Non-linear Hydroelastic Response Analysis in Irregular Head Waves, for a Large Bulk Carrier Structure, and Fatigue based Preliminary Ship Service Life Prediction

EMship
Advanced Design

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Non-linear Hydroelastic Response Analysis in Irregular Head Waves, for a Large Bulk Carrier Structure, and Fatigue based Preliminary Ship Service Life Prediction

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Part 1

- Structural Characteristics of the Bulk Carrier for the Numerical Analysis

- General input data of the studied bulk carrier
- Hull structure scantling

Part 2

- Global-local Strength Analysis in Equivalent Quasi-static Head Waves

- Maximum deck, bottom and side stress (1D-girde and 3D FEM models)
- 3D/1D stress correlation factor

Part 3

- Numerical Hydroelastic Linear and Non-linear Dynamic Response

- The extreme wave loads from slamming, whipping and springing hydroelastic dynamic response

Part 4

- Fatigue Analysis and Preliminary Ship Life Prediction

- Fatigue strength and the ship preliminary service life prediction ,based on Palmgren Miner cumulative damage ratio D, design S-N curves and long term histograms

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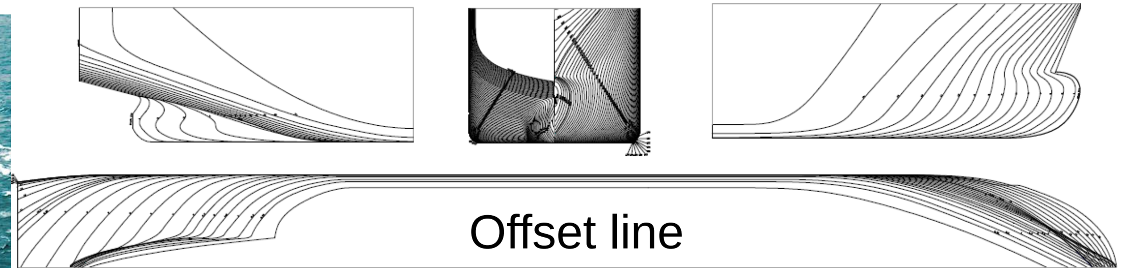
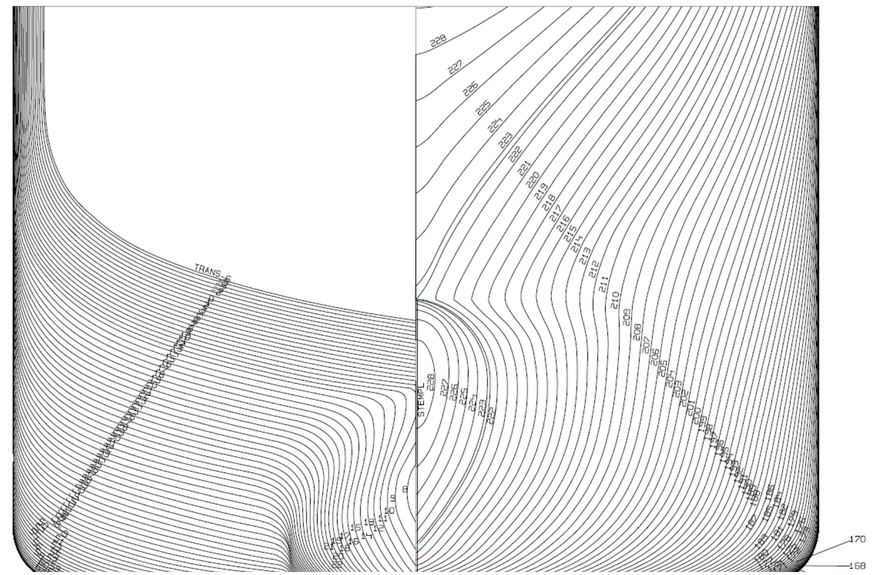
Part 1 – Structural Characteristics of the Bulk Carrier for the Numerical Analysis

Drawings and information from similar ships were granted by ICEPRONAV S.A, from the similar designs developed in the last years.

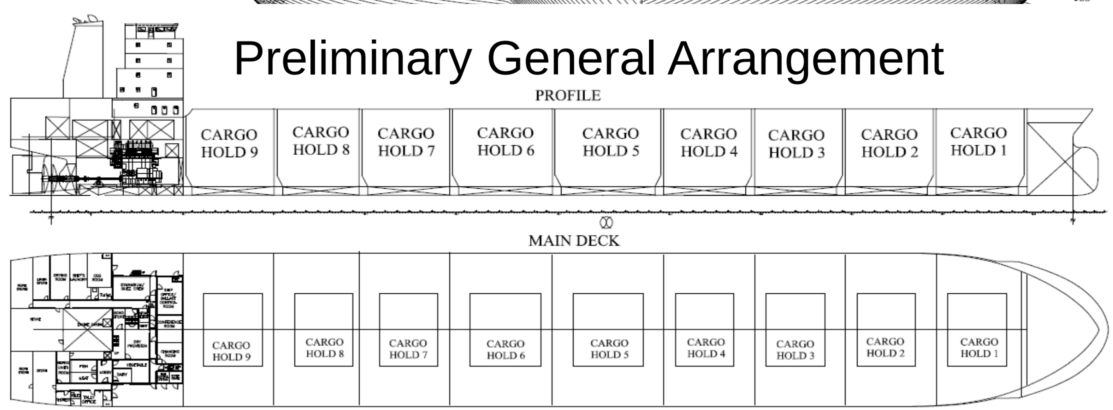
Main Dimensions of the Bulk Carrier	
Dimension	**Value**
Length overall (Loa)	289.87 m
Length between perpendiculars (Lpp)	279.00 m
Rule Length (L)	279.00 m
Breadth (B)	45.00 m
Depth (D)	24.00 m
Design Draft (T)	15.20 m
Service Speed (v_0)	16.00 Knots
Block coefficient (C_B)	0.805
Deadweight (DWT)	162 000 tdw
Number of Cargo Holds	9

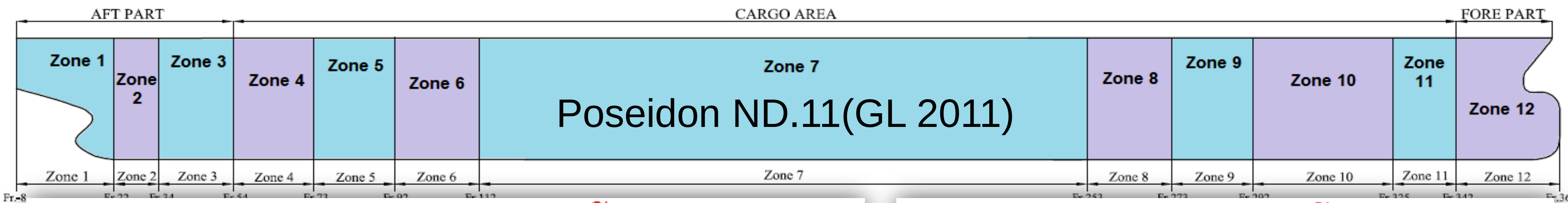


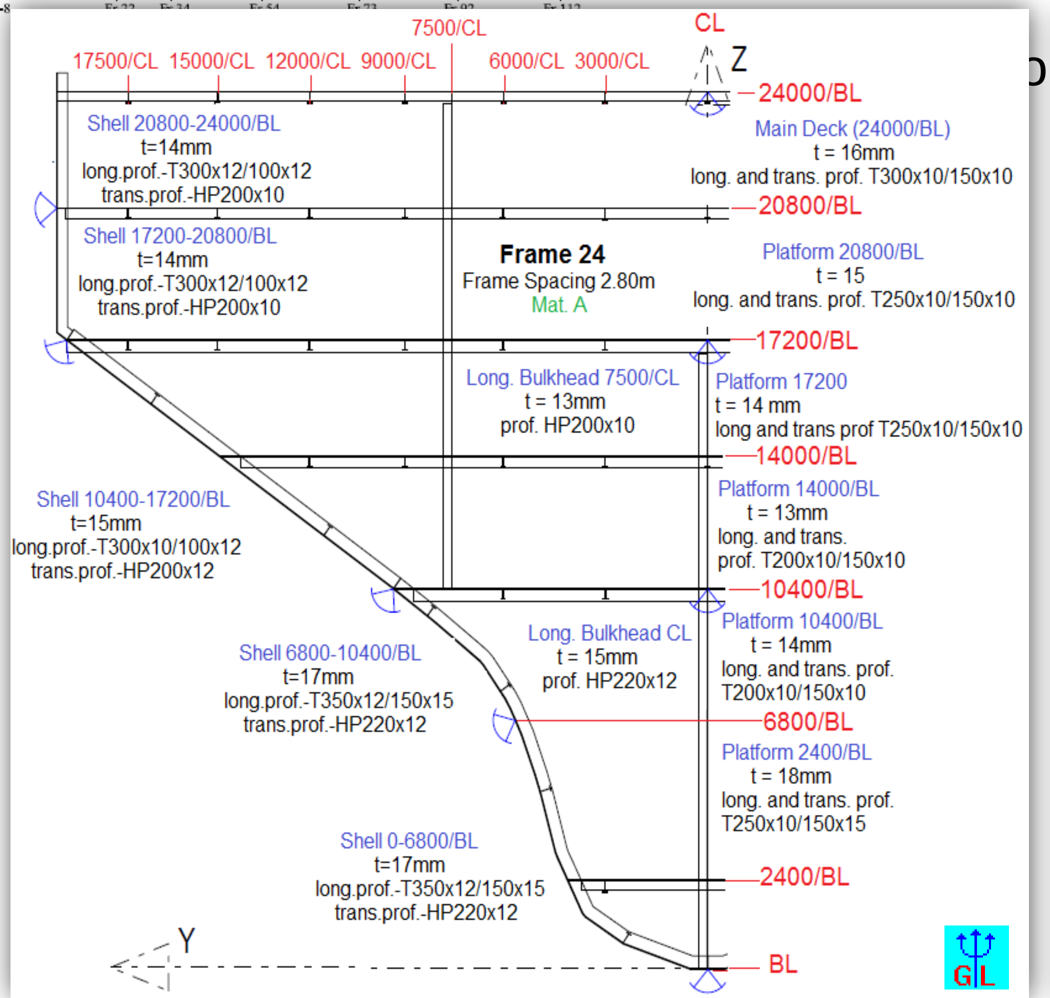
Offset line

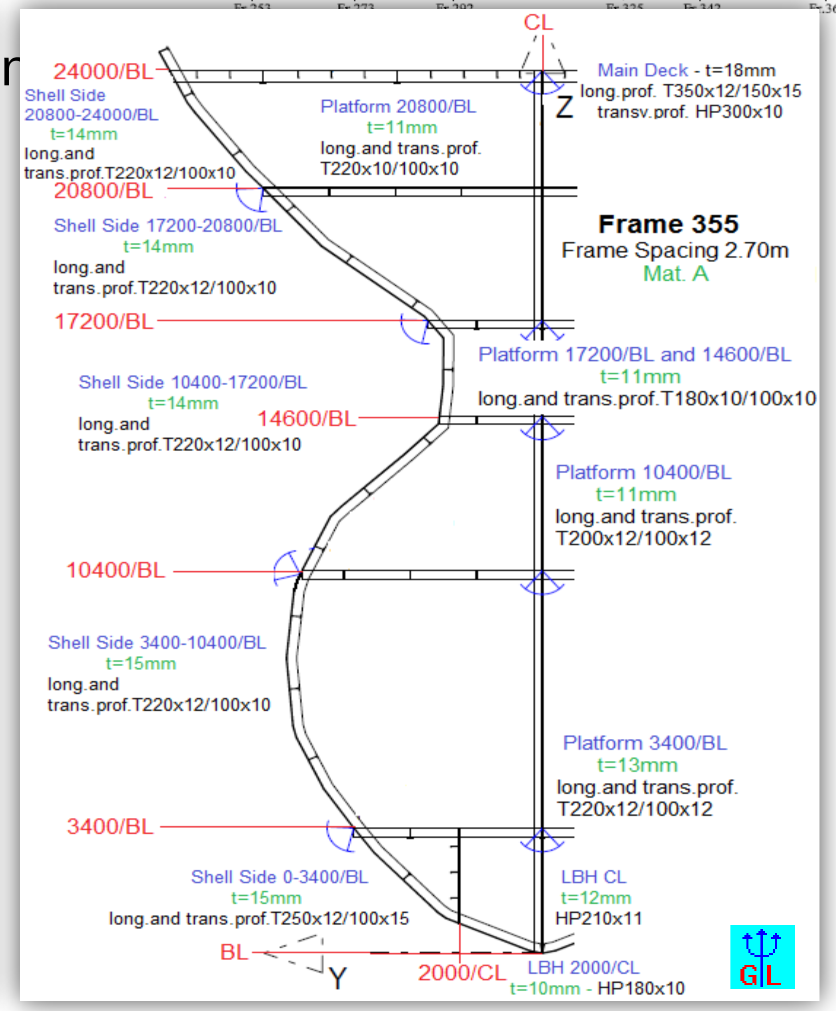


Preliminary General Arrangement





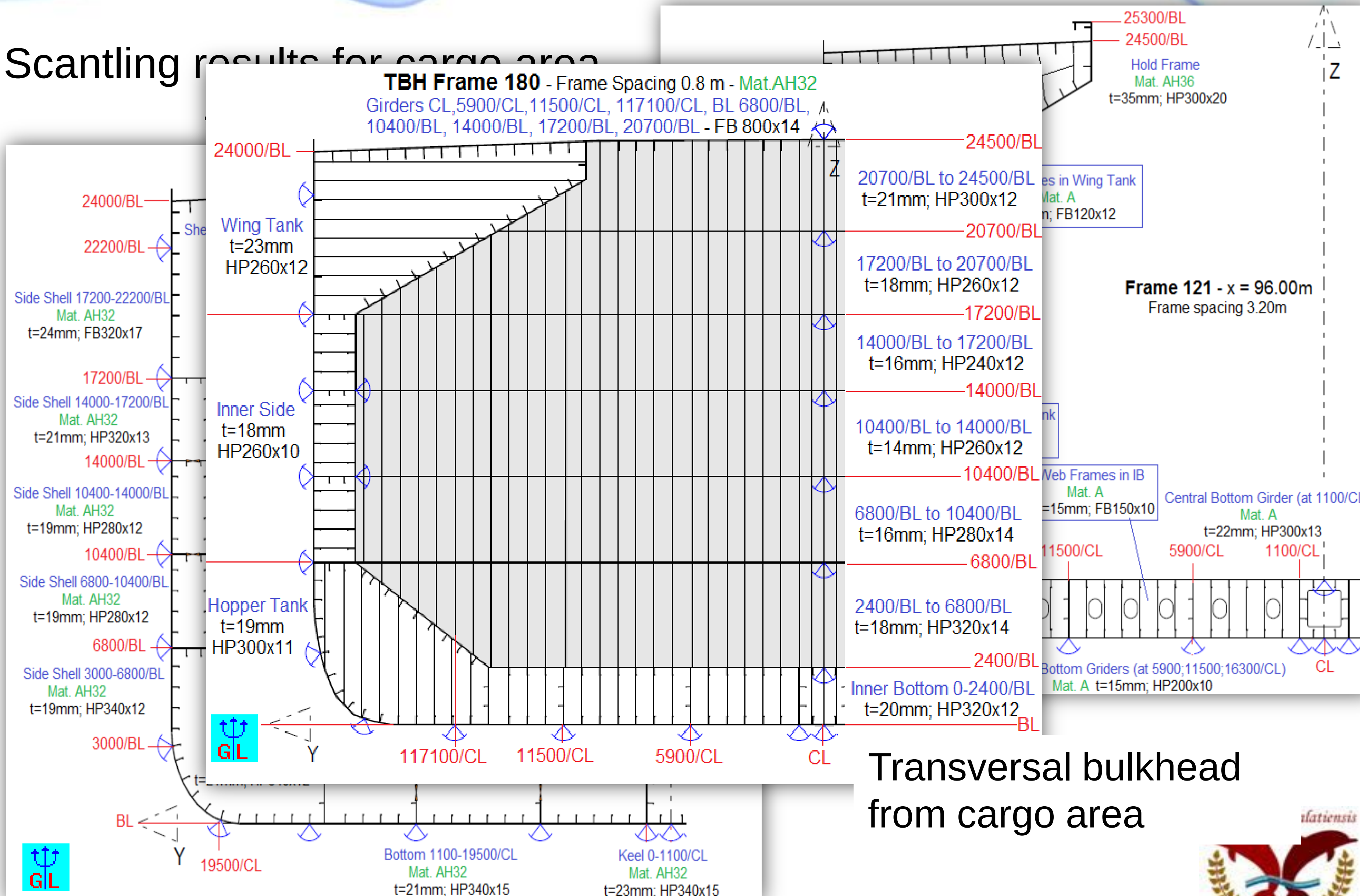




Aft area - zone 2 (Fr. 24, x = 18.50m)

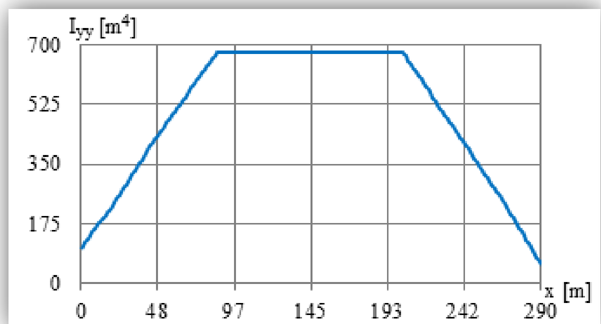
Fore area - zone 12 (Fr.355, x = 273.60m)

Scantling results for cargo area

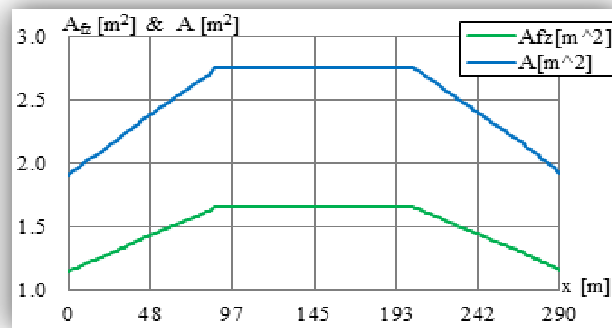


Transversal bulkhead from cargo area

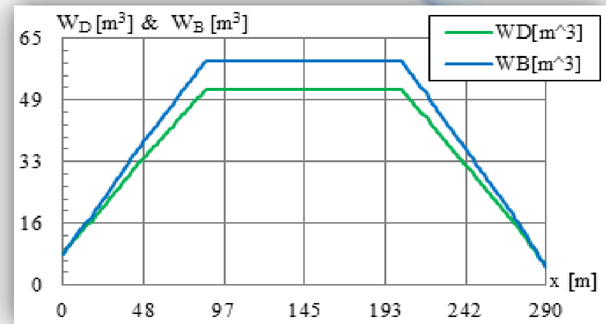
The idealization of the inertia and resistance characteristics of the 1D-girder model



The diagram of the inertial moment

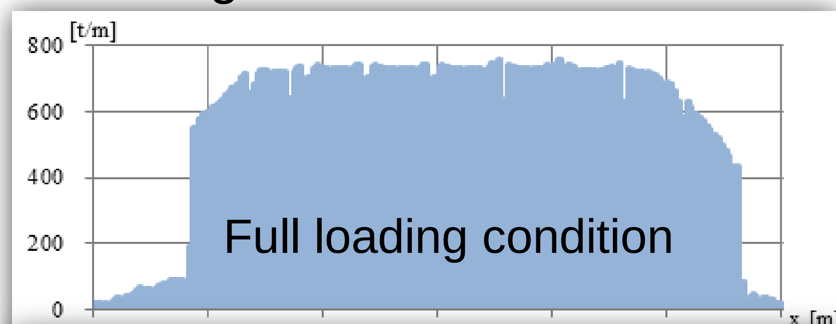


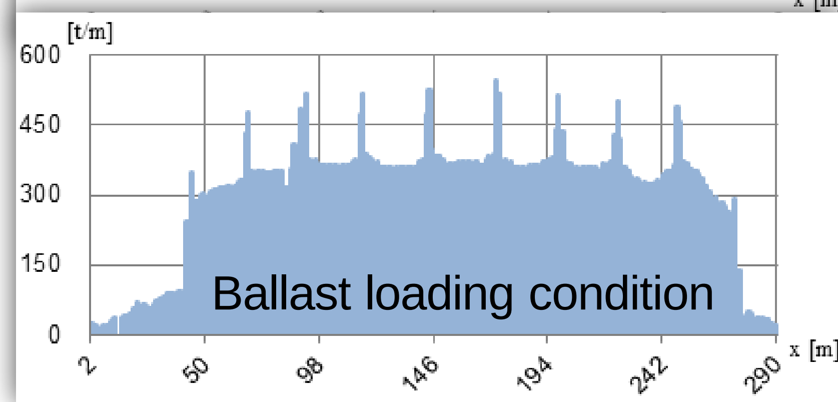
The diagram of the total area and shear area



The diagram of the bending resistance modules of the extreme fibre for bottom and for deck

The diagram of mass distribution



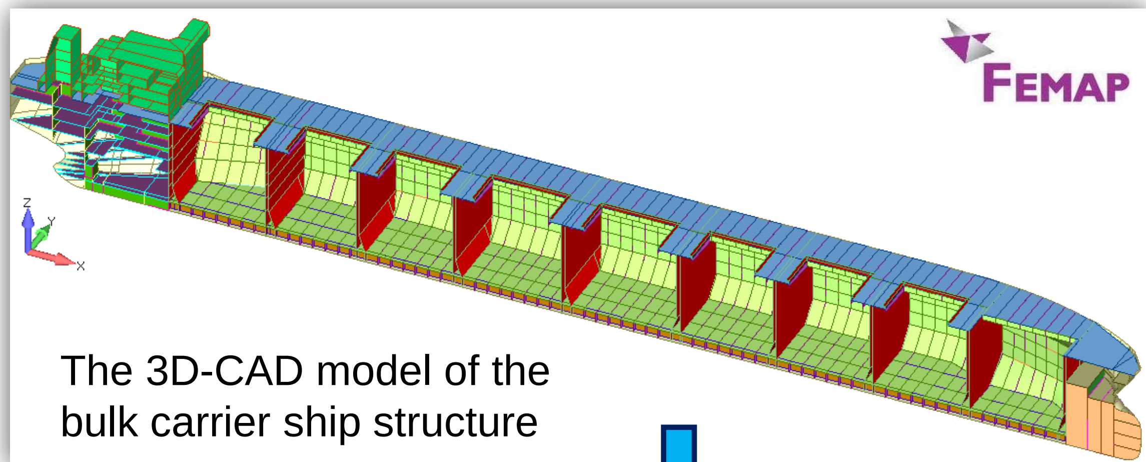


Natural modes frequencies for the two loading conditions

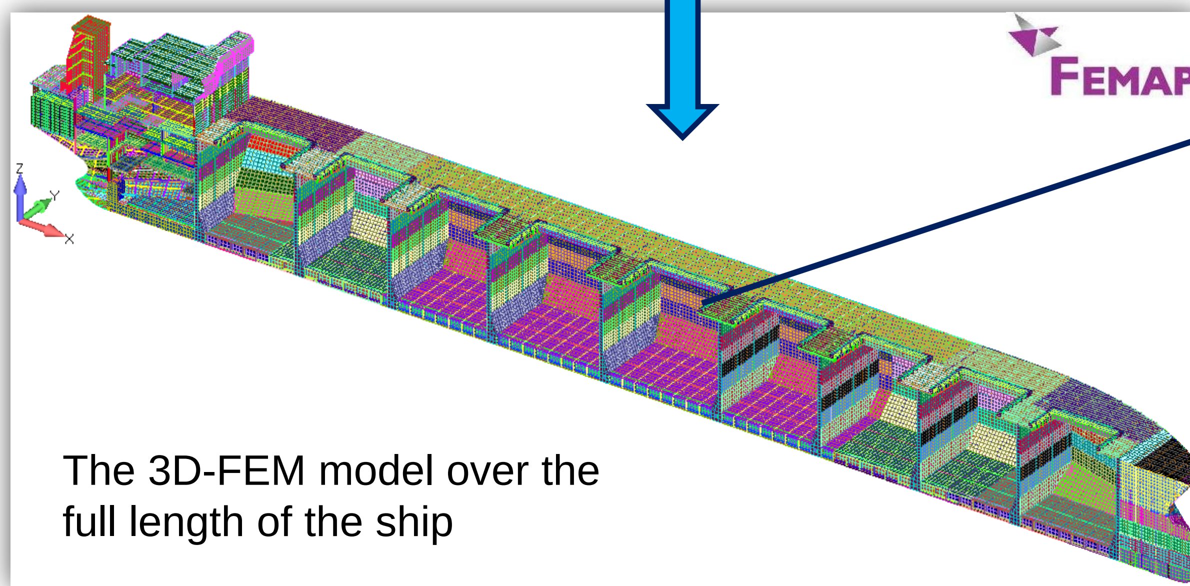
Bulk Carrier		Oscillations f [Hz]		Vibrations f [Hz]		
Mode:		0	1	2	3	4
Nr.	Case					
1	Full Load	0.094	0.103	0.546	1.03	1.51
2	Ballast Load	0.110	0.115	0.663	1.25	1.82

3D-CAD/FEM Model – Model Presentation

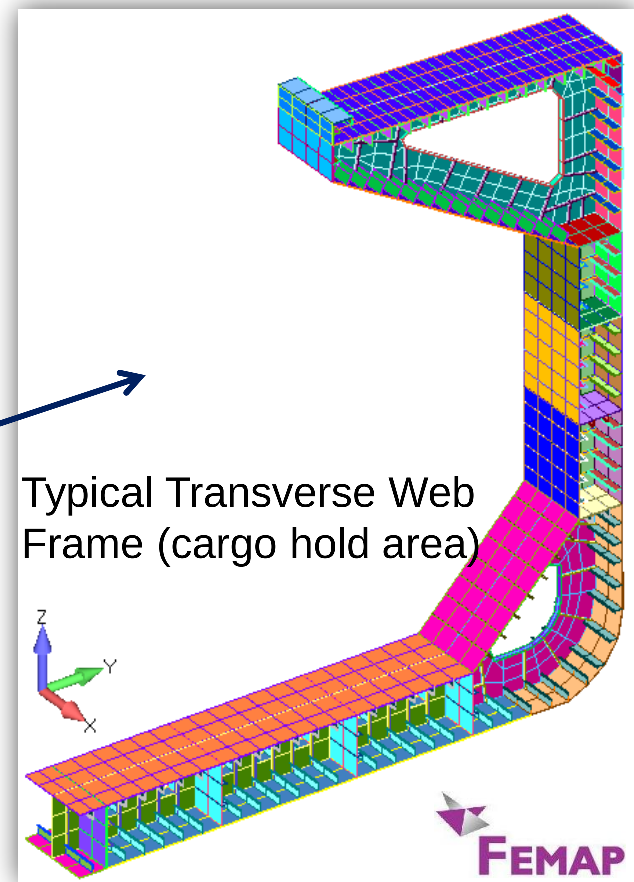
The 3D-CAD/FEM hull model has been developed in NASTRAN NX for FEMAP program.



The 3D-CAD model of the bulk carrier ship structure

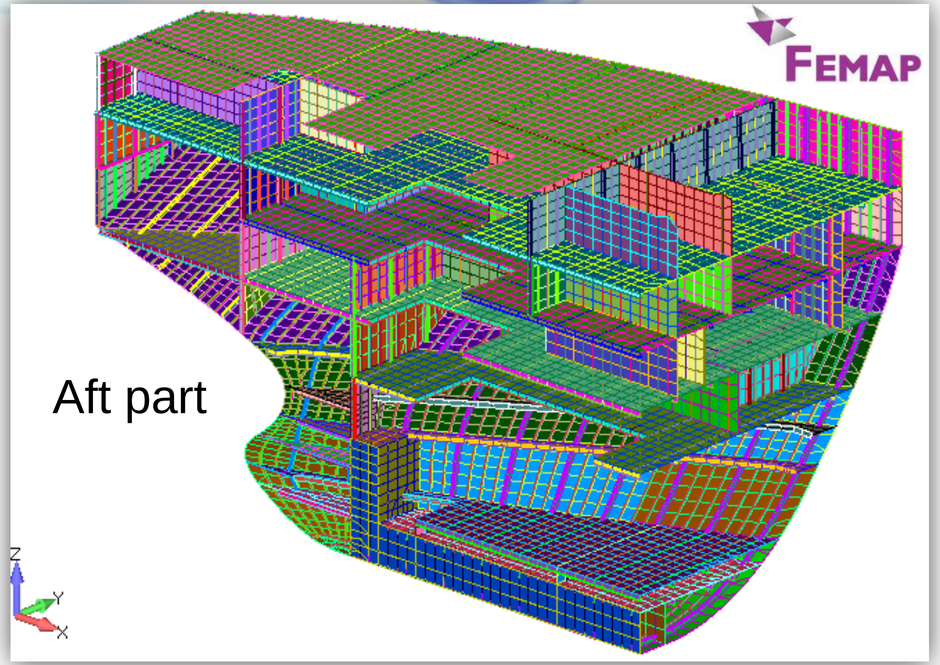


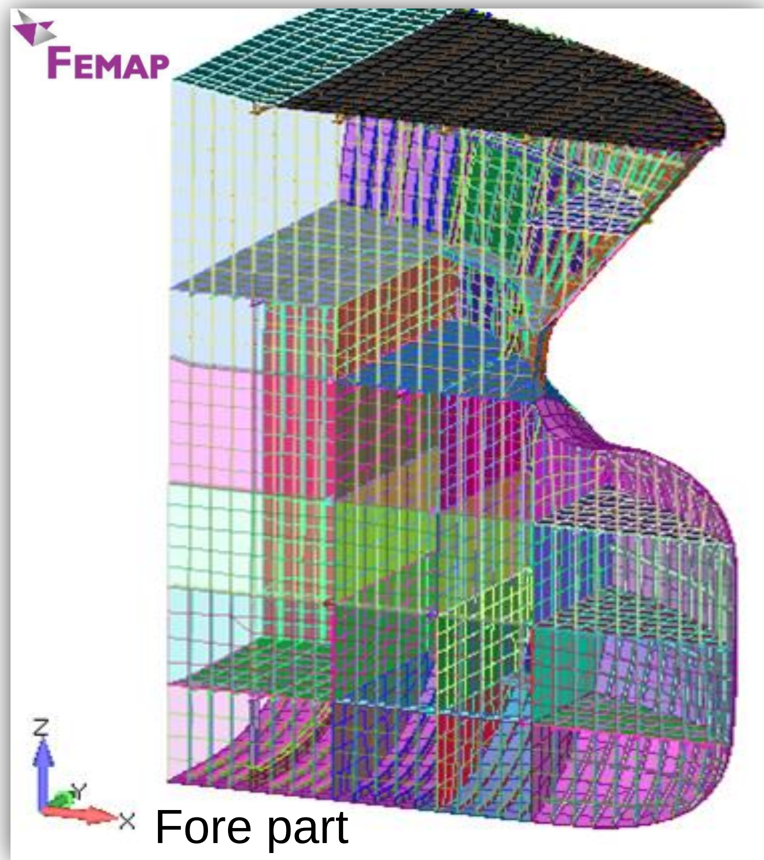
The 3D-FEM model over the full length of the ship

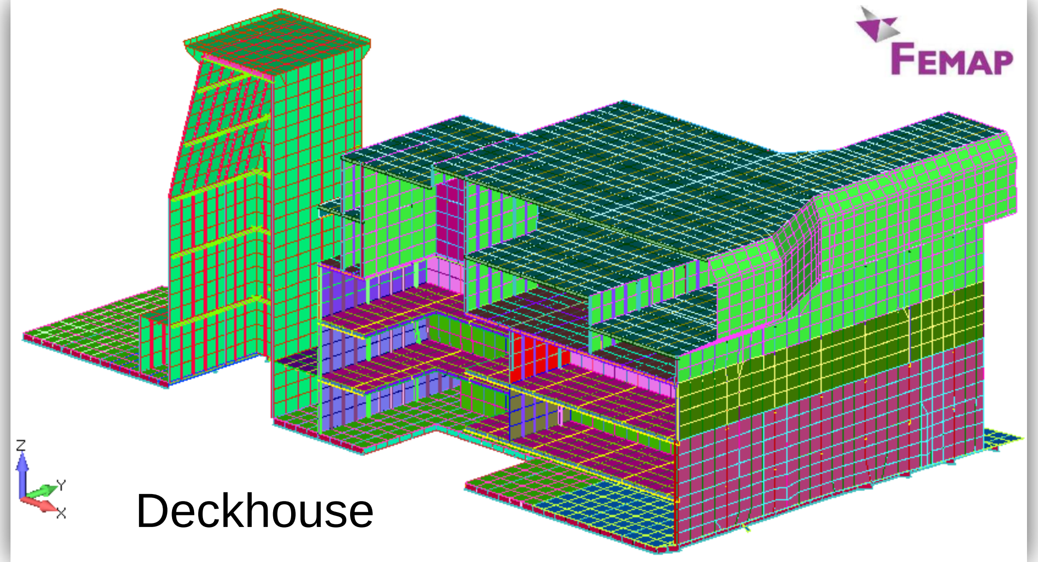


Typical Transverse Web Frame (cargo hold area)

3D-FEM Model Presentation

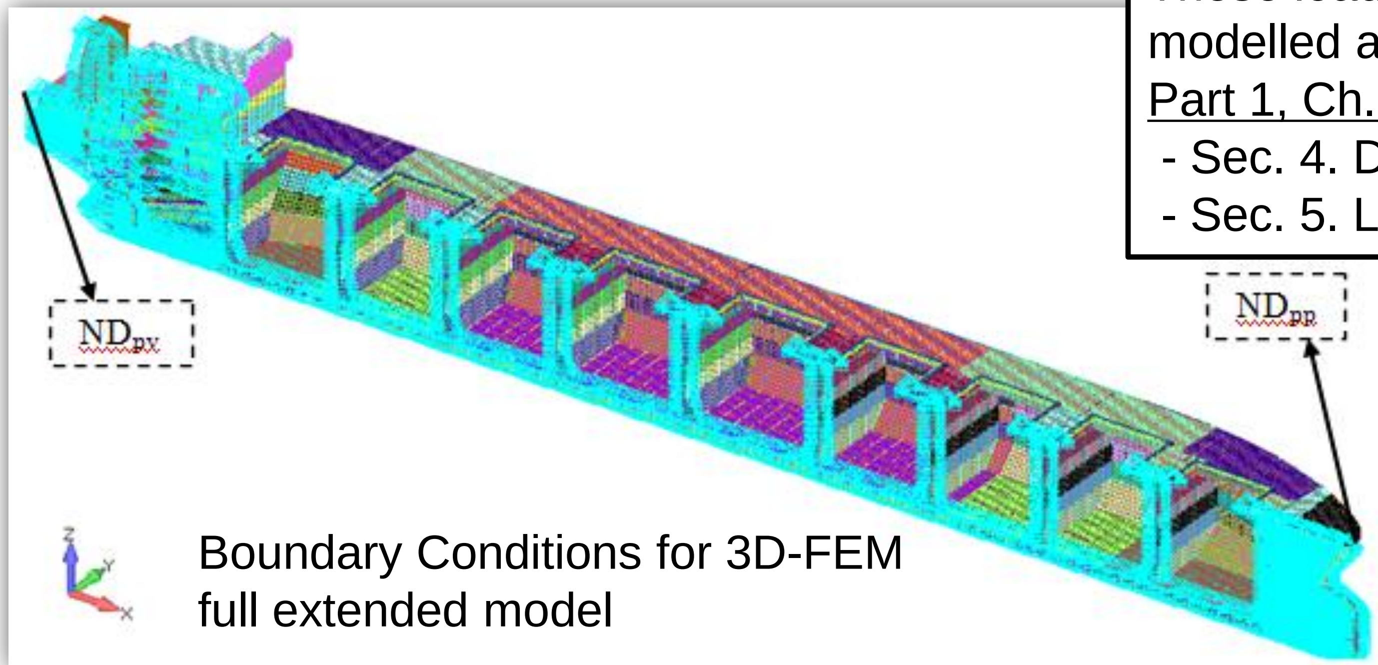






Boundary Conditions

Location of the independent point	Translational			Rotational		
	Ux	Uy	Uz	Rx	Ry	Rz
ND_{pv} at aft peak	Fix	Fix	Fix	Fix	-	Fix
ND_{pp} at fore peak	-	Fix	Fix	Fix	-	Fix
Symmetry Condition in CL	-	Fix	-	Fix	-	-



Boundary Conditions for 3D-FEM full extended model

Loading Case

There were modelled two loading cases:
- full cargo load case (LC_F);
- ballast load case (LC_B).

These loading cases were modelled according to GL 2011 - Part 1, Ch. 1:
- Sec. 4. Design Loads
- Sec. 5. Longitudinal Strength.

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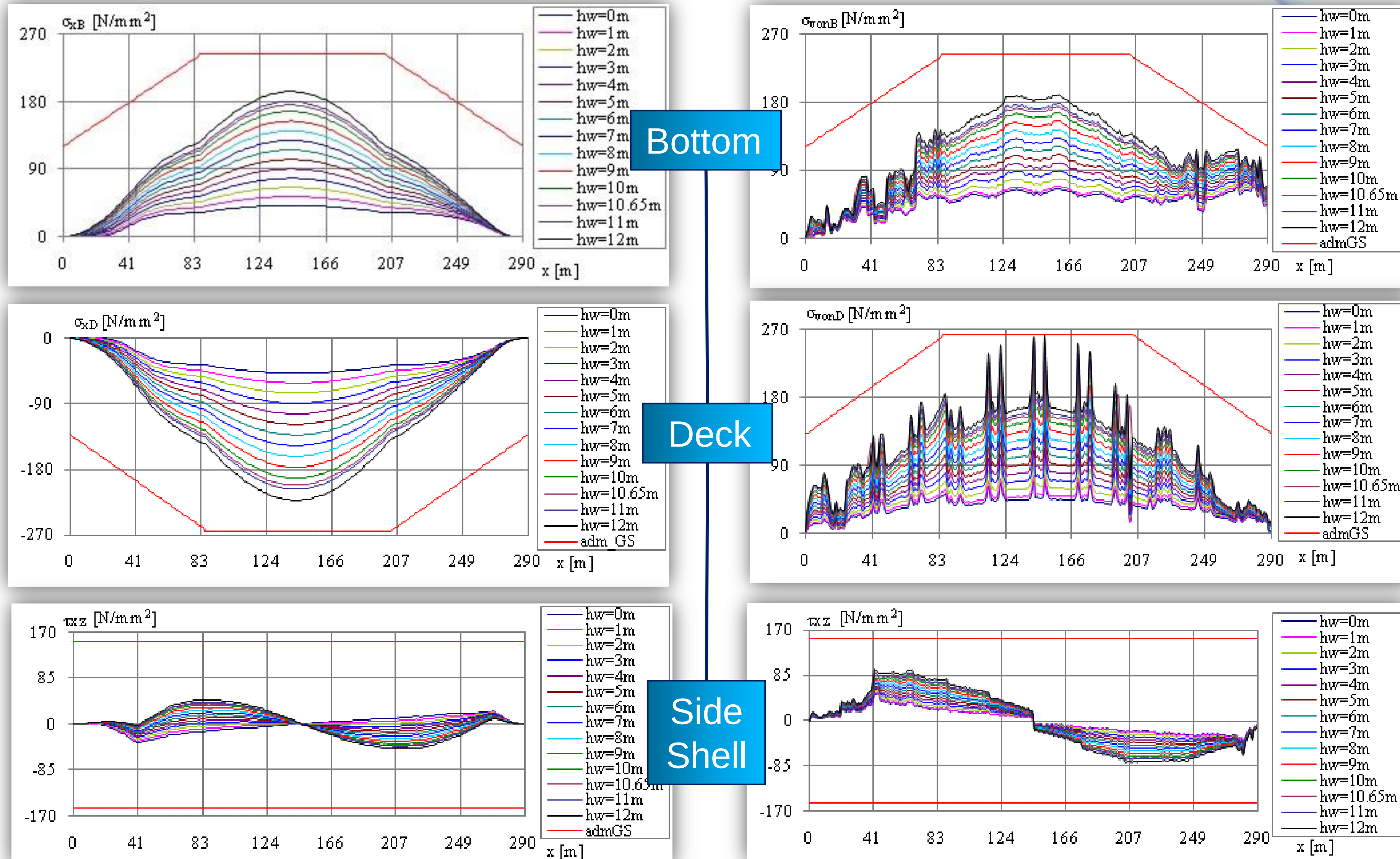
Numerical Results - Full Loading Case – wave in sagging conditions



Results from 1D-girder model

Results from 3D-FEM model

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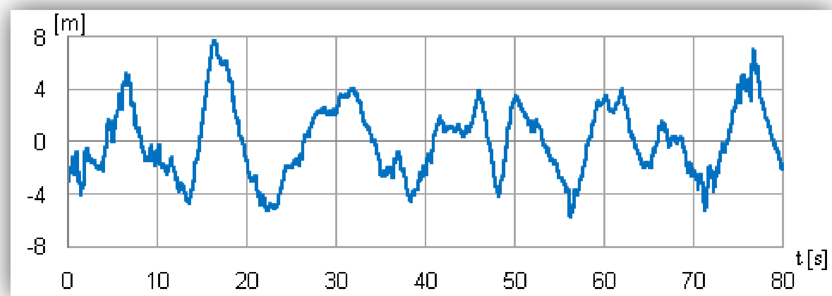
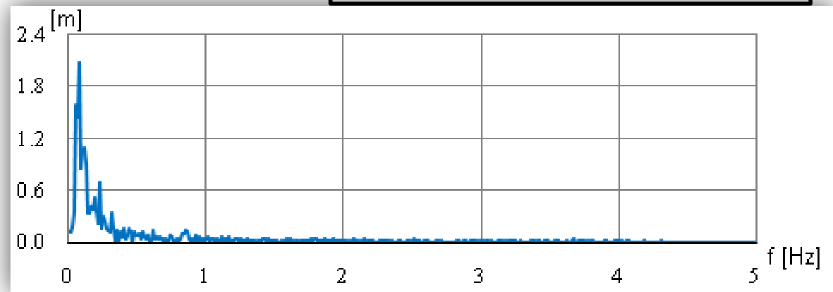
Numerical Results - Full Loading Case

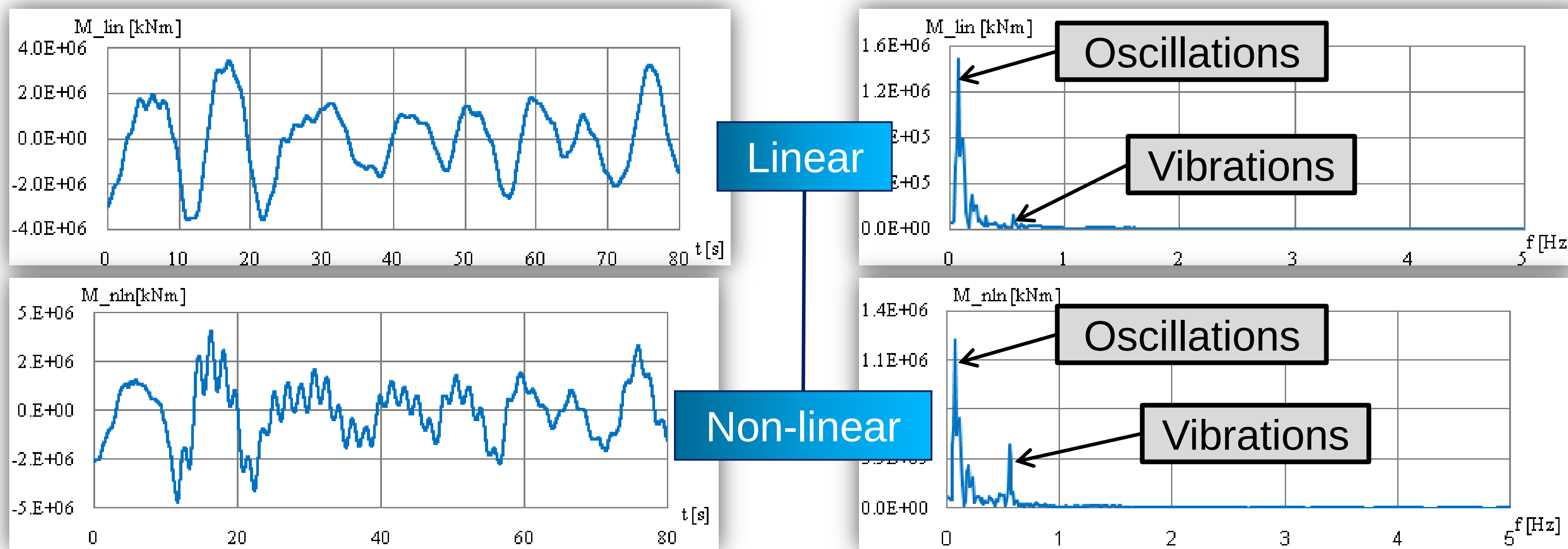
DYN in-house program developed at Galati Naval Architecture Faculty

Wave model Longuet-Higgins, with the first order power density spectrum function ITTC, for significant wave height $h_{1/3}$=10.65m at x/L=0.50





The dynamic bending moment at hydroelastic linear and non-linear analysis, significant wave height $h_{1/3}$=10.65m at x/L=0.5



Time record

Amplitude spectrum FFT

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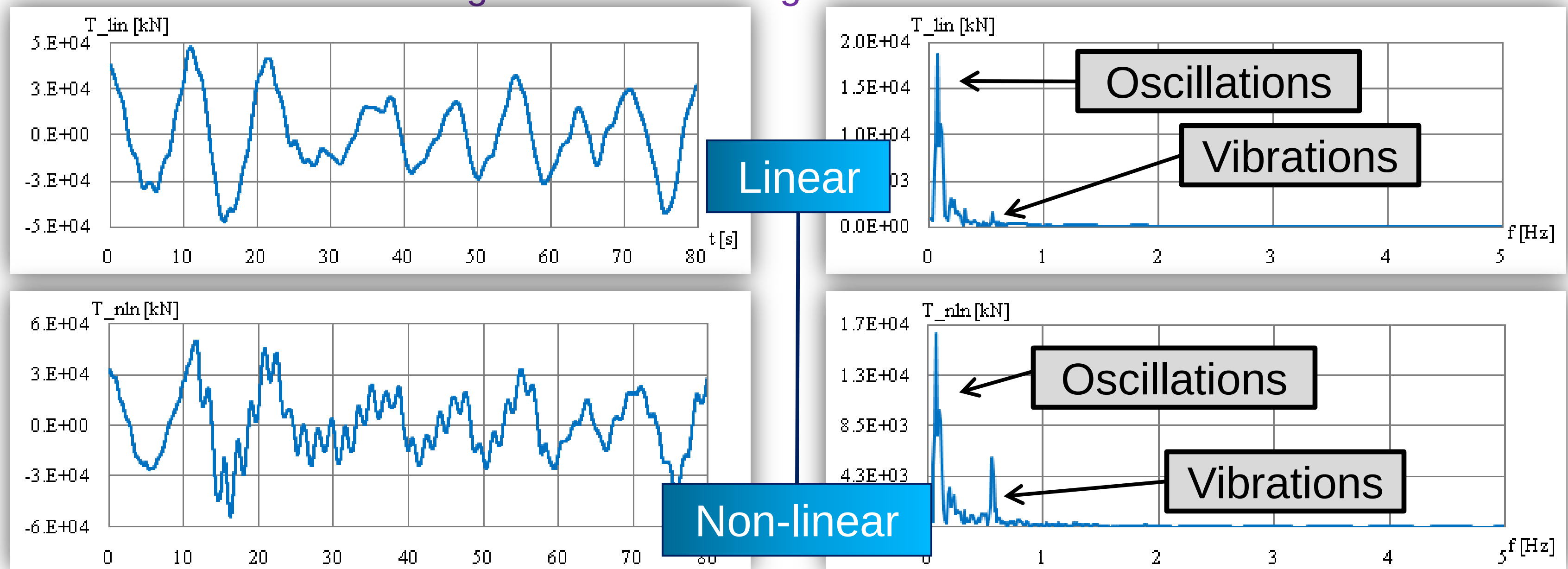
Numerical Results - Full Loading Case

The dynamic shear force at hydroelastic linear and non-linear analysis, significant wave height $h_{1/3}$=10.65m at x/L=0.75



Time record | Amplitude spectrum FFT

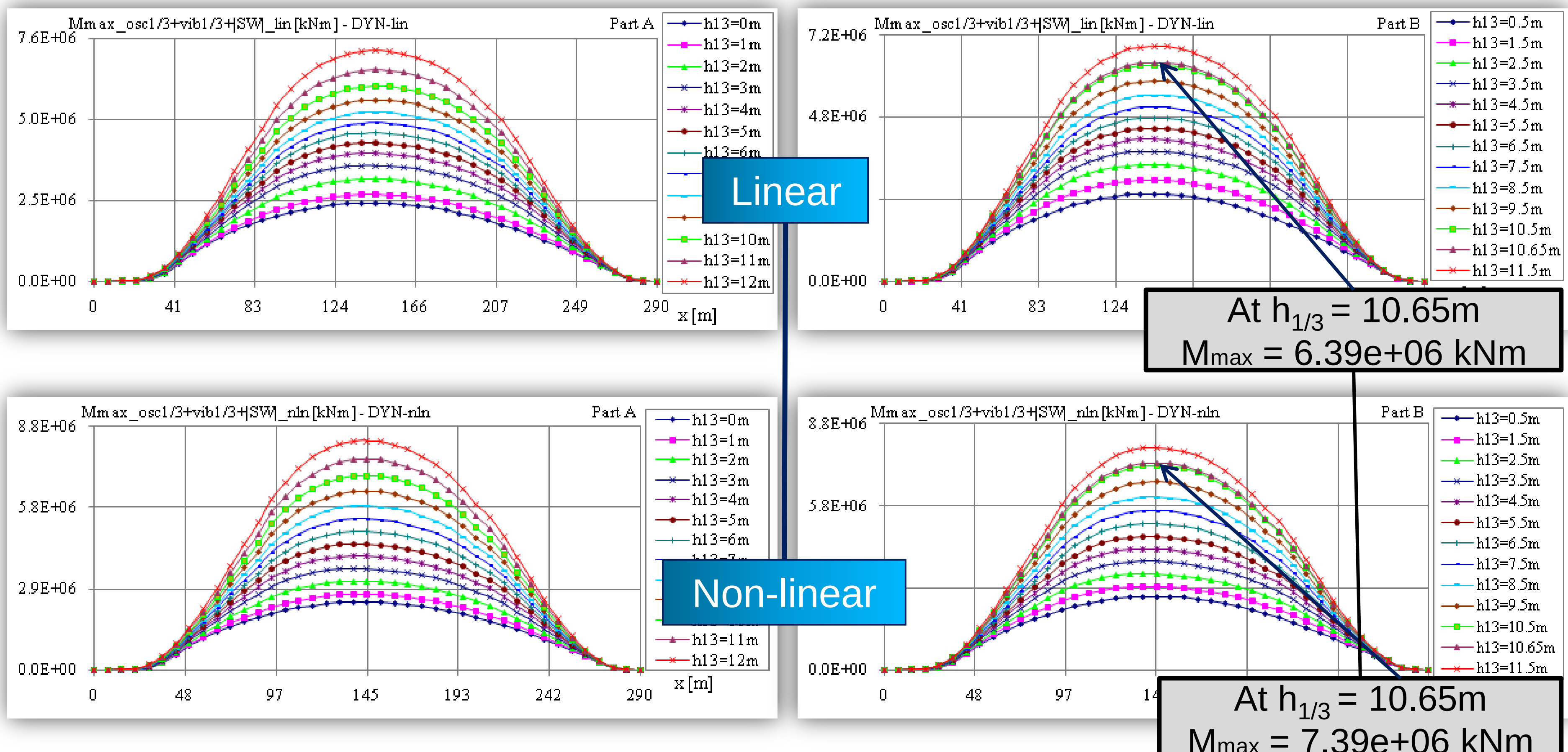
Ratios between short term oscillations and vibrations response, for the significant deformation, bending moment and shear force ($h_{1/3}$ = 10.65m)

$w_{1/3}$_vib / $w_{1/3}$_osc	$M\_vib_{1/3}$ / $M\_osc_{1/3}$	$T\_vib_{1/3}$ / $T\_osc_{1/3}$
Linear 5.68%	Linear 15.07%	Linear 13.86%
Non-linear 5.78%	Non-linear 33.16%	Non-linear 27.37%

<table>
<tr><th colspan="2">Slamming</th><th>Green Sea</th></tr>
<tr><td rowspan="2">Bottom</td><td>Aft, $h_{1/3}$ > 5.75m</td><td>Aft, $h_{1/3}$ > 11.50m</td></tr>
<tr><td>Fore, $h_{1/3}$>12.0m</td><td rowspan="2">Fore, $h_{1/3}$> 10.65m</td></tr>
<tr><td>Side</td><td>Aft and Fore</td></tr>
<tr><th colspan="2">Springing</th><th>Whipping</th></tr>
<tr><td colspan="2">Linear : very reduced</td><td rowspan="2">High intensity</td></tr>
<tr><td colspan="2">Non-linear: small</td></tr>
</table>

Numerical Results - Full Loading Case

The short term significant bending moments at still water + oscillation + vibration over the ship length, at dynamic linear and non-linear analysis for $h_{1/3}$ = 0.0 to 12.0m



Part A - $h_{1/3}$ = 0.0 to 12.0m (step 1.0m)

Part B - $h_{1/3}$ = 0.5 to 11.5m (step 1.0m)

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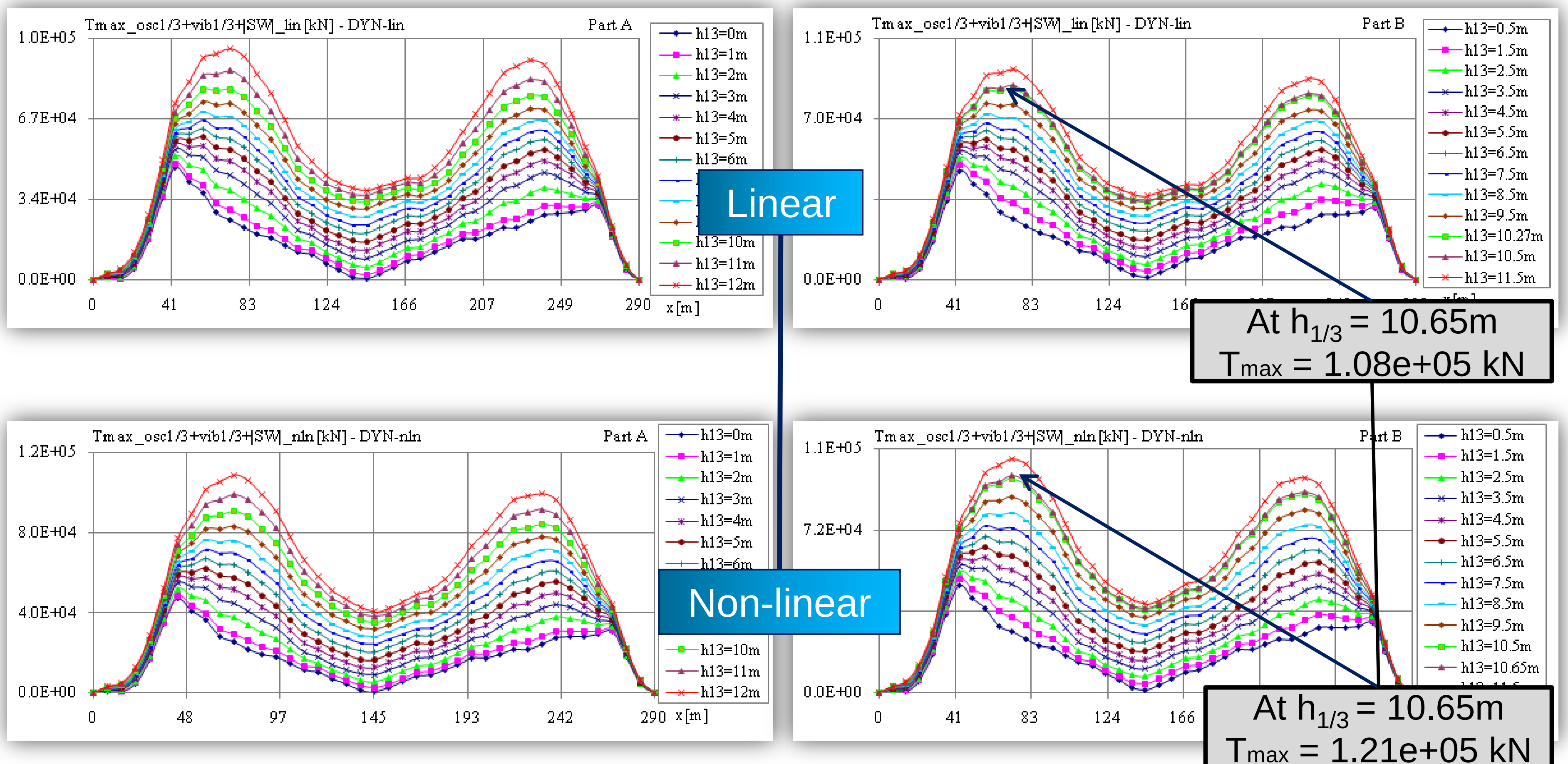
Numerical Results - Full Loading Case

The short term significant shear forces at still water + oscillations + vibration over the ship length, at dynamic linear and non-linear analysis for $h_{1/3}$ = 0.0 to 12.0m

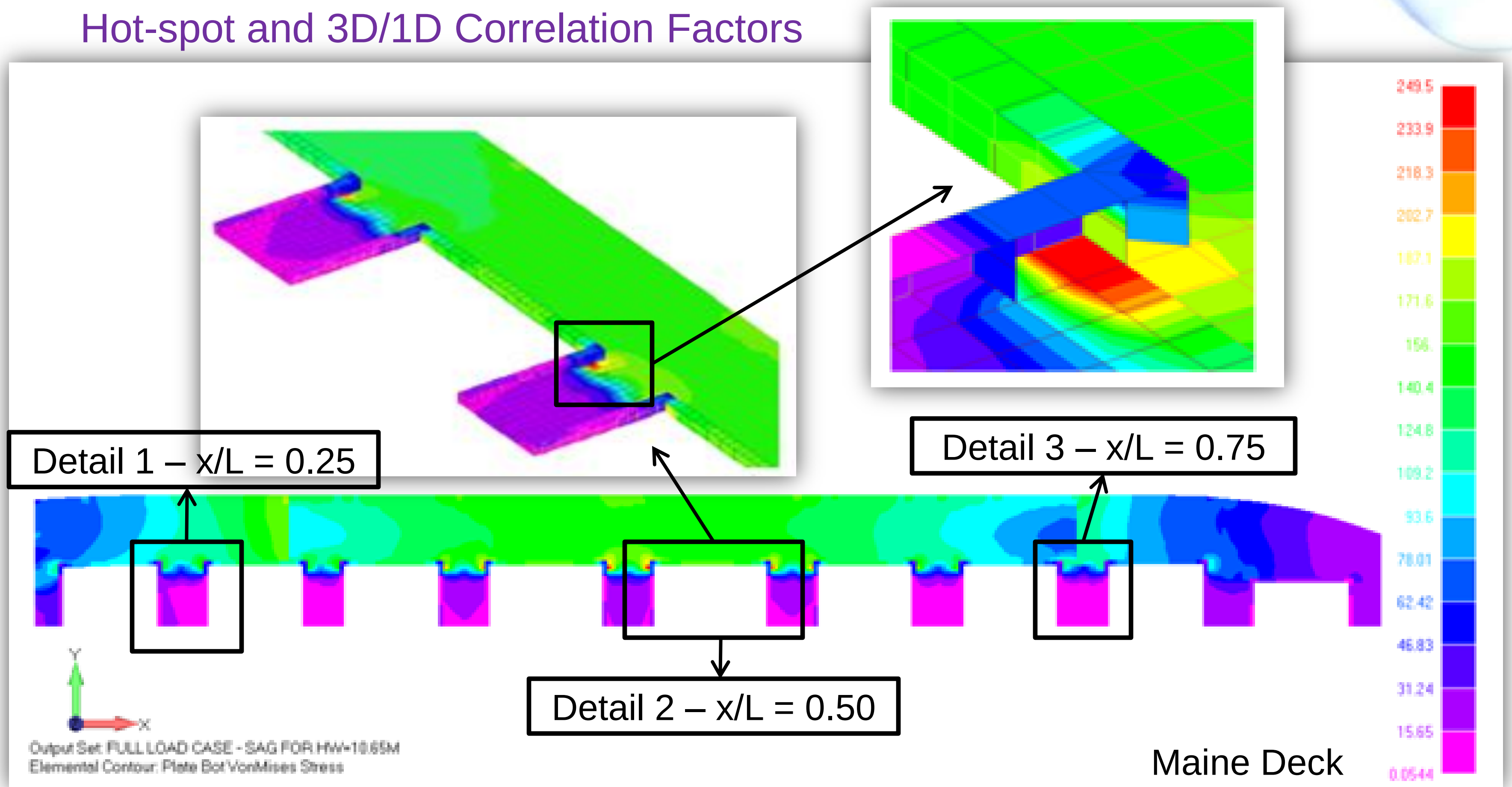


Part A - $h_{1/3}$ = 0.0 to 12.0m (step 1.0m)

Part B - $h_{1/3}$ = 0.5 to 11.5m (step 1.0m)

Input data from Full Loading Case

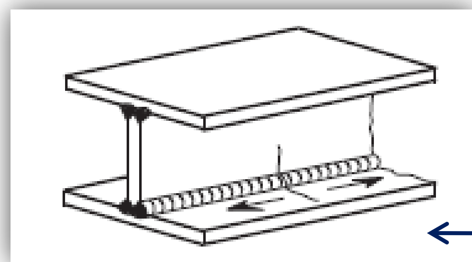
Hot-spot and 3D/1D Correlation Factors



Detail	Maximum σ_{VMD_3D} [N/mm²]	Maximum σ_{xD_1D} [N/mm²]	$k_{3D/1D}$
Detail 1 - x/L=0.25	160.80	116.43	1.381
Detail 2 - x/L=0.50	251.24	200.65	1.252
Detail 3 - x/L=0.75	131.09	101.37	1.293

Input data for fatigue analysis and initial ship service life prediction

GL2011 - I Part 1 Ch.1 Sec.20

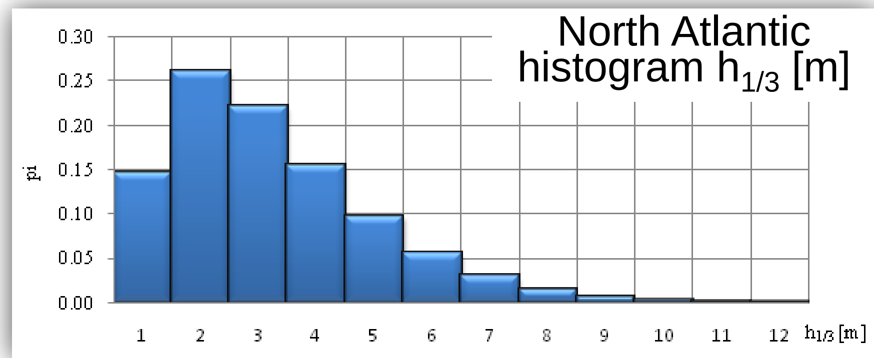


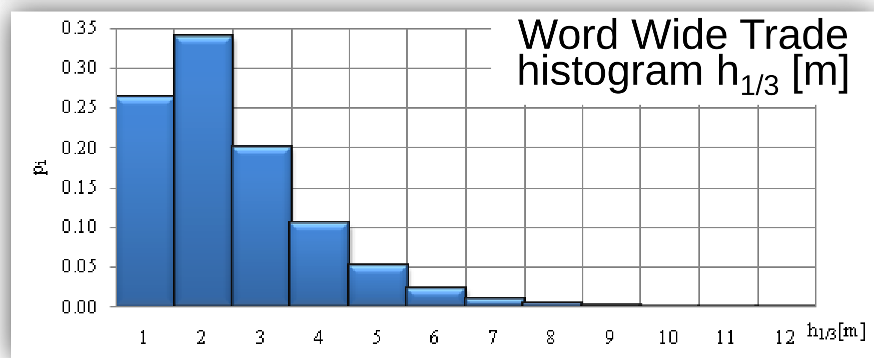
R = 20 years – reference life time

Joint configuration B2 from GL2011

	Full loading	Ballast loading
f_osc	0.102 [Hz]	0.115 [Hz]
T_osc	9.804 [s]	8.688 [s]
n_osc	6.433E+07 [cycles]	9.074E+07 [cycles]
f_vib	0.546 [Hz]	0.663 [Hz]
T_vib	1.832 [s]	1.508 [s]
n_vib	3.444E+08 [cycles]	5.227E+08 [cycles]
R_{eH}	355 [N/mm^2] – the yield point	
R_m	490 [N/mm^2] - the tensile stress limit	
f_R	1.121 [N/mm^2]	
$\Delta\sigma_R$	125.0 [N/mm^2] (see Figure 199)	
f_m	1.0 - welded joint	
f_w	1.4 - full penetration weld	
F_i	1.0 - primary structural element	
m_0	3.0 - for welded joint	
c	0.15 - welded joint subjected to variable stress cycles	

Nr.	Fatigue Cases
1	North Atlantic - 1D-girder model
2	North Atlantic - 3D/1D combined model
3	Word Wide Trade - 1D-girder model
4	Word Wide Trade - 3D/1D combined model





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Numerical Results

3D/1D combined model with North Atlantic histogram

Detail 2 - x/L = 0.50								
	Full Load		Ballast Load		0.5 full load + 0.5 ballast load			
Analysis	D_{SN_osc}	D_{SN_vib}	D_{SN_osc}	D_{SN_vib}	D_{SN_osc}	D_{SN_vib}	$D_{SN\_osc+vib}$	$L_{\_osc\_vib}$
ADV	0.8739	-	0.992	-	0.9330	-	0.9330	21.4
HEL	0.8739	0.0060	0.992	0.0000	0.933	3.0E-03	0.936	21.4
DYN-LN	0.8868	0.0032	1.092	0.001	0.990	1.9E-03	0.992	20.2
DYN-NLN	1.1133	0.0683	1.157	0.037	1.135	5.3E-02	1.188	**16.8**

Fatigue criteria is not satisfied

3D/1D combined model with Word Wide Trade histogram

Detail 2 - x/L = 0.50								
	Full Load		Ballast Load		0.5 full load + 0.5 ballast load			
Analysis	D_{SN_osc}	D_{SN_vib}	D_{SN_osc}	D_{SN_vib}	D_{SN_osc}	D_{SN_vib}	$D_{SN\_osc+vib}$	$L_{\_osc\_vib}$
ADV	0.2651	-	0.305	-	0.2849	-	0.2849	> 35
HEL	0.2651	0.0051	0.305	3.7E-05	0.285	2.5E-03	0.287	> 35
DYN-LN	0.3095	0.0018	0.319	3.5E-04	0.314	1.1E-03	0.315	> 35
DYN-NLN	0.4037	0.0183	0.344	9.0E-03	0.374	1.4E-02	0.387	> 35

Fatigue criteria are satisfied

ADN – linear oscillations response without head wave interference component
HEL – linear hydroelastic response in irregular head waves without interference component
DYN – LN and NLN – linear an non-linear response in irregular head waves with interference component (wave model Longuet-Higgins)

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Final Remarks and Conclusions

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• From the stress distribution in the 3D-FEM model (global-local strength analysis), for both loading cases, it can be observed that the hot spots stress values are located in the main deck, around the cargo hold frames.

• From the hydroelastic linear and non-linear dynamic response analysis (irregular head waves), results that the bending moments and shear forces are higher in the non-linear analysis then in linear analysis. For this it is recommended to use the non-linear analysis for more accurate results.

• For stress based on non-linear hydroelastic analysis and using North Atlantic wave histogram the maximum $\mathbf{D_{SN(3D)}}$ results **1.188 > 1**, so than the ship service life is reduced at 16.8 years < 20 years. In the case of using Word Wide Trade wave histogram no restriction occurs.

• The numerical results are pointing out that for large ships having high wave induced global vibration response, it is necessary to carry out an non-linear hydroelastic analysis, under irregular waves, in order to have a more realistic long term fatigue analysis.

• The study should continue with a finer mesh 3D-FEM model analysis in the areas where were identified the hot-spot stress.

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Thank You!

Bianca Cristea

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