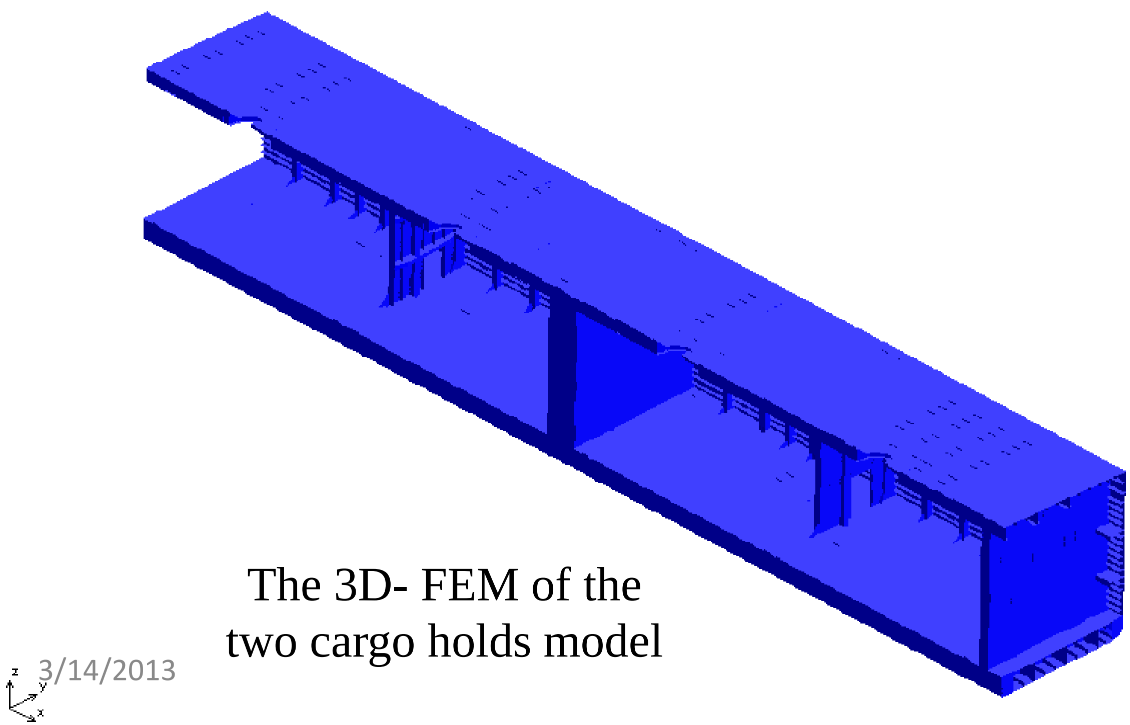
Maximum hogging stresses based on 3D-FEM full extended model

The Global-Local Ship Hull Strength Analysis, Based on 3D-FEM Coarse Mesh Model Extended on Two Cargo Holds



The two cargo holds compartments of the ship (Ship Design Group 2007)

The longitudinal coordinates along X axis of the two cargo holds model are from 31.772 m to 80.224 m, including the bulkhead at the end of the second cargo hold.

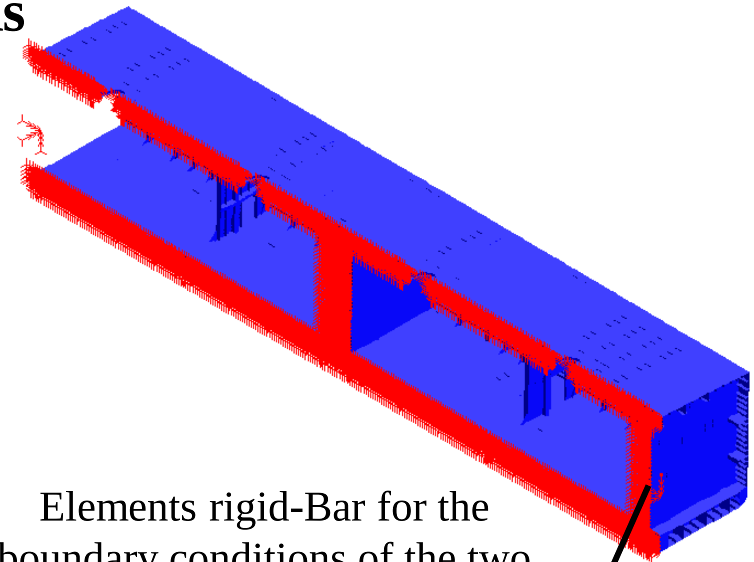


The 3D- FEM of the two cargo holds model

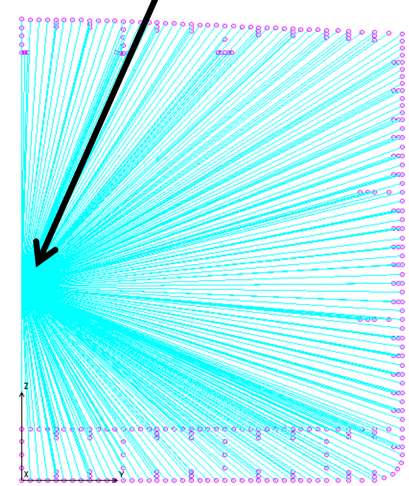
The Global-Local Ship Hull Strength Analysis, Based on 3D-FEM Coarse Mesh Model Extended on Two Cargo Holds

Boundary Conditions

Nodes	Constraints	Type
ND_AFT	UX	Neutral
	UY; RX	Symmetry, Natural
	RZ	Neutral
ND_FORE	RZ	Neutral
	UY; RX	Symmetry, Natural
CENTRE LINE PLANE	UY; RX	Symmetry, Natural



Elements rigid-Bar for the boundary conditions of the two cargo holds 3D-FEM model

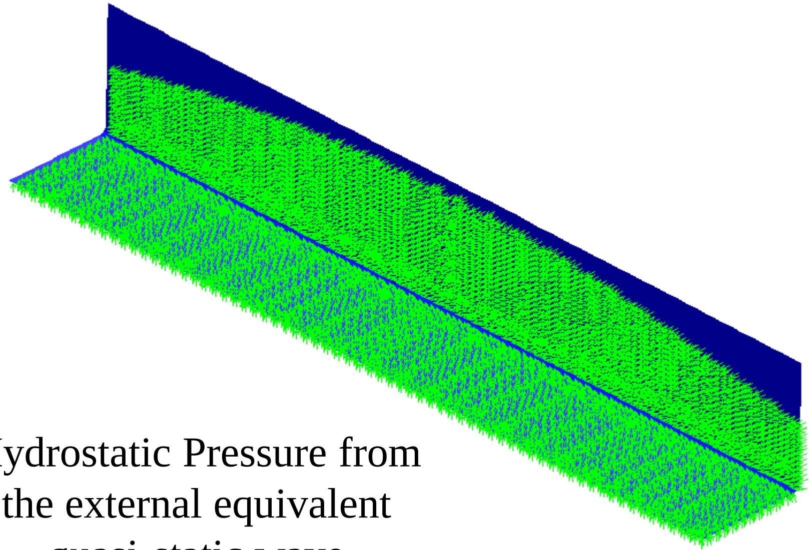


Displacements and rotations

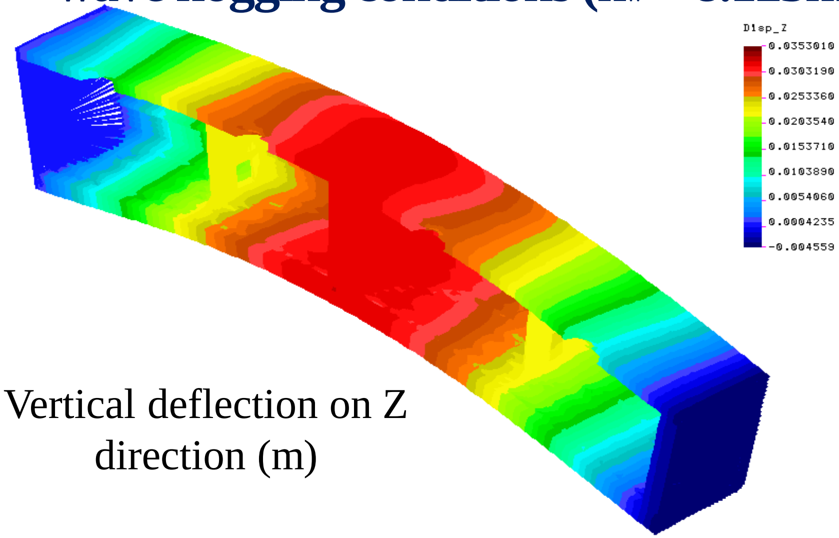
Conditions	Still water		Hogging		Sagging	
Node location	Node AFT	Node FORE	Node AFT	Node FORE	Node AFT	Node FORE
Coordinate [m]	31.712	80.224	31.712	80.224	31.712	80.224
Displacement w [m]	0.0066	0.0054	0.0722	0.0676	-0.0960	-0.085
Rotation ϴ[rad]	0.00009	0.00015	-0.0019	0.0021	0.0024	-0.0026

The Global-Local Ship Hull Strength Analysis, Based on 3D-FEM Coarse Mesh Model Extended on Two Cargo Holds

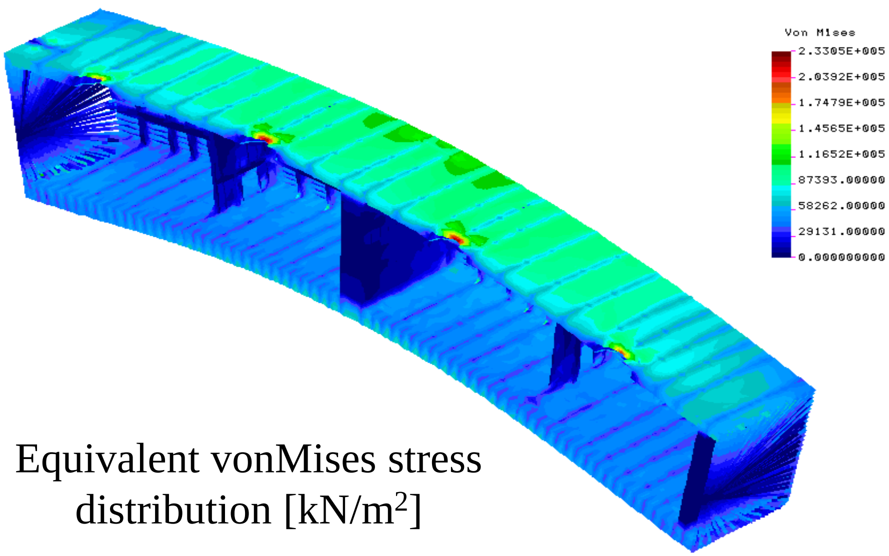
Results – wave hogging conditions (h_w = 8.123m)



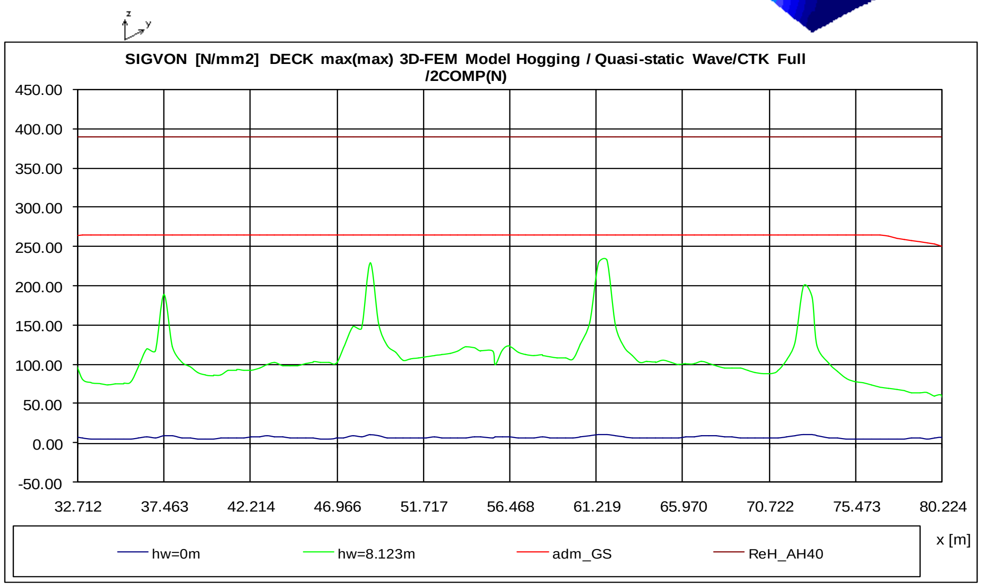
Hydrostatic Pressure from the external equivalent quasi-static wave



Vertical deflection on Z direction (m)



Equivalent vonMises stress distribution [kN/m^2]



Equivalent vonMises Deck Stress,σ_{von} [Mpa]

The Global-Local Ship Hull Strength Analysis, Based on 3D-FEM Coarse Mesh Model Extended on Two Cargo Holds

Results

Deck elements:

h_w = 8.123 m	Max. σ_x Stress 3D Full [MPa]	Max. σ_x Stress 3D 2 Comp [MPa]	σ_x 3D Full / σ_x 3D 2 Comp	Maxi. σ_{vonM} Stress 3D Full [MPa]	Max. σ_{vonM} Stress 3D 2 Comp [MPa]	σ_{vonM} 3D Full / σ_{vonM} 3D 2 Comp
Hogging	241.20	257.90	0.94	217.80	233.00	0.93
Sagging	329.90	321.30	1.03	297.90	290.10	1.03

Bottom elements:

h_w = 8.123 m	Maximum σ_x Stress 3D Full [MPa]	Max. σ_x Stress 3D 2 Comp [MPa]	σ_x 3D Full / σ_x 3D 2 Comp	Max.σ_{vonM} Stress 3D Full [MPa]	Max. σ_{vonM} Stress 3D 2 Comp [MPa]	σ_{vonM} 3D Full / σ_{vonM} 3D 2 Comp
Hogging	94.89	98.01	0.97	85.62	88.60	0.97
Sagging	111.30	118.90	0.94	106.50	105.46	1.01

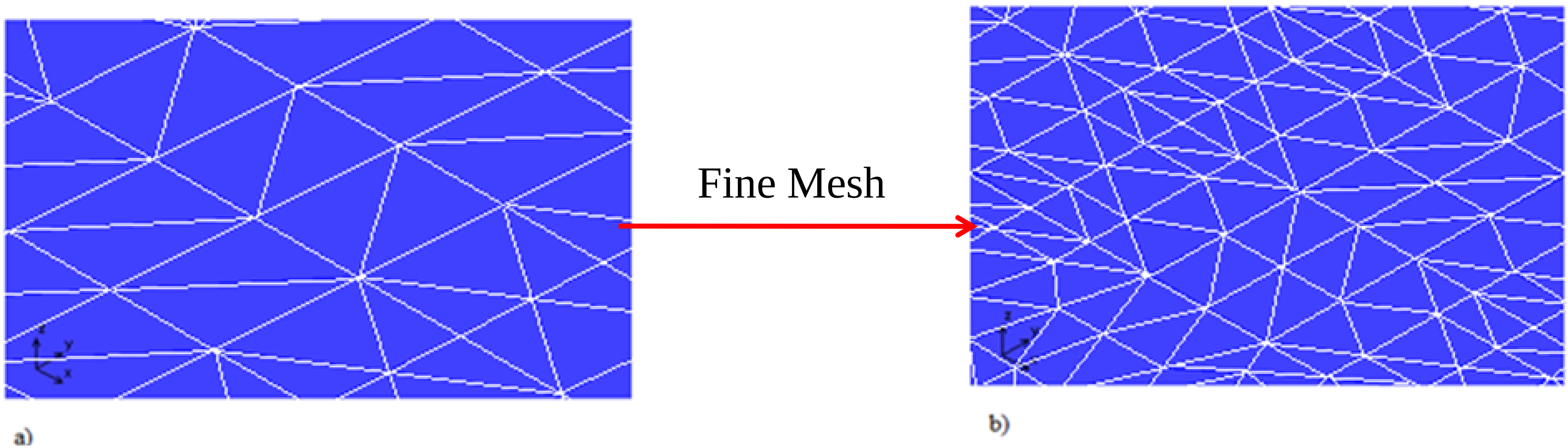
Side elements:

h_w = 8.123 m	Max.τ_{xz} Stress 3D Full [MPa]	Max. τ_{xz} Stress 3D 2 Comp [MPa]	τ_{xz} 3D Full / τ_{xz} 3D 2 Comp
Hogging	34.70	35.78	0.97
Sagging	47.85	42.36	1.13

±3% differences

The Global-Local Ship Hull Strength Analysis, Based on 3D-FEM Fine Mesh Model Extended on Two Cargo Holds

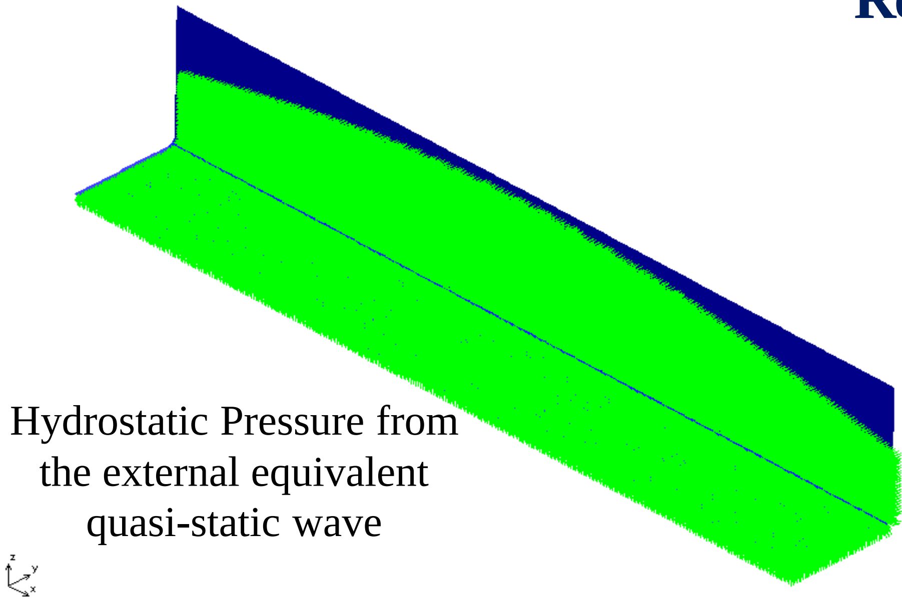
A finer mesh mode was developed between the longitudinal coordinates of x=31.772 m to 80.224 m. The model was realised by using triangle shell elements, having a total number of elements of 203171 and a total number of nodes of 95437



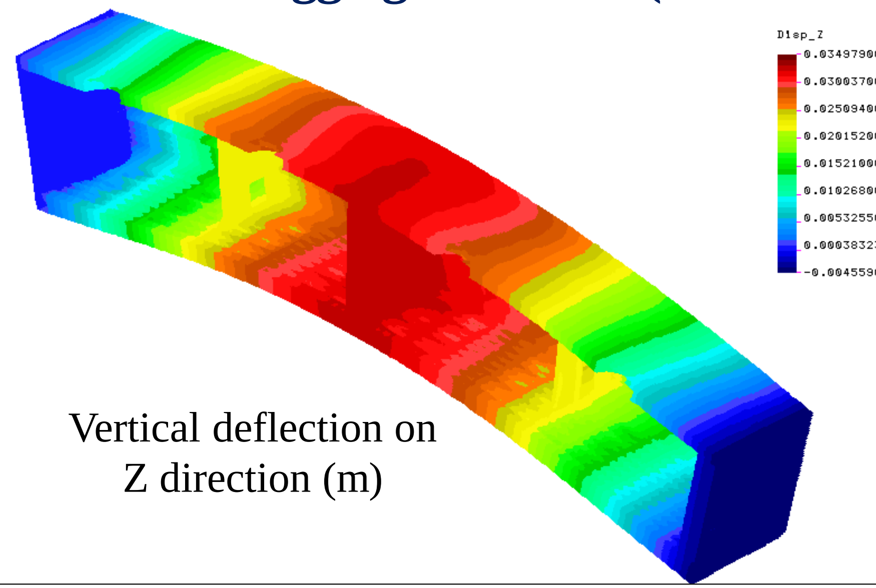
Mesh size comparison between a) coarse mesh size in 3D FEM full extended model and b) fine mesh size two cargo holds compartments 3D FEM model

The Global-Local Ship Hull Strength Analysis, Based on 3D-FEM Fine Mesh Model Extended on Two Cargo Holds

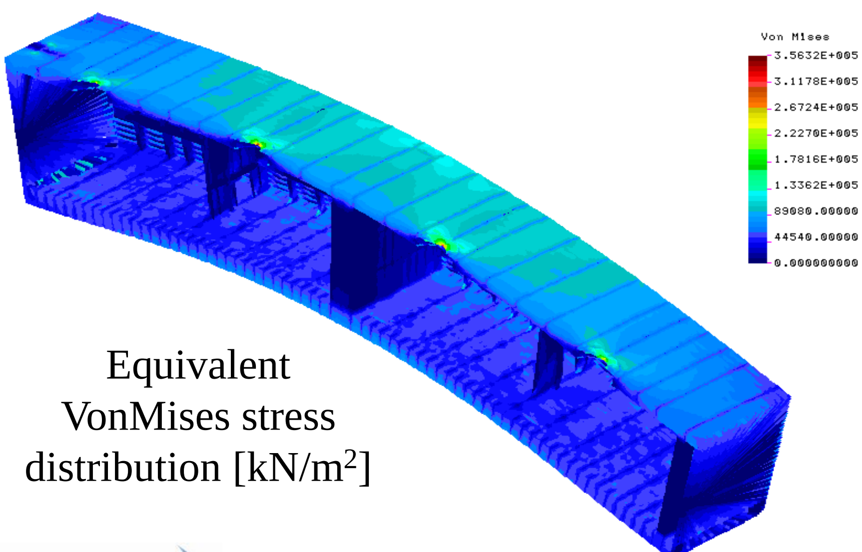
Results – wave hogging conditions (h_w = 8.123m)



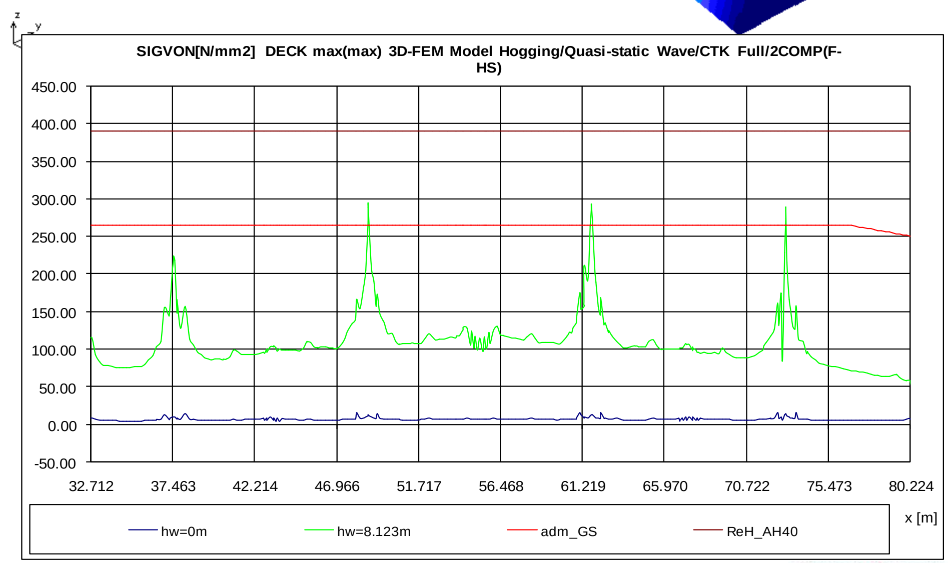
Hydrostatic Pressure from the external equivalent quasi-static wave



Vertical deflection on Z direction (m)



Equivalent VonMises stress distribution [kN/m²]



Equivalent vonMises Deck Stress, σ_{von} [Mpa], with Hotspot correction

The Global-Local Ship Hull Strength Analysis, Based on 3D-FEM Fine Mesh Model Extended on Two Cargo Holds

Results – wave hogging conditions (h_w = 8.123m)

Deck elements

hw = 8.123m	Max σ_x Stress 3D Full [MPa]	Max σ_x Stress 3D 2 Comp Fine mesh [MPa]	σ_x Fine 2C/3D Full	Max σ_{vonM} Stress 3D Full [MPa]	Max σ_{vonM} Stress 3D 2 Comp Fine mesh [MPa]	σ_{vonM} Fine 2C/3D Full
Hogging	241.20	321.57	1.33	217.80	294.76	1.35
Sagging	329.90	389.90	1.18	297.90	371.64	1.25

Bottom elements

hw = 8.123m	Max σ_x Stress 3D Full [MPa]	Max σ_x Stress 3D 2 Comp Fine mesh [MPa]	σ_x Fine 2C/3D Full	Max σ_{vonM} Stress 3D Full [MPa]	Max σ_{vonM} Stress 3D 2 Comp Fine mesh [MPa]	σ_{vonM} Fine 2C/3D Full
Hogging	94.89	109.30	1.15	85.62	100.40	1.17
Sagging	111.30	120.70	1.08	106.50	107.80	1.01

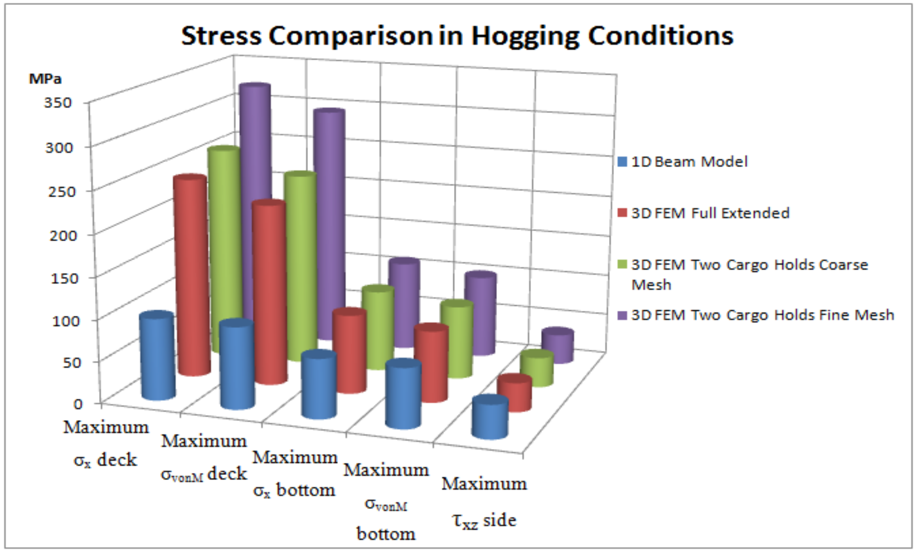
Side elements

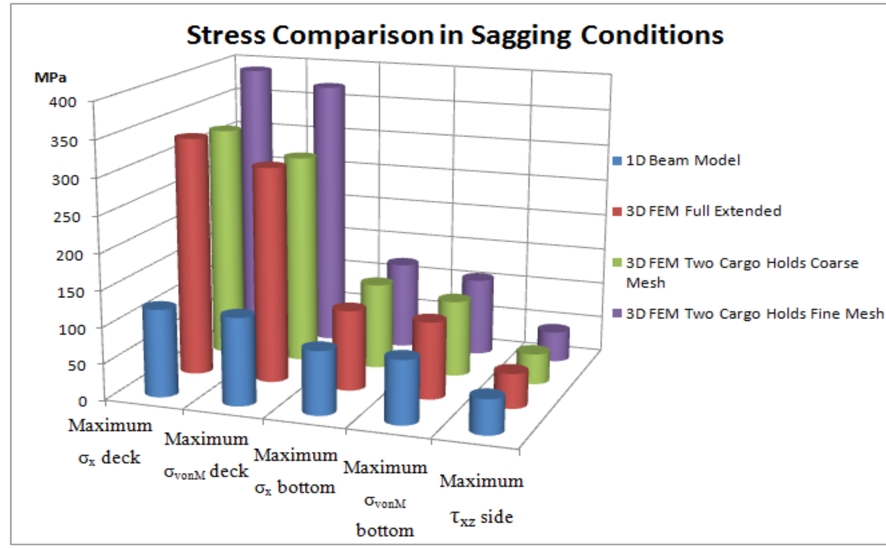
hw = 8.123m	Maximum τ_{xz} Stress 3D Full [MPa]	Maximum τ_{xz} Stress 3D 2 Comp Fine Mesh [MPa]	τ_{xz} Fine 2C/3D Full
Hogging	34.70	36.52	1.05
Sagging	47.85	42.41	0.89

The safety coefficient with reference to the yield stress limit has the minimum value for the deck stress in hogging 1.213 and in sagging 1.

max 35% differences

Comparative Results and Conclusions





Stress comparison on all components for each numerical model analysed

In conclusion, by using the user subroutines developed with Solid Works Cosmos/M 2007 FEM software, the numerical FEM analysis provides reliable data for the ship strength assessment (under equivalent quasi-static head waves), having a good concordance between the structural models developed in this study. For further studies, as fatigue analysis, should combine the advantages of the four structural models analysed in this work, taking into account the sensitivity of the ship hull structure models, for higher risk panels identification

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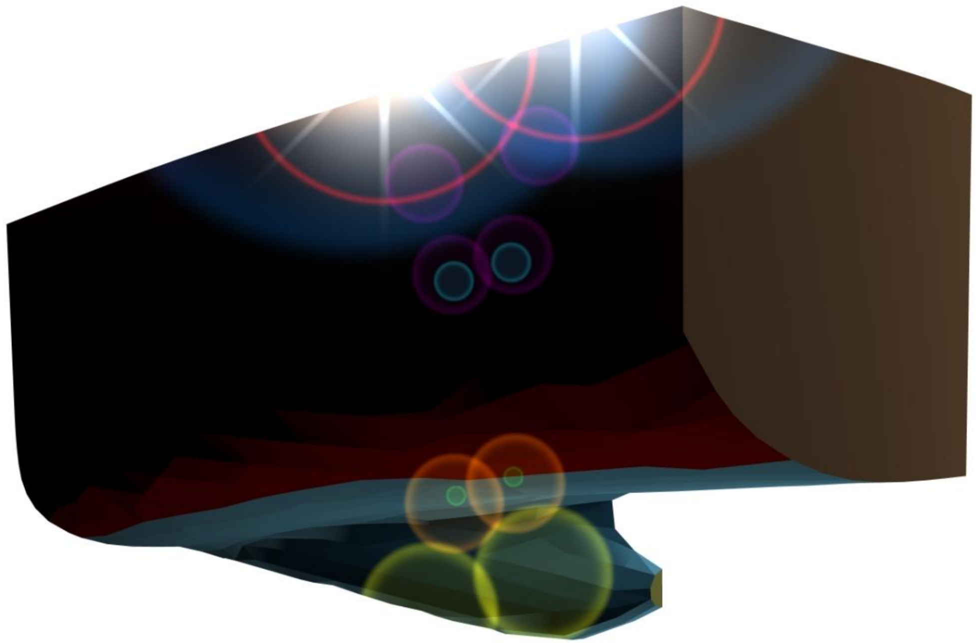

THANK YOU FOR YOUR ATTENTION !