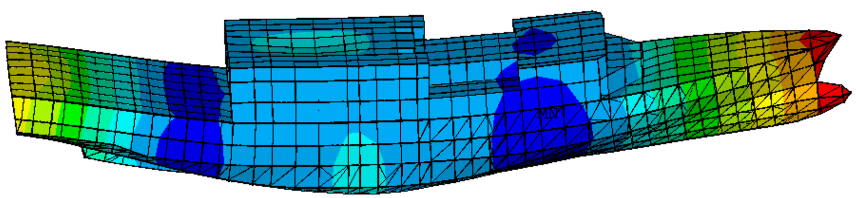
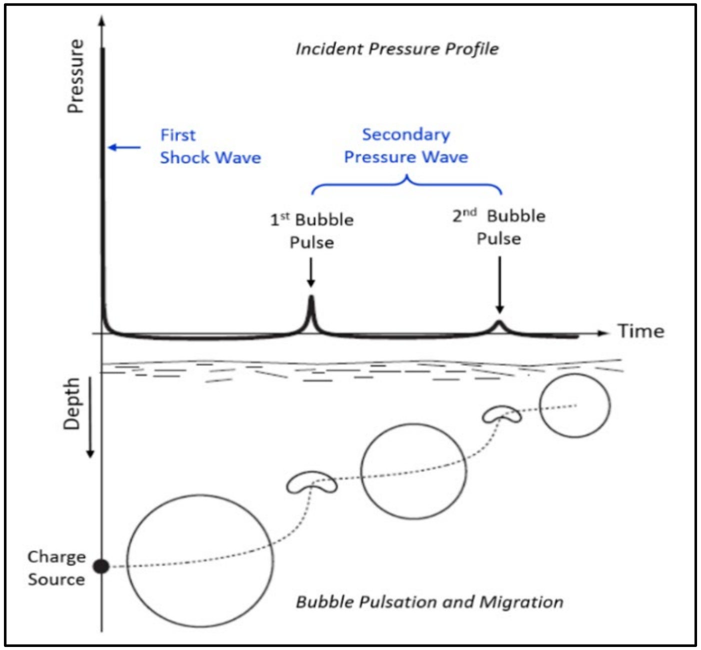
Analysis of Added Mass Effect on Surface Ships Subjected to Underwater Explosions



By
Ruturaj Trivedi
Under Guidance of
Professor Herve Le Sourne
Mr. Simon Paroissien
Mr. Clement Lucas
Reviewer- Professor Lionel Gentaz

Content

Motivation



- **First shock wave**
  - Exponential decay
  - Short time
  - High energy and Pressure
  - Plastic deformation-local

- **Bubble oscilations**
  - Non-linear
  - Long time duration
  - Low frequency
  - Global bending

Objectives

-Study existing added mass calculation methods

-Develop tool →ANSYS-APDL (Ansys Parametric Design language) →Added mass effect → Verification

-Modal and Underwater Explosion Analysis

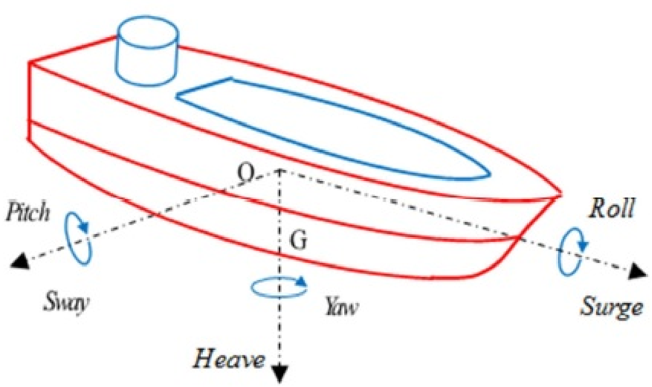
Added Mass

- Weight added to system because of acceleration or deceleration of body in fluid medium

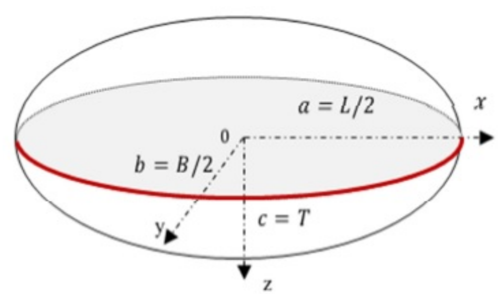
$$F = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} & m_{15} & m_{16} \\ m_{21} & m_{22} & m_{23} & m_{24} & m_{25} & m_{26} \\ m_{31} & m_{32} & m_{33} & m_{34} & m_{35} & m_{36} \\ m_{41} & m_{42} & m_{43} & m_{44} & m_{45} & m_{46} \\ m_{51} & m_{52} & m_{53} & m_{54} & m_{55} & m_{56} \\ m_{61} & m_{62} & m_{63} & m_{64} & m_{65} & m_{66} \end{pmatrix} \begin{pmatrix} \dot{u}_1 \\ \dot{u}_2 \\ \dot{u}_3 \\ \dot{u}_4 \\ \dot{u}_5 \\ \dot{u}_6 \end{pmatrix}$$

Degrees of freedom	Description	Velocities
1	Surge- motion in x direction	- Linear
2	Sway-motion in y direction	- Linear
3	Heave- motion in z direction	- Linear
4	Roll- rotation about x axis	- Angular
5	Pitch- rotation about y axis	- Angular
6	Yaw- rotation about z axis	- Angular

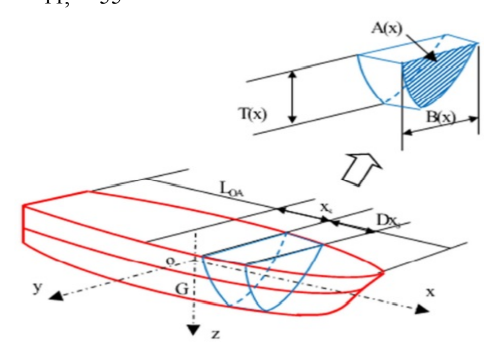
$$M_A = \begin{pmatrix} m_{11} & 0 & m_{13} & 0 & m_{15} & 0 \\ 0 & m_{22} & 0 & m_{24} & 0 & m_{26} \\ m_{31} & 0 & m_{33} & 0 & m_{35} & 0 \\ 0 & m_{42} & 0 & m_{44} & 0 & m_{46} \\ m_{51} & 0 & m_{53} & 0 & m_{55} & 0 \\ 0 & m_{62} & 0 & m_{64} & 0 & m_{66} \end{pmatrix}$$

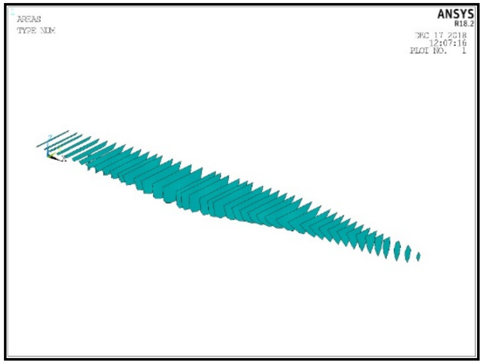


- **Ellipsoid Method [1]**
- Ship is assumed to be an ellipsoid
- Accuracy depends on shape of the ship
- This method cannot determine some components of the added mass matrix like : m_{24} , $m_{26}, m_{35}, m_{44}, m_{15}$, m_{51}

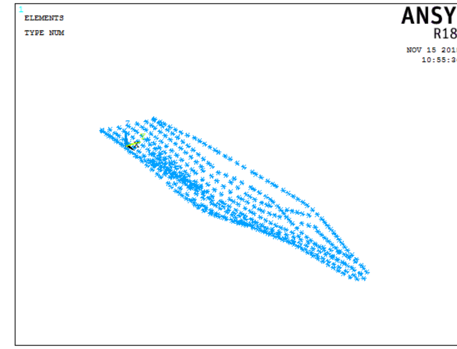


- **Strip Theory Method [1]**
- Ship can be made up of a finite number of transversal 2D slices
- Each slice has a form resembling the segment of the representative ship
- The added mass of the whole ship is obtained by integration of the 2D value over the length of the hull $m_{11,} m_{55}$





Development of ANSYS tool and Verification with Previous Literature [2]



- The ship used for comparison is from the article [2]

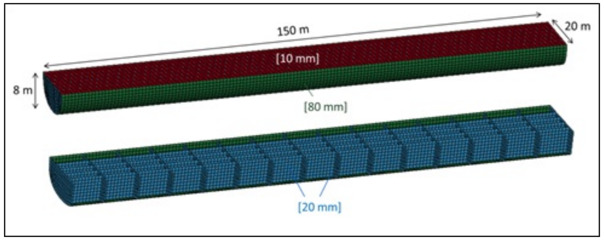
		Added Mass Coefficients		mij	
Sr No	Added Mass Coefficients	Obtained	In Research paper	Method Used	Error (%)
1	m11	0.035	0.035	Ellipsoid	0
2	m22	1.113	1.113	Strip theory	0
3	m33	1.440	1.44	Strip theory	0
4	m24	0.814	0.814	Strip theory	0
5	m44	0.013	0.014	Strip theory	0.09
6	m55	0.034	0.034	Ellipsoid	0
7	m26	0.028	0.028	Strip theory	0
8	m35	0.002	0.002	Strip theory	0
9	m46	0.092	0.092	Strip theory	0
10	m66	0.065	0.065	Strip theory	0
11	m15	-0.026	-0.026	Strip theory	0

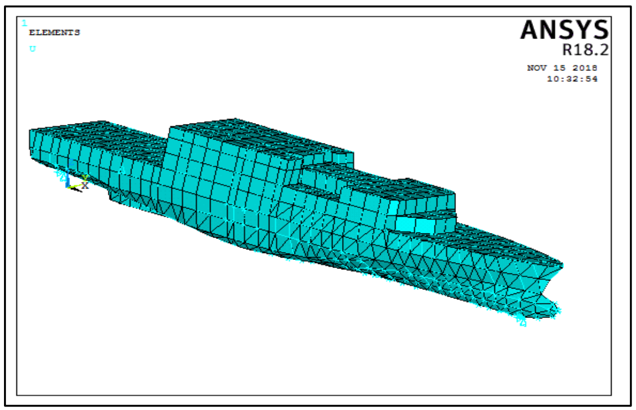
	Added Mass	
Sr No	Added Mass Component	Added Mass (Tonne)
1	m11	261.92
2	m22	8213.47
3	m33	10629.62
4	m24	6010.57
5	m44	93.78
6	m55	251.19
7	m26	205.18
8	m35	12.91
9	m46	675.93
10	m66	479.13
11	m15	191.67
	Displacement of Ship	9178

- The values of m22 and m33 are very near to the displacement of the ship. The value of m24 is 65.48% of the displacement. Other components are much smaller than the displacement

Model Preparation

1. Dry Model

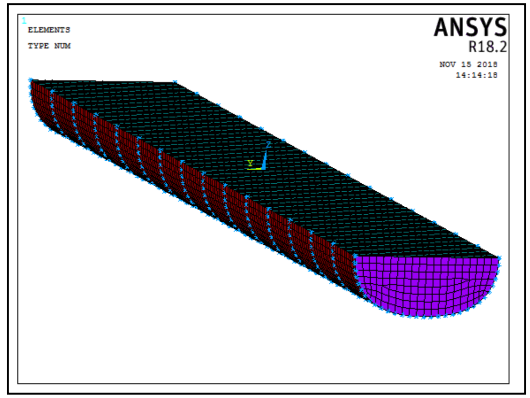


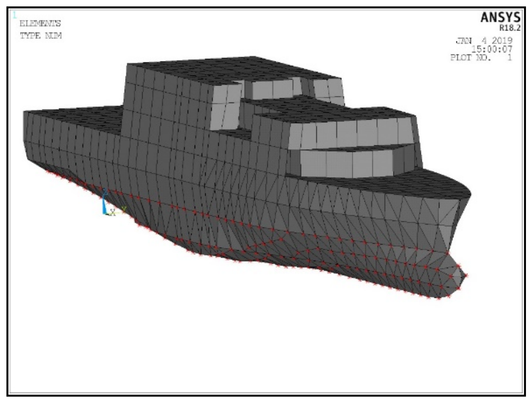


Semi- Cylinder Like-ship
Parameters-
L=150m
B=20m
T=8m
Displacement=4276.56MT
Obtained from Tsai 2017 [3]

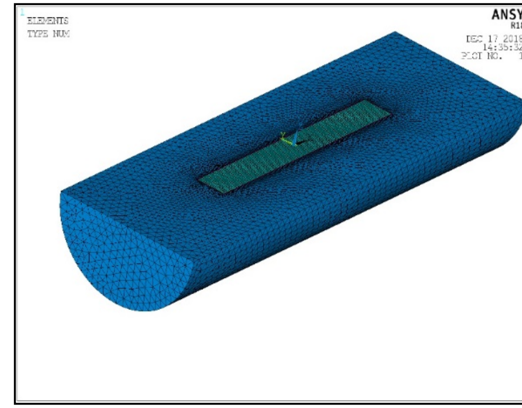
Surface Ship
Parameters-
L=100.9m
B=15.53m
T=4.75m
Displacement=3512.478 MT

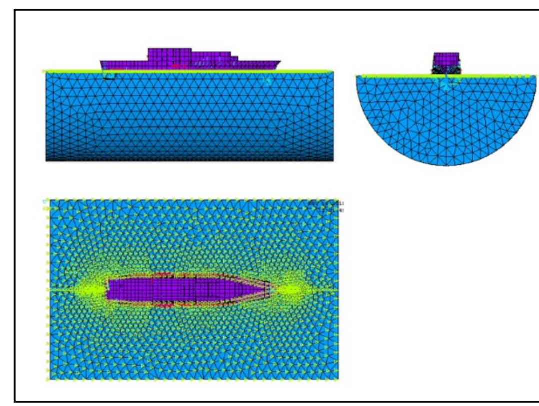
2. Nodal Mass Model





3. Fluid Mesh Model





Calculated Added Masses for Models

Semi-Cylinder like-ship

Added Mass Component	Added Mass (Tons)
m11	135.00
m22	15589.27
m33	24094.78
m24	7497.31
m44	28.22
m55	537.45
m26	0.00
m35	0.00
m46	0.00
m66	941.23
m15	125.97
Displacement	4181.69

Surface Ship

Added Mass Component	Added Mass (Tons)
m11	140.89
m22	2723.57
m33	5537.33
m24	257.59
m44	159.08
m55	74.49
m26	3499.8
m35	28.83
m46	1891.26
m66	284.76
m15	181.05
Displacement	3512.48

- Added mass is function of geometry of body and density of fluid

Modal Analysis

Semi-cylinder like-ship

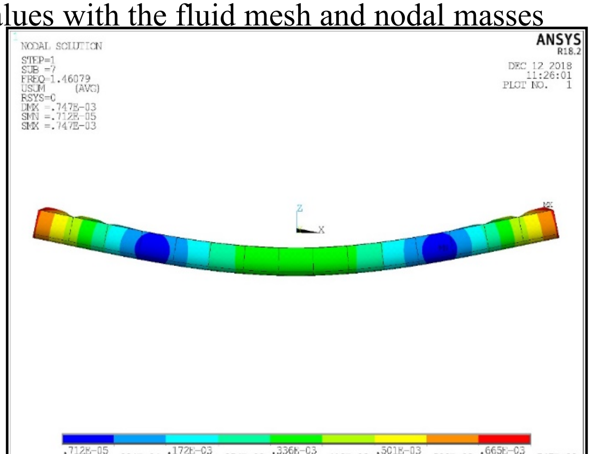
		Frequency			Difference	
Sr No	Mode shape	Dry Model (Hz)	Nodal Mass model (Hz)	Fluid Mesh model (Hz)	Dry and Nodal mass models (%)	Dry and Fluid mesh models (%)
1	1st Vertical Bending	1.46	0.74	0.84	49	42

In this case, substituting the appropriate values in equation 1 the wet natural frequency is 1.03 Hz, which is 27% more than the obtained values with the fluid mesh model and nodal masses model

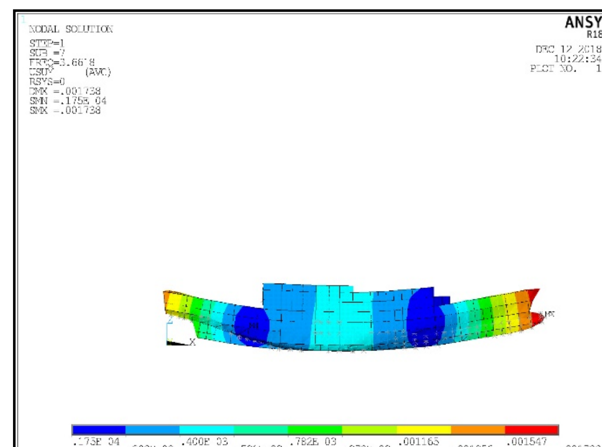
Surface Ship

		Frequency			Difference	
Sr No	Mode shape	Dry Model (Hz)	Nodal mass model (Hz)	Fluid Mesh model (Hz)	Dry and nodal mass models (%)	Dry and Fluid mesh models (%)
1	1st Vertical Bending	3.66	2.46	2.7	33	26

In this case, substituting the appropriate values in equation 1, the wet natural frequency is 2.59 Hz which is 4.98% more than the obtained values with the fluid mesh and nodal masses



$$\omega_{wet} = \frac{\omega_{dry}}{\sqrt{2}} \qquad (1)$$



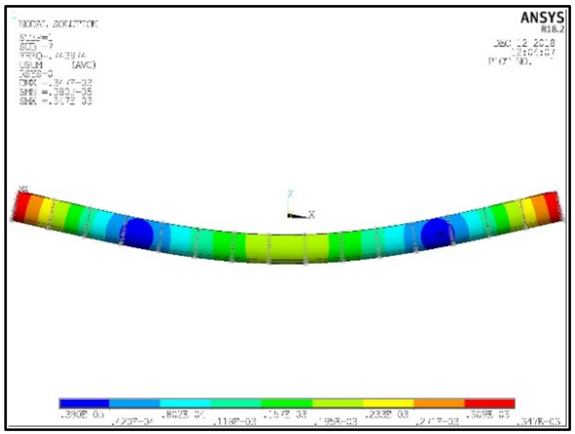
Modal Analysis

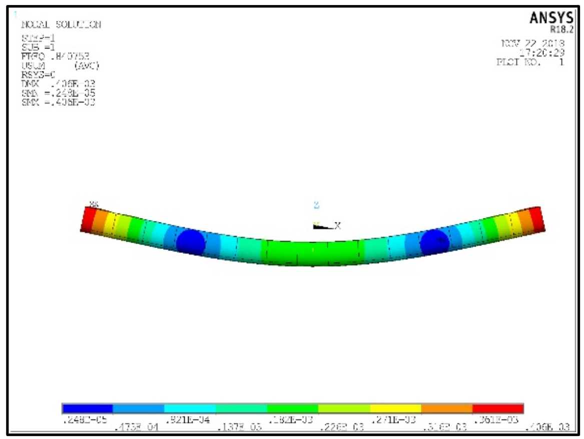
Semi-cylinder like-ship

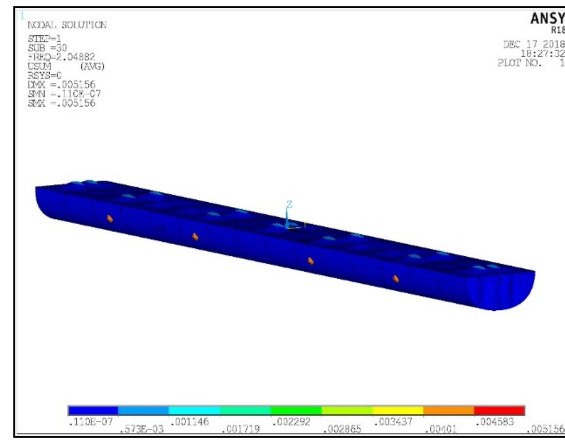
		Frequency (Hz)		
Sr No	Mode shape	Nodal mass model	Fluid mesh model	Error (%)
1	1st Vertical Bending	0.74	0.84	12
2	2nd Vertical Bending	1.97	2.31	14
3	1st Torsional	1.50	2.53	41

Wet model- Nodal added mass **Wet model- fluid mesh**

1st Vertical Bending (2 nodes)

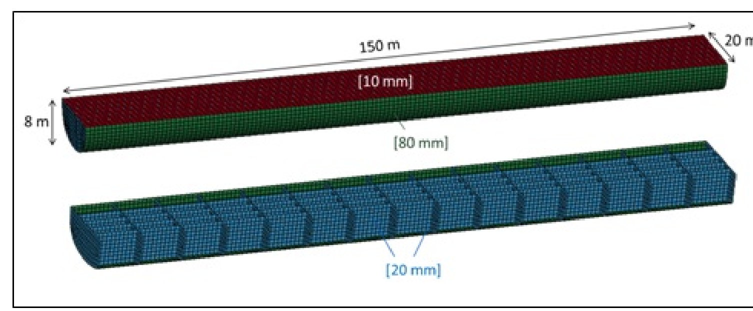






(7th mode, f=0.74 Hz) (1st mode, f=0.84 Hz)

- Acc. to Chantiers de l'Atlantique, real ship global mode shapes →5-6 Hz
- Local Modes → absence of longitudinals and girders→ not correct representation

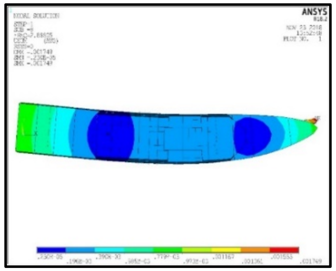


Surface Ship

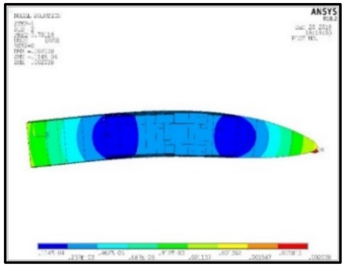
Modal Analysis

		Frequency (Hz)		
Sr No	Mode shape	Nodal masses model	Fluid mesh model	Error (%)
1	1st Vertical Bending	2.46	2.7	9
2	2nd Vertical Bending	3.98	4.29	7
3	1st Transverse Bending	2.89	3.7	22
4	2nd Transverse Bending	5.19	6.66	22
5	1st Torsional mode	4.9	6.99	28
6	2nd Torsional mode	6.92	9.19	35

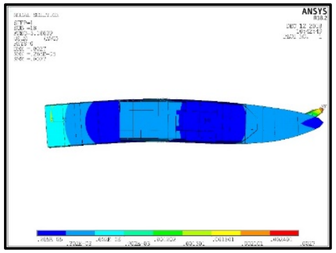
Transverse bending



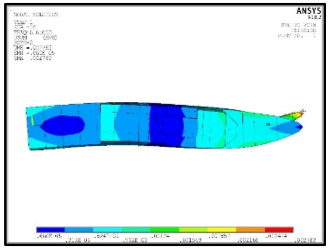
(8th mode, f=2.89 Hz)



(2nd mode, f=3.7 Hz)

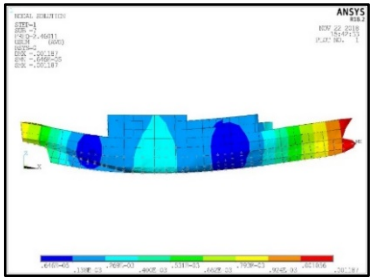


(18th mode, f=5.19 Hz)

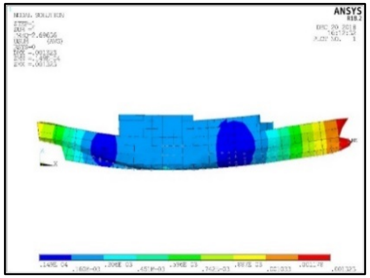


(16th mode, f=6.66 Hz)

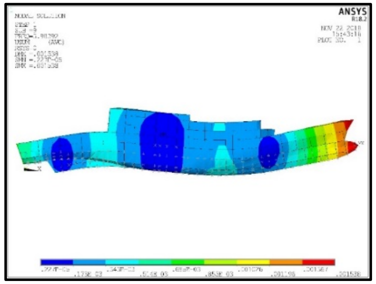
Vertical Bending



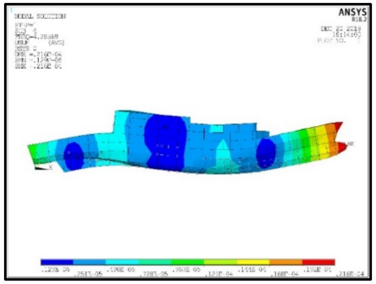
(7th mode, f=2.46 Hz)



(1st mode, f=2.7 Hz)

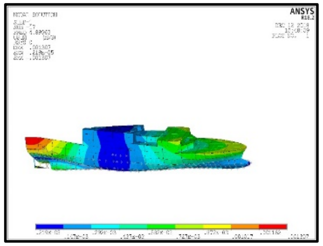


(9th mode, f=3.98 Hz)

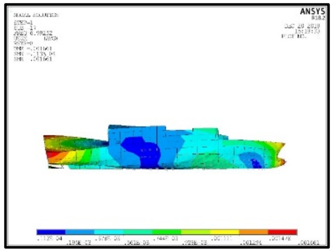


(4th mode, f=4.29 Hz)

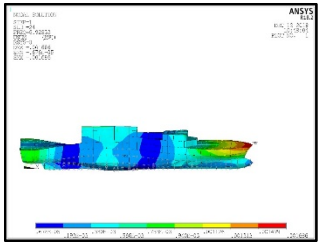
Torsion



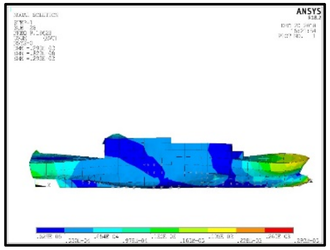
(17th mode, f=4.9 Hz)



(17th mode, f=6.99 Hz)



(24th mode, f=6.92 Hz)



(28th mode, f=9.19 Hz)

Modal Analysis & UNDEX

Validation by Chantiers de l'Atlantique

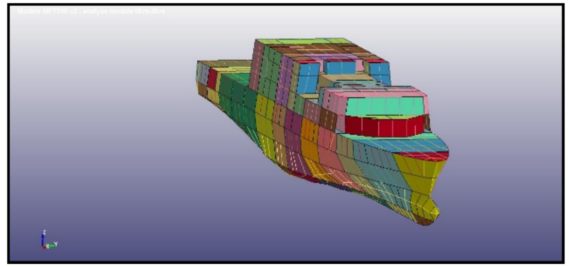
- Data from Cruise ship
- Modal frequencies undisclosed
- Error= Difference between measured and calculated natural frequencies

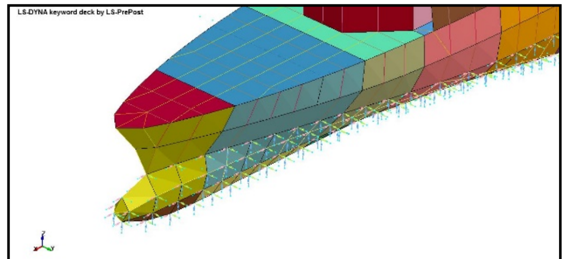
Mode type	Error Fluid element	Error Added mass
1st Vertical	3%	-2%
1st Transversal	3%	-14%
1st Torsion	1%	-22%
2nd Vertical	3%	-4%
3rd Vertical	4%	-6%
2nd Torsion	2%	-21%

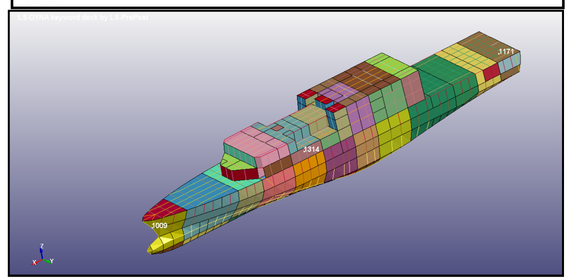
	Description
m_c	TNT charge mass, m_c= 500 kg
di	Distance from charge to free surface, di= 50 m
r	Distance from charge to standoff point, r = 45.25 m
S	Density of charge, = 1600 kg/m^3
SF	Shock factor = 0.49

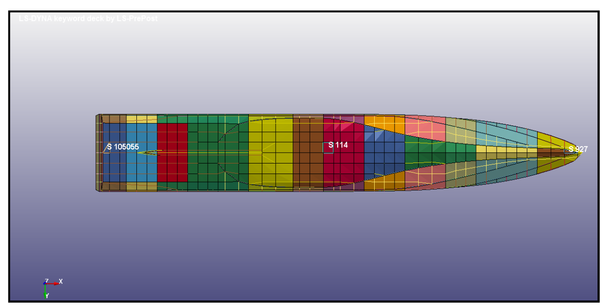
Explosions Parameters Tsai [3]

Dry Model

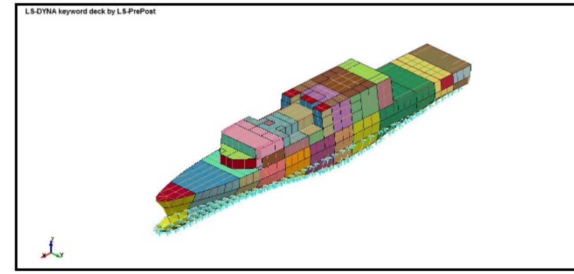


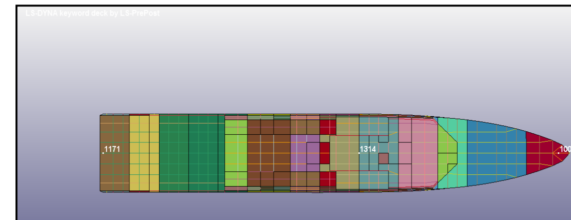


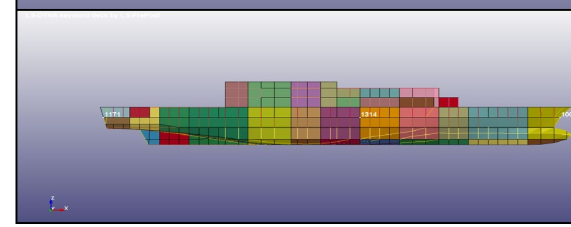


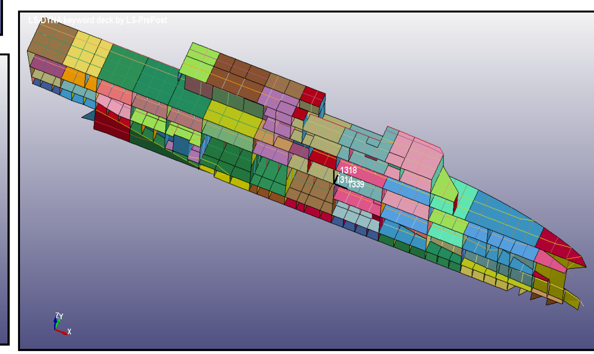


Wet Model



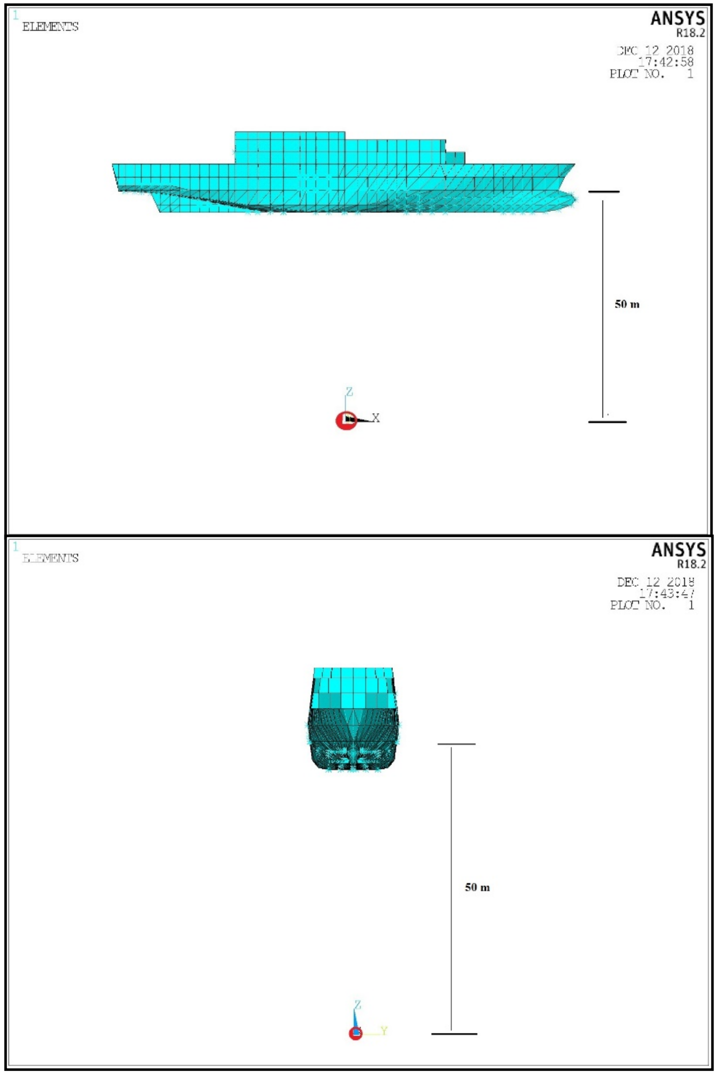


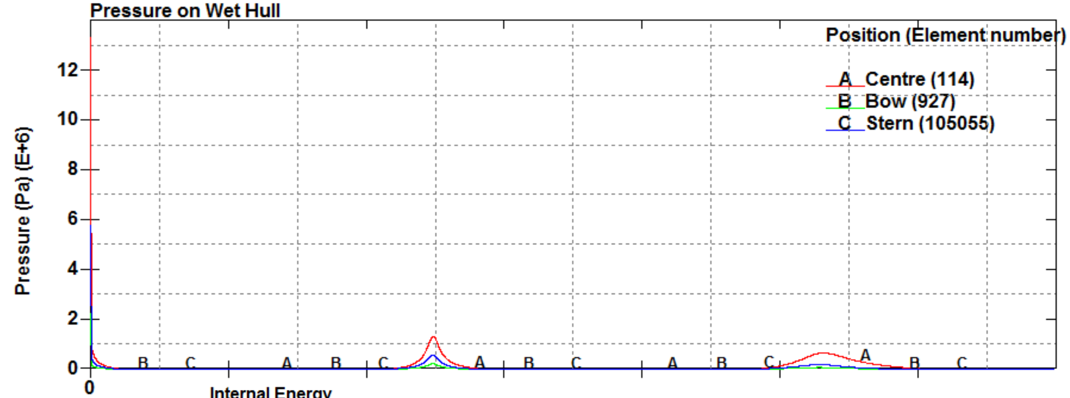




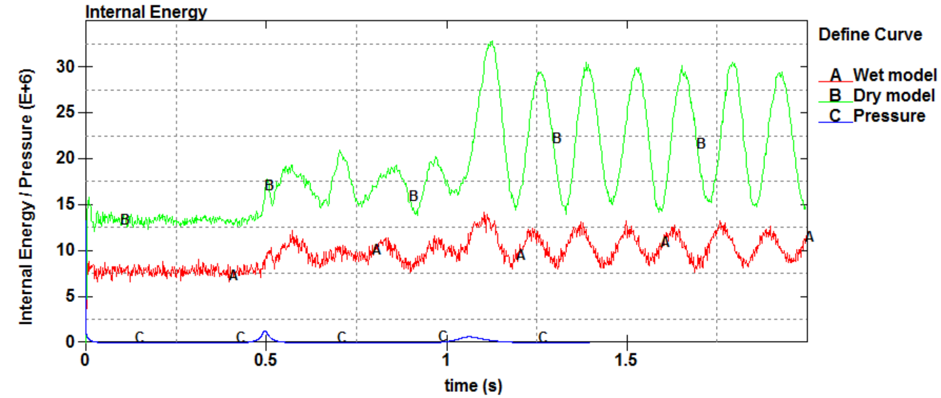
Underwater Explosions

Location of Charge and Selected Nodes



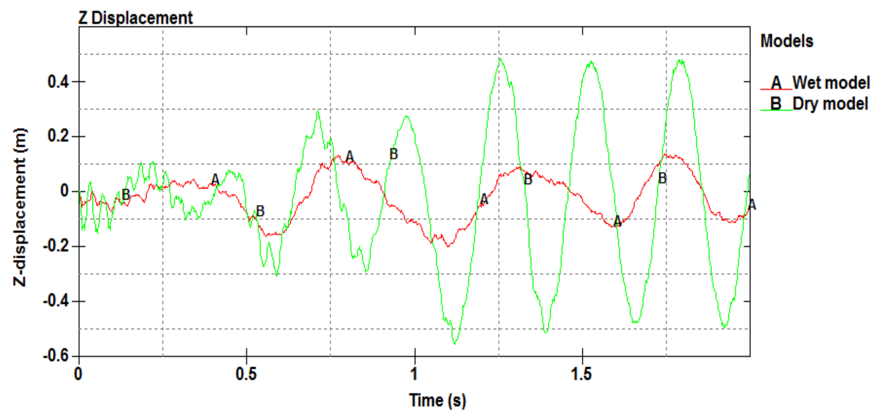


Energies



Nodal Vertical Displacements

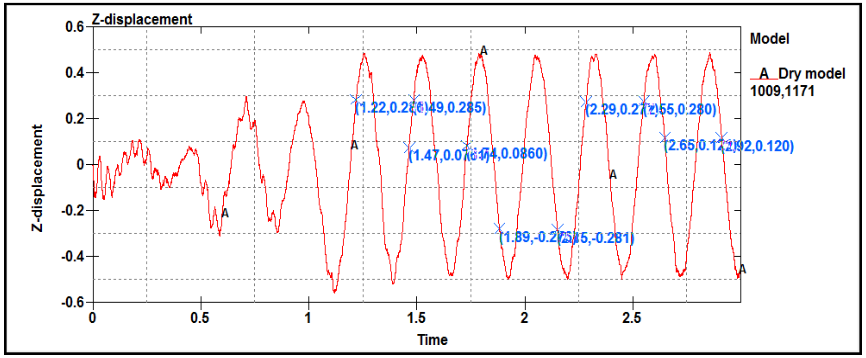
- Time period of oscillation
  - Wet> Dry
- Natural Frequency
  - Wet< Dry
- Added Inertia



Underwater Explosions-Results

Frequency Analysis from Displacement Plot

Dry Model



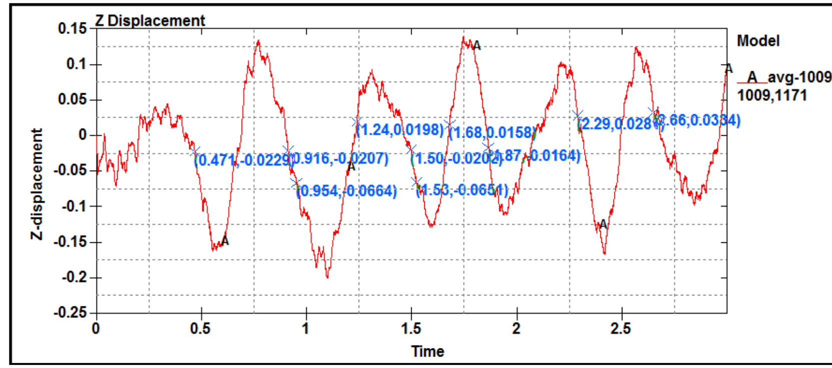
Sr No	Time period (s)	Frequency (Hz)
1	0.27	3.70
2	0.27	3.70
3	0.26	3.85
4	0.26	3.85
5	0.27	3.70
	Average	3.76

-From ANSYS-
First natural frequency = 3.66 Hz
- First natural frequency not excited

Worst case scenario: Ship vibrating at first natural frequency

[redacted]

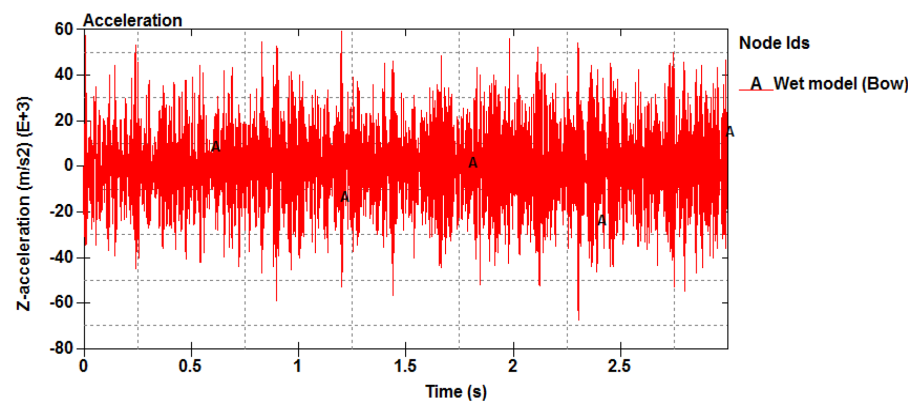
Wet Model



Sr No	Time period (s)	Frequency (Hz)
1	0.445	2.25
2	0.576	1.74
3	0.44	2.27
4	0.37	2.70
5	0.37	2.70
	Average	2.33

-From ANSYS-
First natural frequency = 2.46 Hz (nodal mass method) /2.69 Hz (fluid mesh)
- First natural frequency not excited

Accelerations



Conclusion & Future Work

Conclusion

- Accuracy - Strip theory > Ellipsoid method - Combination
- Developed APDL macro was validated
- Modal analysis
  - Nodal mass model verified
  - Natural Frequency- Reduced when added mass considered
  - UNDEX bubble phase → ship hull whipping phenomena
  - If, frequency of bubble oscillation = first natural frequency of ship → one or several natural bending modes excited → worst case scenario
- UNDEX analysis
  - Vertical displacement of nodes- Reduced
  - Energy level and its fluctuation – Reduced
  - Time period of oscillations – Increased
  - Natural frequency- Reduced

Future Work

- Stress and strain analysis for worst case scenario
- Shock response spectrum analysis of embarked equipment
- UNDEX simulations- with fully coupled fluid acoustic mesh model
- Modification of strip theory and ellipsoid methods →

Match results : nodal mass method = fluid mesh

Acknowledgement

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- Reviewer- Professor Lionel Gentaz
- All professors and staff of ICAM

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- Department of Acoustics & Vibrations

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