Global Flexible Hull Girder Loads on Intact and Damaged Ships

by

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Visions of Tomorrow, Engineered Today

2022/11/30

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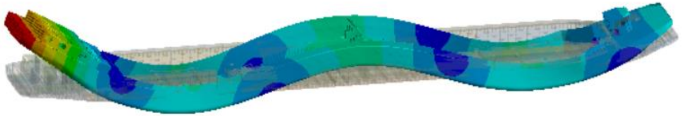
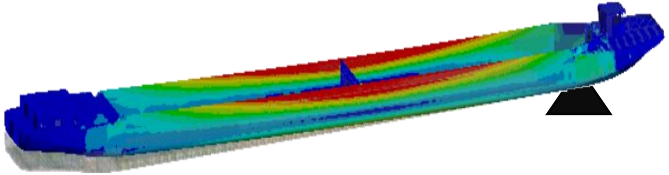
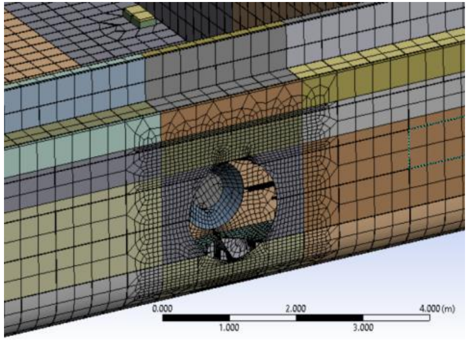
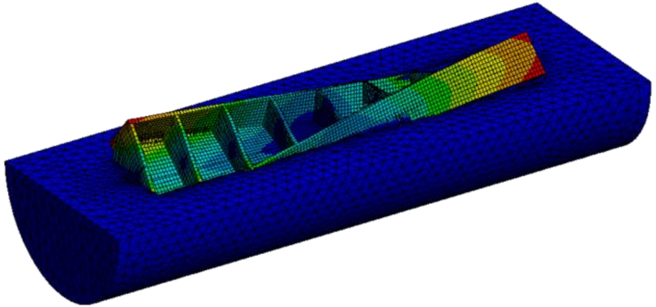
Outline

- Marine accidents – the role of hydroelasticity
- Literature review and thesis objectives
- Methodology
- Four study cases
- Conclusions

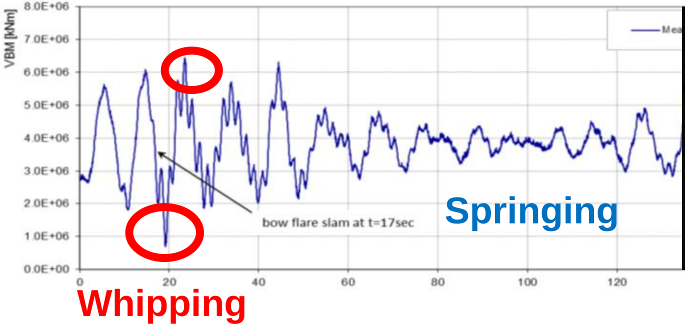




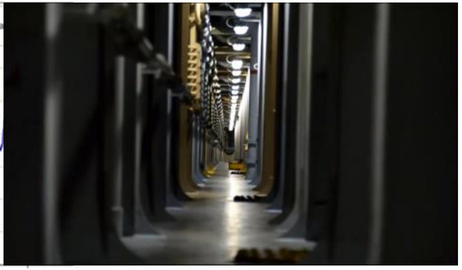


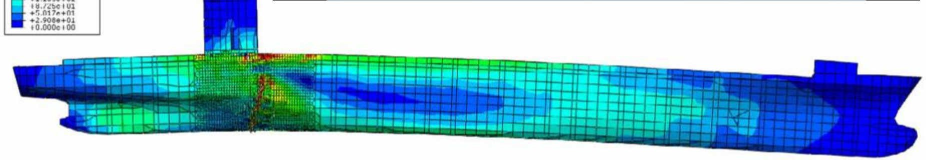
Marine accidents – the role of hydroelasticity

Marine accidents:

- MOL COMFORT 2013 (**Whipping**)
- MSC Napoli 2007 (**Whipping**)
- Elastic body response: **Springing** and whipping (60% of fatigue damage).







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Literature review

- **Elastic** responses (**springing** and **whipping**) of practical importance for long slender ships and multi-hulls.
- **3D hydroelasticity** using **BEM** is usually employed.
- **Flexible** responses of **damaged** and **grounded** ships are **not** studied.
- The use of **acoustic** element methods is **rarely** considered.

Thesis objectives

- Critical **review** (identify literature gaps)
- Study of the **sensitivity** of elastic responses to **loading conditions**
- Gain overview of the impact of **damages** and **grounding** on global **responses** using commercial codes.
- Evaluate the effects of **resonances** on **intact** and **damaged** ships using BEM and the Acoustic Element Method (AEM).

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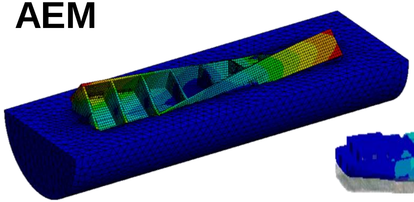
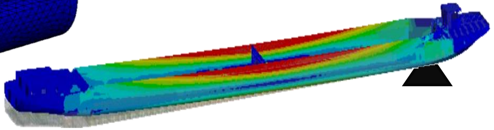
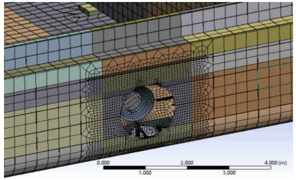
AEM



Grounded

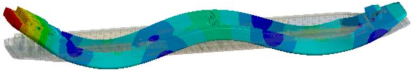


Damaged



Wet

Dry



Methodology (I)

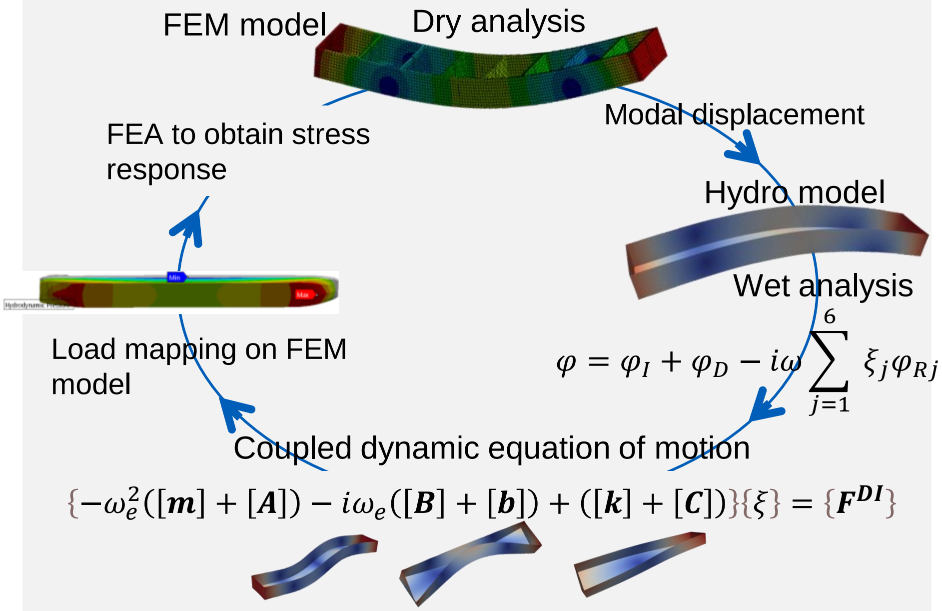
3D Hydroelasticity theory

- Dry analysis (Block Lanczos):
  - Dry eigenmodes: FEM
  - $[\widehat{\boldsymbol{M}}][\ddot{\hat{\xi}}] + [\widehat{\boldsymbol{K}}][\hat{\xi}] = 0 \quad , [\ddot{\hat{\xi}}]= \omega_i^2[\hat{\xi}_i]$

- Wet analysis (BEM):
  - linear potential flow theory in frequency domain

$\widehat{\boldsymbol{M}}$ mass matrix, $\widehat{\boldsymbol{K}}$ stiffness matrix, $\hat{\xi}$ eigenvector or mode shape, i natural mode number, ω_i eigen angular frequency

Flexible Fluid Structure Interactions FFSI (BEM)



$$\varphi = \varphi_I + \varphi_D - i\omega \sum_{j=1}^{6} \xi_j \varphi_{Rj}$$

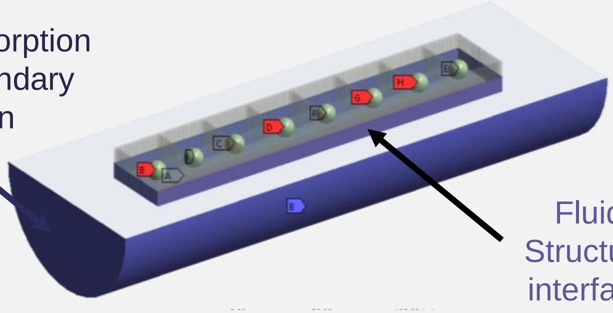
$$\{-\omega_e^2([\boldsymbol{m}]+[\boldsymbol{A}]) - i\omega_e([\boldsymbol{B}]+[\boldsymbol{b}]) + ([\boldsymbol{k}]+[\boldsymbol{C}])\}\{\xi\} = \{\boldsymbol{F}^{DI}\}$$

$\hat{\xi}$ motion vector, φtotal potential, φ_I Incident potential, φ_D diffraction potential, φ_{Rj} radiation potential, $\boldsymbol{m}$ modal structural mass, $\boldsymbol{A}$ hydrodynamic added mass, $\boldsymbol{B}$ hydrodynamic damping, $\boldsymbol{b}$ structural damping, $\boldsymbol{k}$ structural stiffness, C hydrostatic restoring.

Methodology (II)

Acoustic Element Method (AEM)

- **Simpler** and **faster** than BEM
- **Acoustic modal analysis** solver in ANSYS



Acoustic Absorption surface boundary condition

Fluid Structure interface $[\boldsymbol{R}]$

Fully coupled FFSI

Dynamic equation of motion (structure model)

$$[M_S]\{\ddot{u}_e\} + [C_S]\{\dot{u}_e\} + [K_S]\{u_e\} - [\boldsymbol{R}]\{\boldsymbol{p}_e\} = \cancel{\{f_S\}}$$

Wave equation (Fluid domain)

$$[M_F]\cancel{\{\ddot{p}_e\}} + [C_F]\cancel{\{\dot{p}_e\}} + [K_F]\{p_e\} + \bar{\rho}_0[R]^T\{\ddot{u}_{e,F}\} = \cancel{\{f_F\}}$$

Incompressible fluid

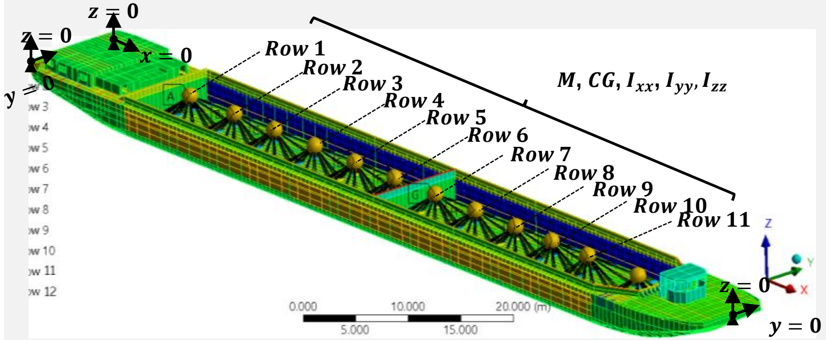
$$\begin{bmatrix} [M_S] & 0 \\ \bar{\rho}_0[R]^T & [M_F] \end{bmatrix} \begin{Bmatrix} \{\ddot{u}_e\} \\ 0 \end{Bmatrix} + \begin{bmatrix} [C_S] & 0 \\ 0 & [C_F] \end{bmatrix} \begin{Bmatrix} \{\dot{u}_e\} \\ 0 \end{Bmatrix} + \begin{bmatrix} [K_S] & -[R] \\ 0 & [K_F] \end{bmatrix} \begin{Bmatrix} \{u_e\} \\ \{p_e\} \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix}$$

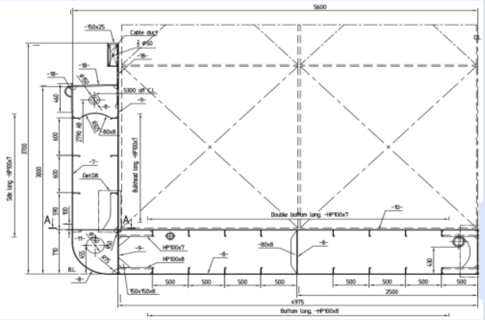
$[M_S]$, $[C_S]$, $[K_S]$: structure mass, damping, and stiffness matrices respectively, $\{f_S\}$: external force vector in the structure, $[R]$: coupled matrix represents the coupling conditions on FS interface, $[M_F]$, $[C_F]$, $[K_F]$: : acoustic fluid mass, damping and stiffness matrix, $\{f_F\}$: acoustic fluid load vector, P_e nodal pressure vector, $\{u(t)\}$ nodal displacement vector

Case study I (Intact Container barge)

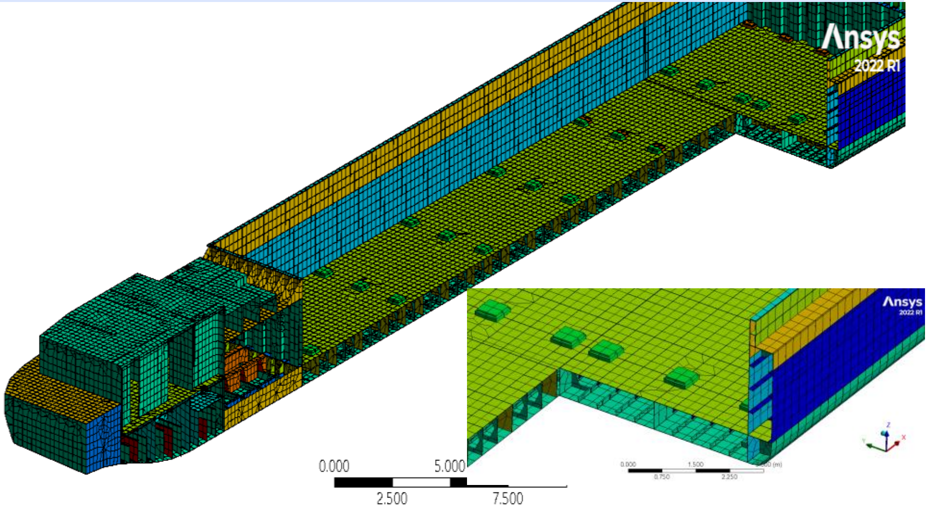
Finite Element Model

- Restricted service **slender** container barge
- **FEM** elements:
    - ○ **Mass points** (weights)
    - ○ **Rigid body** elements.
    - ○ **SHELL(181)** elements.
    - ○ **Contact** elements.





Length overall (L_{OA})	100.2m
Breadth molded (B)	11.2m
Depth (D)	3m
Design draught (T_f)	2.2m
Containers	92 TEU

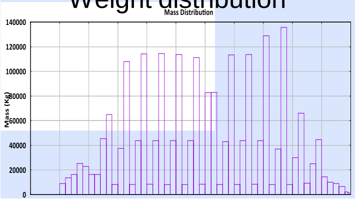


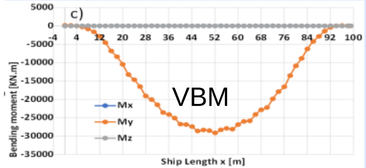
Case study I : Dry analysis

Loading conditions

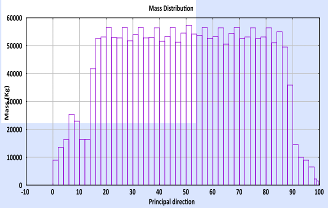
- **Fully** loaded condition (**containers**)
- **Fully** loaded by **grains**
- **Ballast** condition
- **Lightship** weight

Fully loaded "containers"
Weight distribution

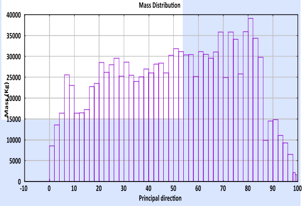


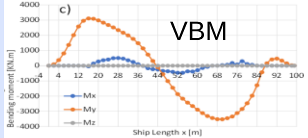


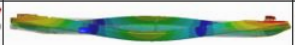
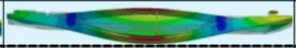
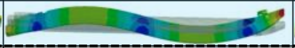
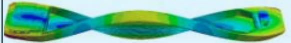
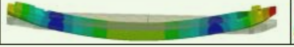
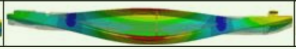
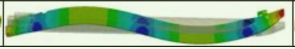
Fully loaded "grains"
Weight distribution



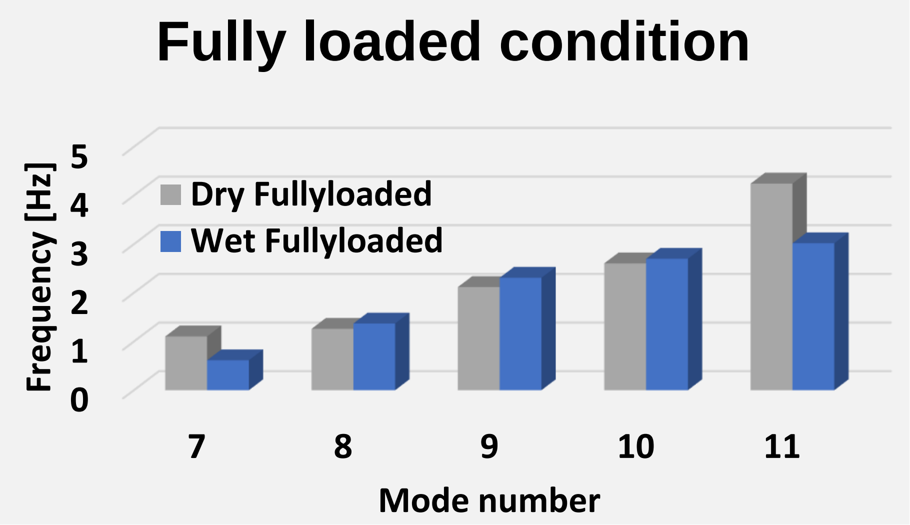
Ballast condition
Weight distribution

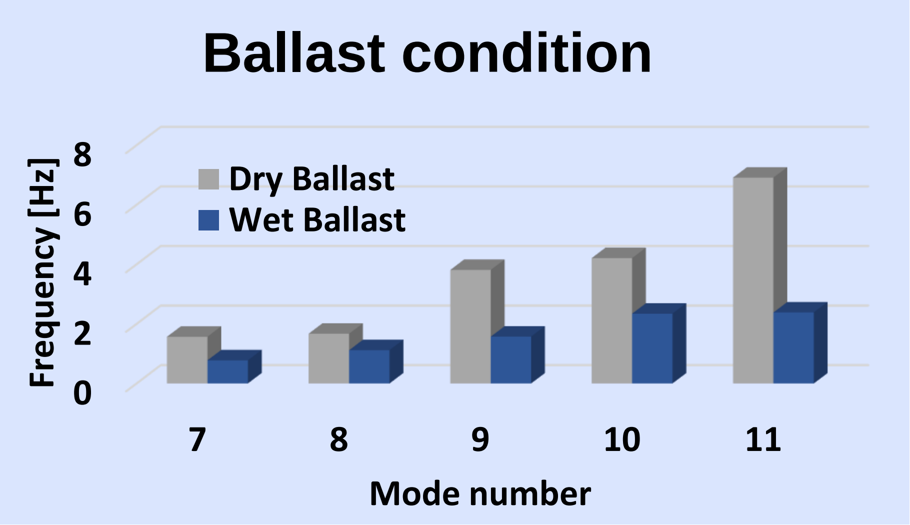




		Mode 7	Mode 8	Mode 9	Mode 10	Mode 11
Fully loaded "containers"	ω_n	1.1042	1.2607	2.1193	2.6048	4.2451
	S					
Fully loaded "grains"	ω_n	1.1091	1.384	2.6758	2.6776	4.4527
	S					
Ballast condition	ω_n	1.5727	1.6855	3.8358	4.3835	7.0072
	S					
Light ship	ω_n	1.7747	2.07	4.1949	4.9294	7.4433
	S					

Case study I: wet analysis





- **First mode resonance** is **smaller** in **Fully loaded** condition.
  - ➢ The most critical mode
- **Ballast condition** has **smaller resonance** of **higher modes**

Mode number	FL wet Hz	B. Wet Hz	FL wet/ B. wet
7	0.61	0.78	79%
8	1.37	1.12	123%
9	2.31	1.57	147%
10	2.70	2.34	115%
11	3.02	2.38	127%

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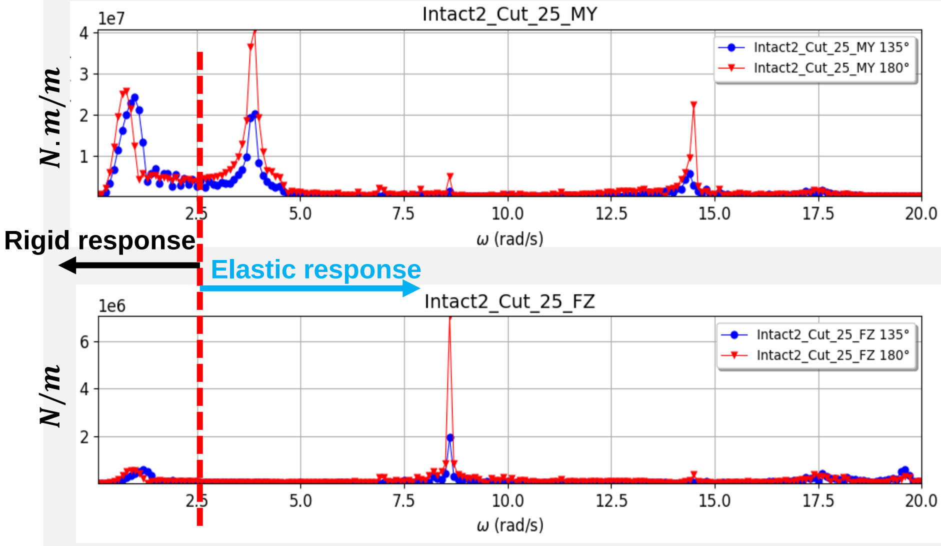
Case study I: Modal internal loads

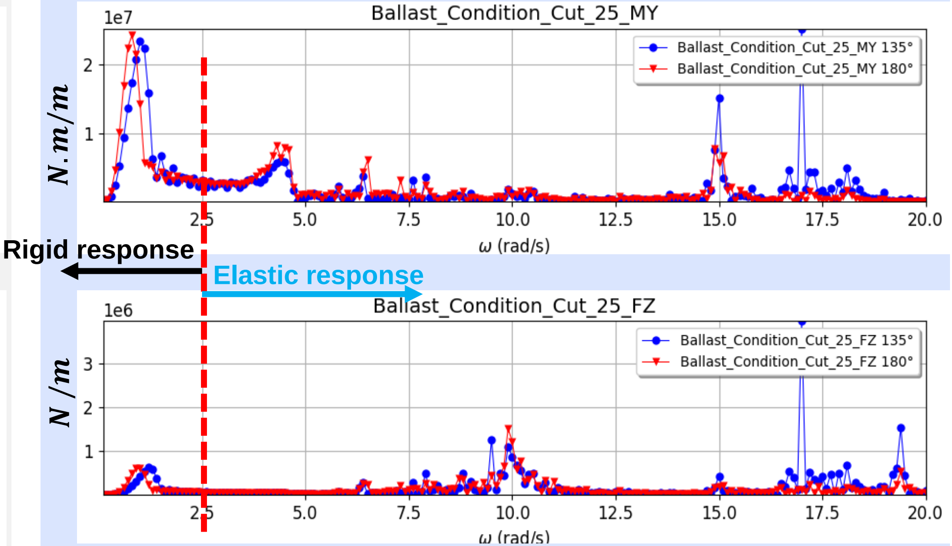
Fully loaded condition

- **Higher** elastic moment and shear force
- **Smaller** resonance frequencies

Ballast condition

- **Smaller** elastic moment and shear force
- **Shifted peaks** towards high frequencies





Total modal internal loads at amidship

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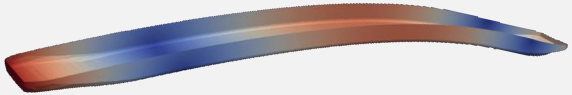
Case study I: Elastic moments and stresses

Fully loaded condition

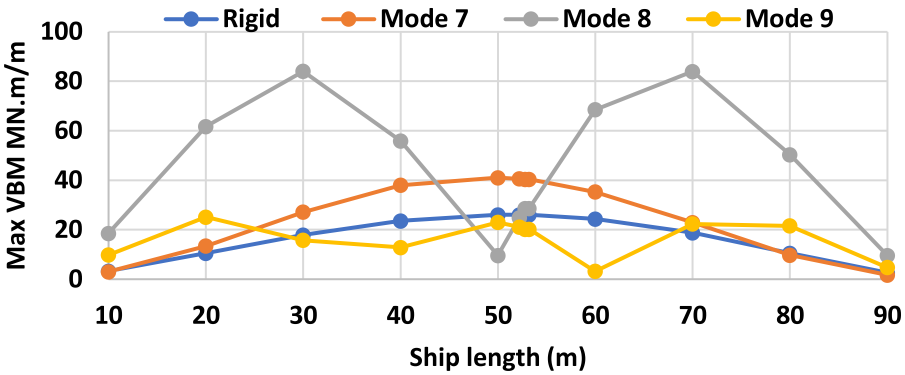
- **Rigid response:**
  - Max moment amidship when $L_w / L_{pp} = 1$

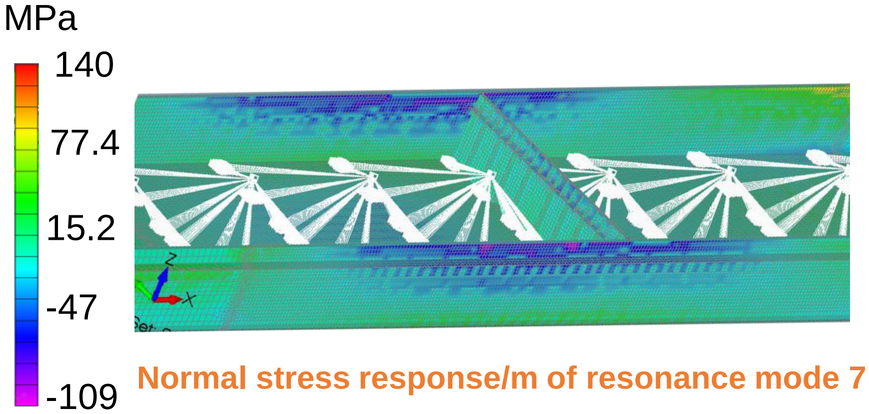
- **Elastic response:**
  - **Mode 7: $L_w = 3\ m$**



  - **Mode 8: $L_w = 0.8\ m$**

  - **Mode 9: $L_w = 0.2\ m$**





Normal stress response/m of resonance mode 7

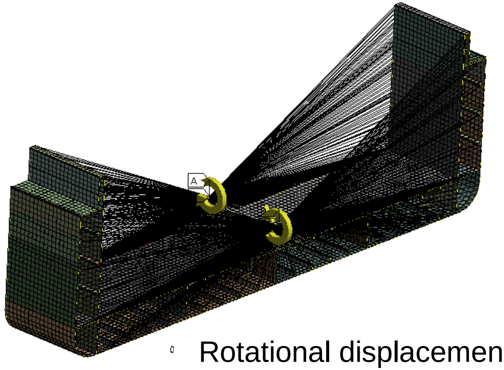
Case study II: grounded condition

Grounded condition:

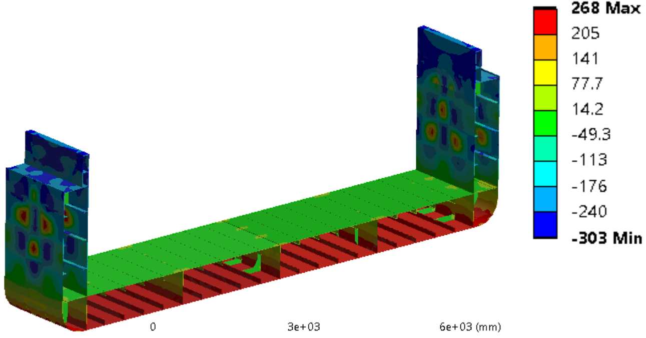
- Plastic deformation amidship.
- Moment less than ultimate BM.

Nonlinear analysis:

- Used to **obtain** the **UBM** and **Elastic limit.**
- **Geometrical** nonlinearity
- **Material** nonlinearity

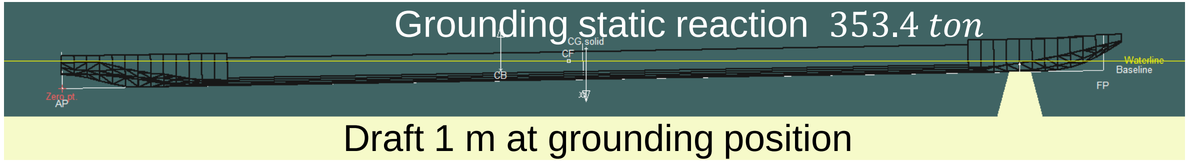


Rotational displacement

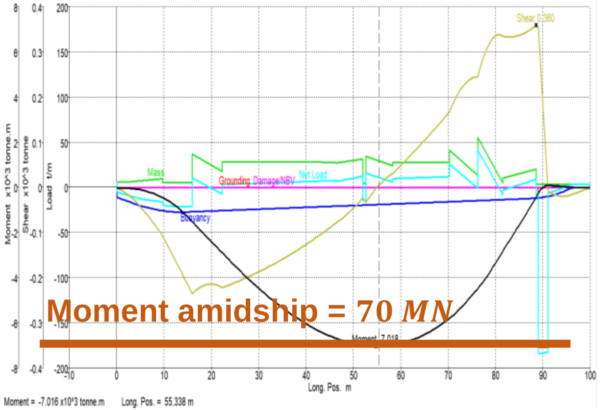


Normal stress in x direction

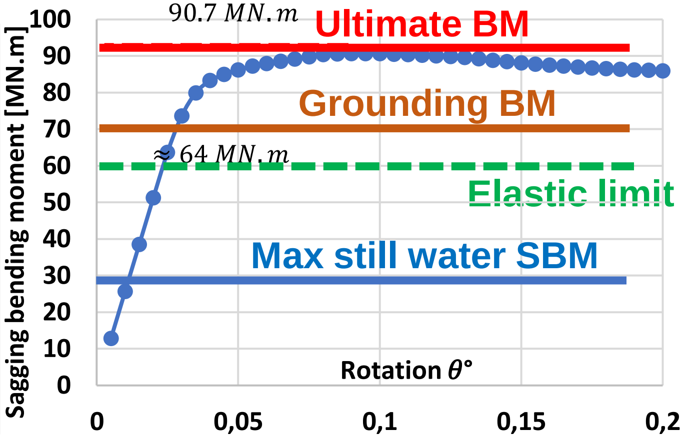
Grounding static reaction $353.4\ ton$



Draft 1 m at grounding position



Moment amidship = $70\ MN$



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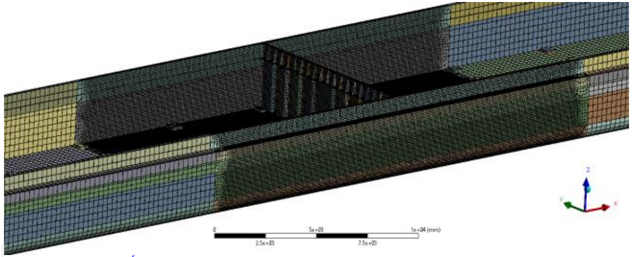
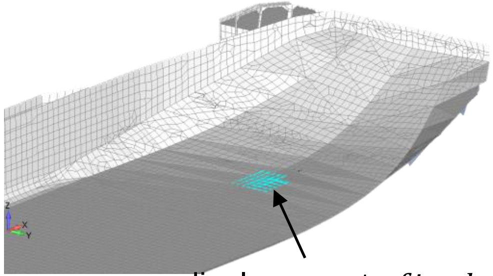
Case study II: Dry analysis

- **Prestressed** analysis displays **same modal shapes** of an **intact** ship.
  - Linear modal analysis

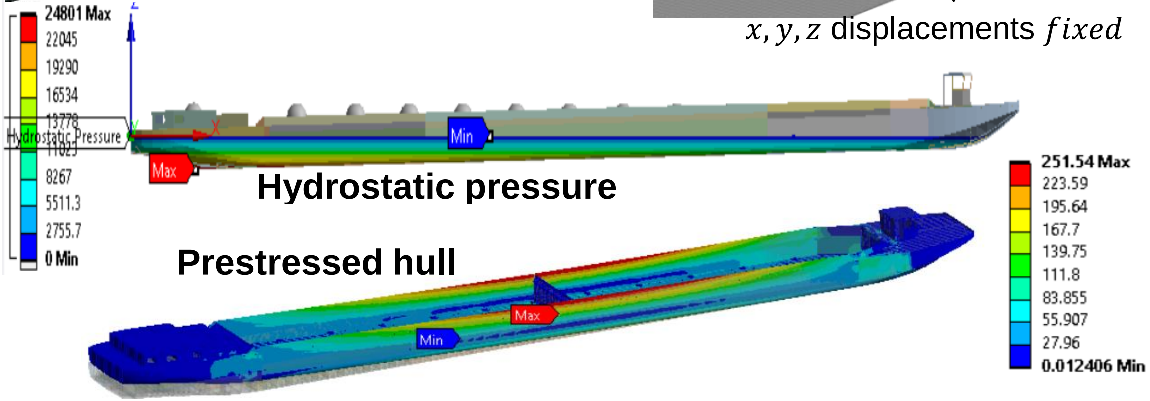
- **Small** changes in **modal values.**

- **Boundary condition influences** the **dynamic** response





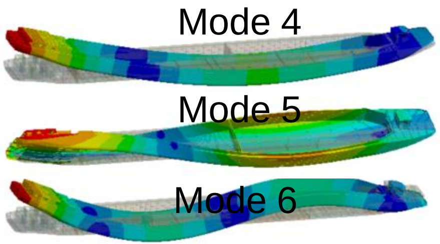
x, y, z displacements $fixed$



Hydrostatic pressure

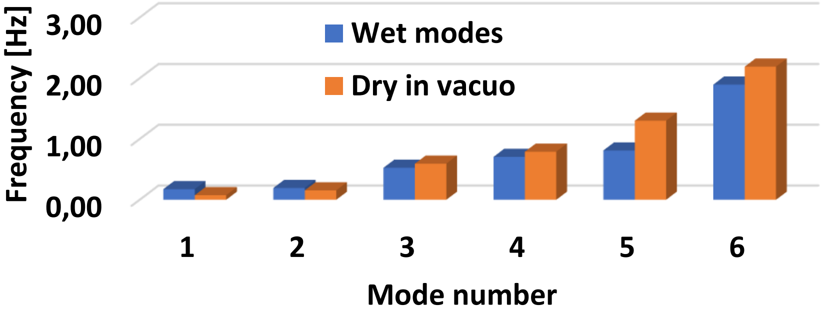
Prestressed hull

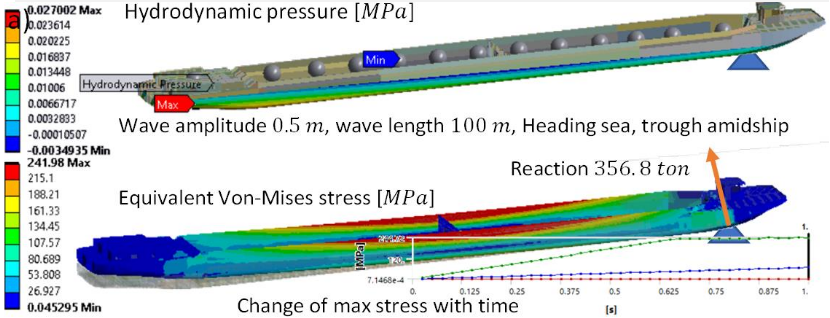
Mode	Prestressed	Vacuo	Ratio
4	0.79	0.79	100%
5	1.44	1.30	111%
6	2.22	2.19	101%

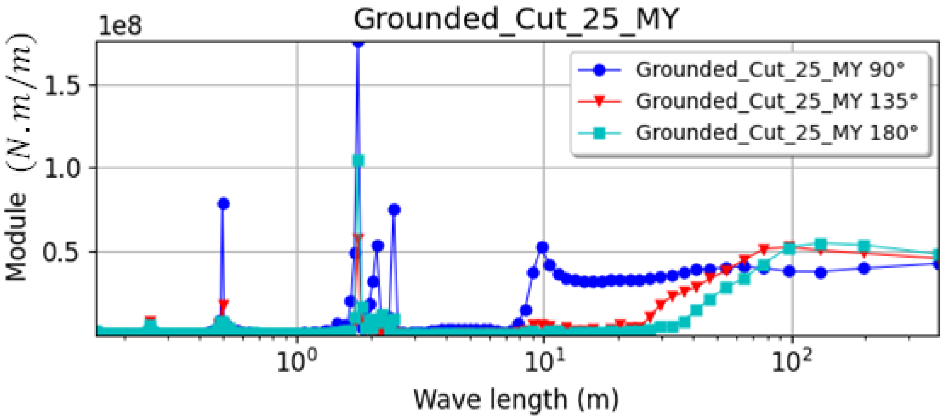


Case study II: Wet analysis

- **Wet** analysis **without Prestresses**
- Grounding **VBM RAOs** are a function of **grounding reactions.**
- The **variation** of grounding **reaction** for small wave amplitudes **is 3%** of the static reaction.







Static reaction 354 ton

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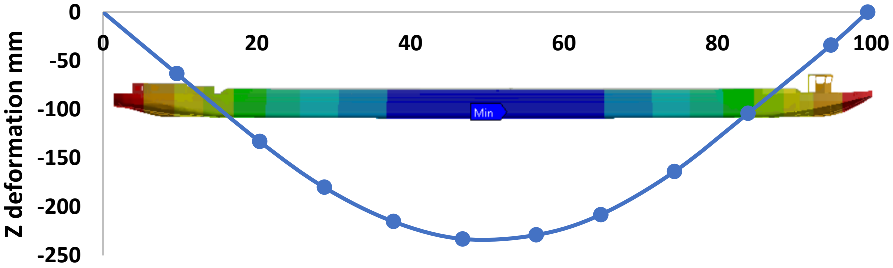
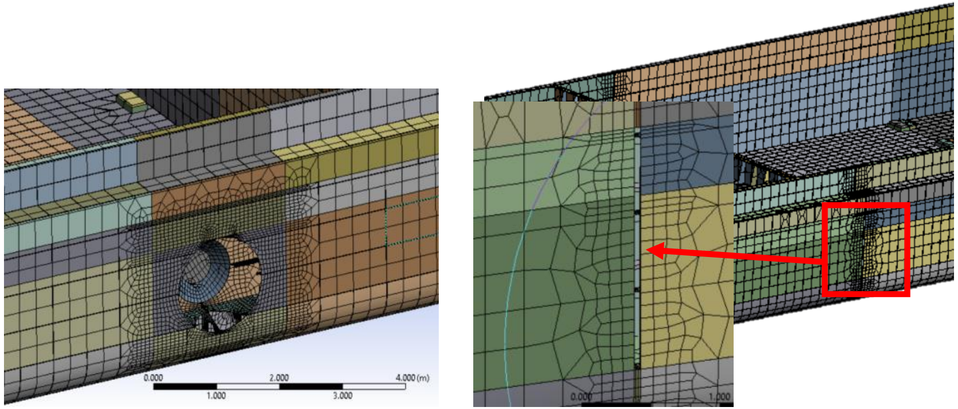
Case study III (Damaged elastic analysis, BEM)

- **Three** damages scenarios
  - Sagging **Deformation**
  - **Crack** at side shell penetrates the side longitudinal
  - **Collision**

- **No changes** in the **dry** and **wet** eigen modes

#	Intact/Deformed	Intact/Cracked	Intact/Collided
7	100%	102%	100%
8	101%	100%	100%
9	101%	100%	100%
10	100%	100%	101%
11	102%	100%	102%





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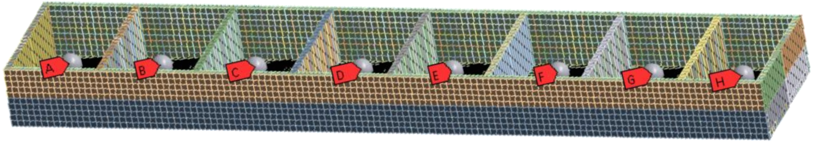
Case study IV (Damaged elastic analysis, AEM)

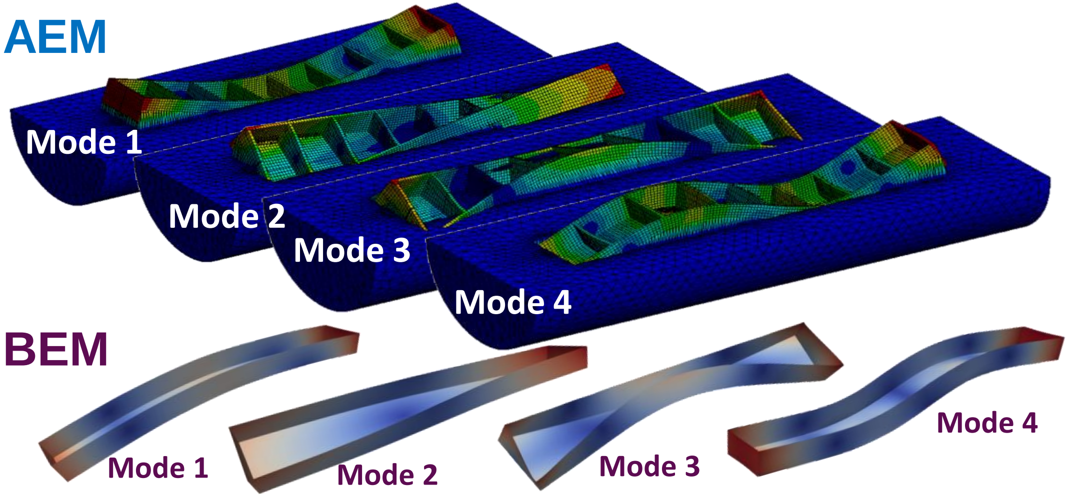
- **Validation against BEM.**
  - Same mode shapes
  - Conservative resonance frequency of elastic mode 1

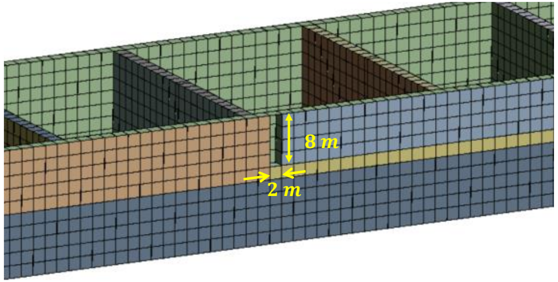
Wet Acoustic Hz	$\mathbf{0.19}$	$\mathbf{0.27}$	$\mathbf{0.37}$	$\mathbf{0.53}$
Wet BEM Hz	0.25	0.27	0.37	0.55
Ratio AEM/BEM	76%	100%	100	96%

- **Damaged AEM (Crack)**
  - **Same** observation to **BEM**
  - **Damage** does **not affect** the **global dry** and **wet** eigen modes of the ship structure.



Length = 250 m
Breadth = 45 m
Depth = 20 m
Draft = 10 m





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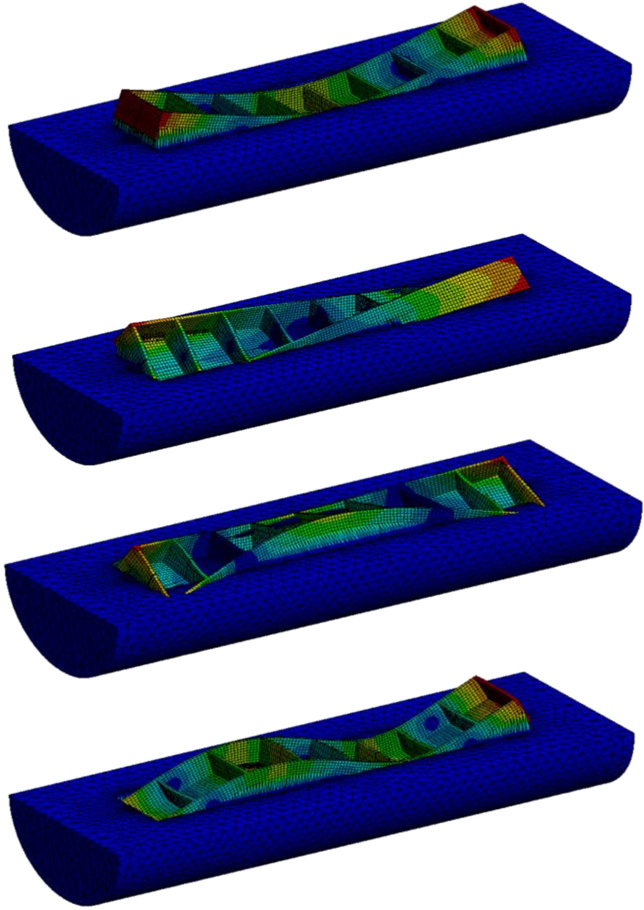
Conclusions

- **Loading conditions** cause high **variation** of dry eigenfrequencies and wet resonances.
- **Fully loaded** condition has the **smallest resonance** frequency and the **highest internal modal** elastic loads.
- **Grounding** boundary conditions remarkably **change** the **dynamic** response.
- Effect of **prestress** on the dry analysis seem to be **negligible** (Assuming **linear modal** analysis)
- The **AEM** gives similar results to the **BEM**.
- **BEM** and **AEM** show **no** impact of **damages** on the **global** eigen modes.



Thanks for your attention!
Questions?

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