E-LASS
16 September 2020

Composites Structural Design

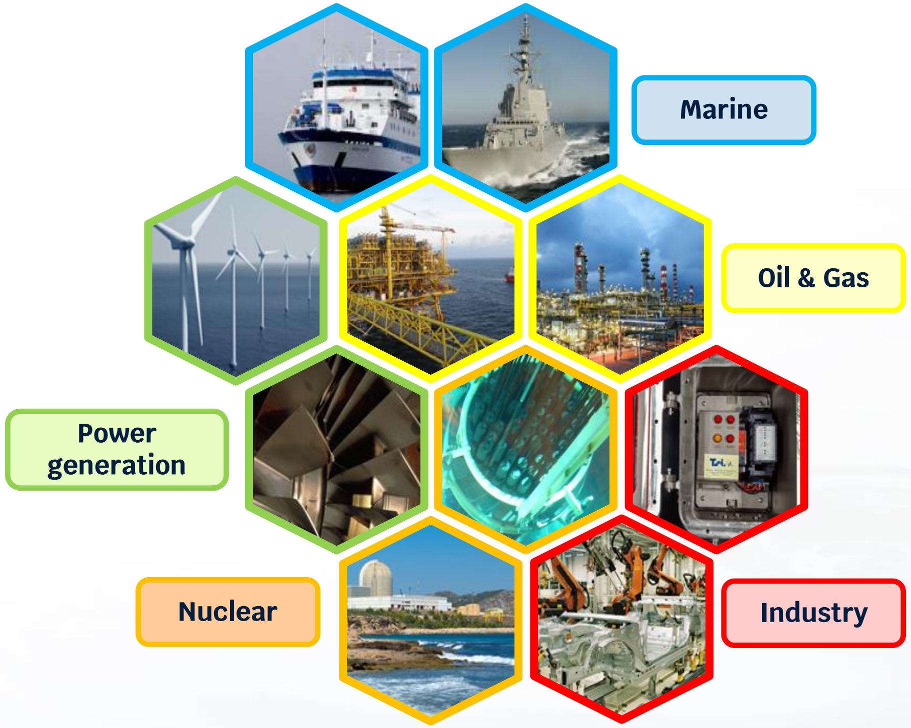
Vessels over 500 GT

Mariano Suchy

Index

TSI Presentation

*TSI – Técnicas y Servicios de Ingeniería S.L. is a Spanish SME founded in 1983 with the main objective of proposing **high-added value engineering solutions related to Noise & Vibrations** in different industrial sectors.*



ENGINEERING SERVICES
▪ Structures optimization ▪ Calculations and simulation (dynamic and static analysis) ▪ Root-Cause Analysis Consultancy (RCA) ▪ Measurements and tests ▪ Monitoring ▪ Industry 4.0 & Digitization ▪ Condition-Based Maintenance (CBM)

The clue:

FLEXIBILITY + OUT-OF-THE BOX THINKING

FIBRESHIP Project Description

FIBRESHIP Project

- FIBRESHIP addresses the **feasibility** of using **FRP** technology for **large-length vessels**, trying to overcome the identified technical challenges and promote a change in the regulatory framework that enables their design, building, and operation.

Market acceptance and impacts → FRP for marine applications → CAE tools for FRP design → Vessel design feasibility → Adaptation of production methodologies → Life-cycle management

Guidelines and recommendations based on the achieved findings and safety criteria

ENABLING FIBRE-BASED LARGE VESSELS

FIBRESHIP

Main particulars of FIBRESHIP:

- Grant Number: 723360
- Duration: 36 months (June2017-May2020)
- Project Budget / EU Contribution: €11M / €8,7M
- TRL: 7-9
- International collaboration among 18 partners of 11 European countries with a broad experience in different disciplines

H2020 Project Management

This project has recived funding from European Union's Horizon 2020 research and innovation programme under grant agreement Nº 723360

FIBRESHIP– FRV Structural Design

STANDARD SCANTLING FOR STRUCTURAL DESIGN

Classification Society Rules

Structural configuration definition

Materials and laminates definition

→ Midship and Web-frame Scantling

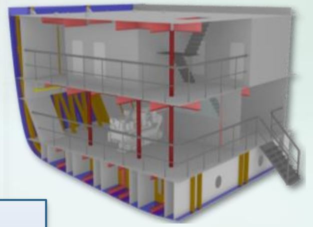
1st stage

3D MODELLING

From Midship to a full 3D ship structure

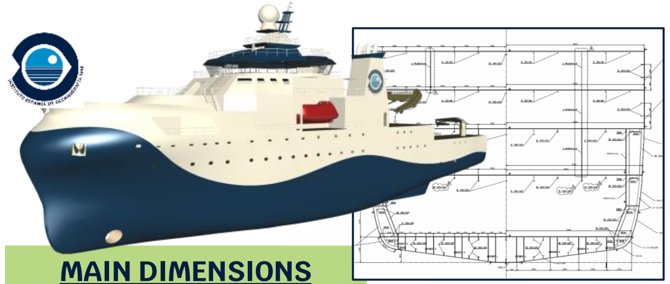
2nd stage

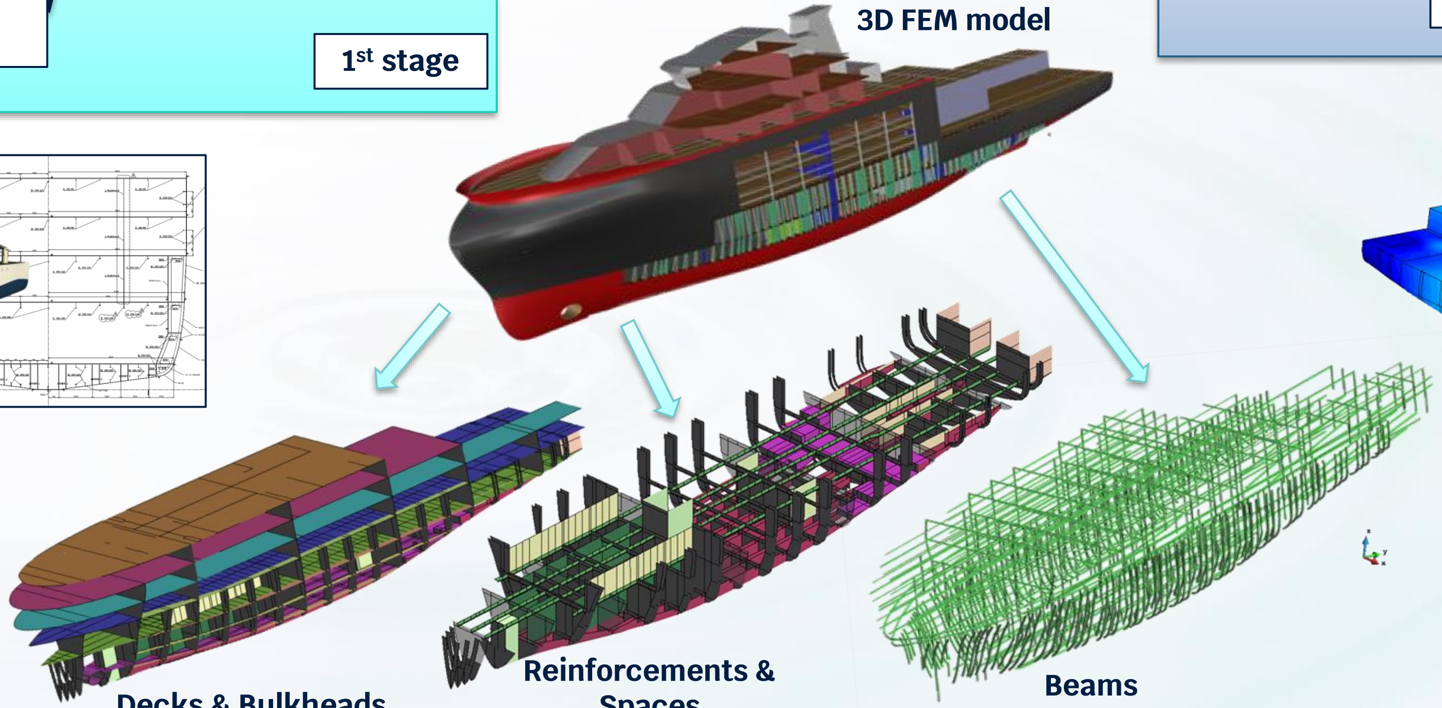
Demonstrator design for construction

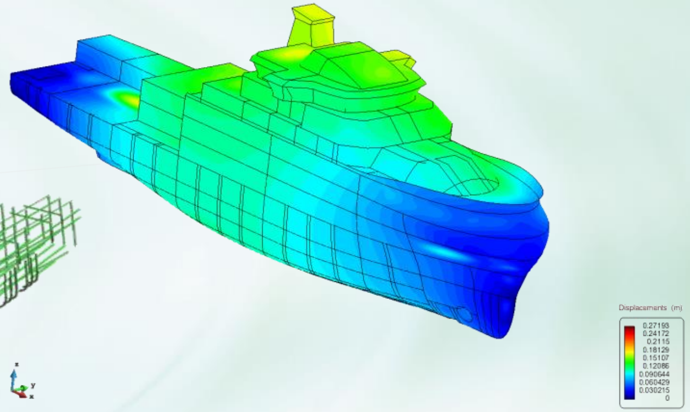


FEM Analysis

Optimization stage





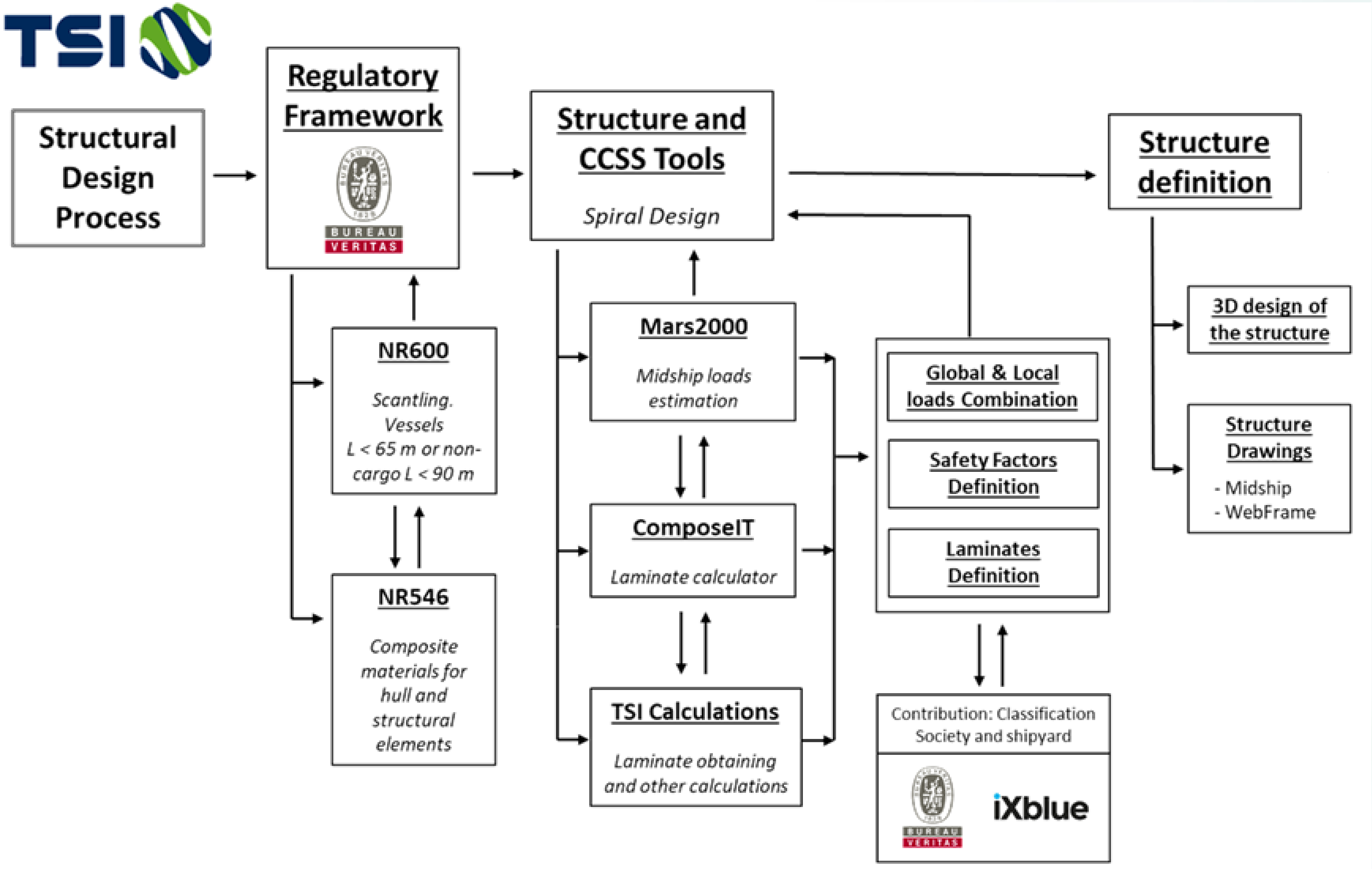


MAIN DIMENSIONS

LOA:	85.0 m
Lpp:	79.9 m
Breadth:	19.0 m
Propulsion:	Diesel-Elec.
Nº Propellers:	2
Cruise speed:	14 Kn
Crew:	20
PAX/Scient.:	35

Structure Definition - Design Basis

Structure Definition - Flowchart



Structure Definition - Design Strategy

The vessel structure in composite material behaves differently to a steel structure.

FEM stiffness matrix

$$[F] = [K] * [D] \qquad [K] = f(E, Geom)$$

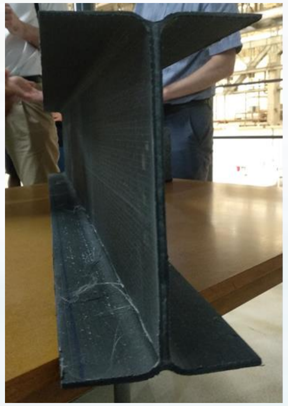
Material mechanical properties of the resulting laminates are lower than typical steel's properties.

A composite structural element with the same cross section that its steel equivalent will have much lower stiffness.

For designing suitable composite structures, the rigidity needs to be increased through the modification of geometrical characteristics.

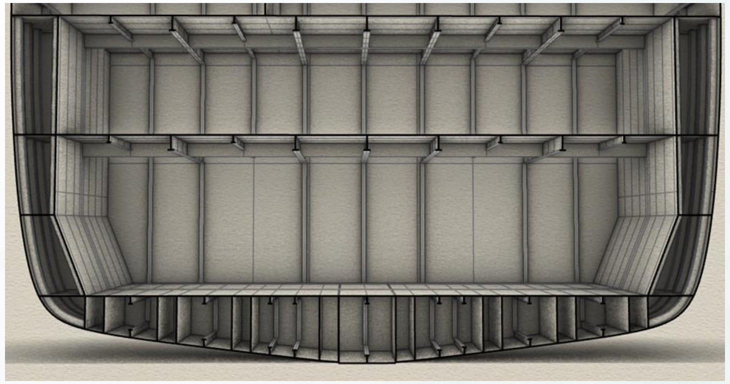
- Increase of scantling thicknesses
- Extensive use of sandwich laminates
- Use of I profile stiffeners instead of typical Ω profiles
- **Double structural configuration**

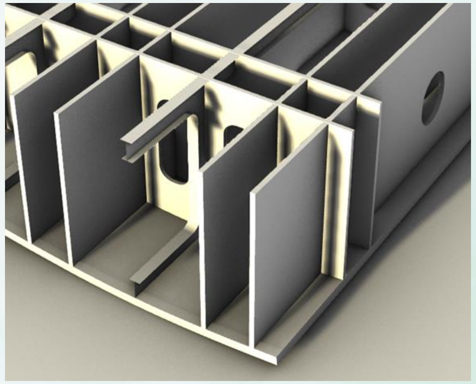
iXblue I Profile



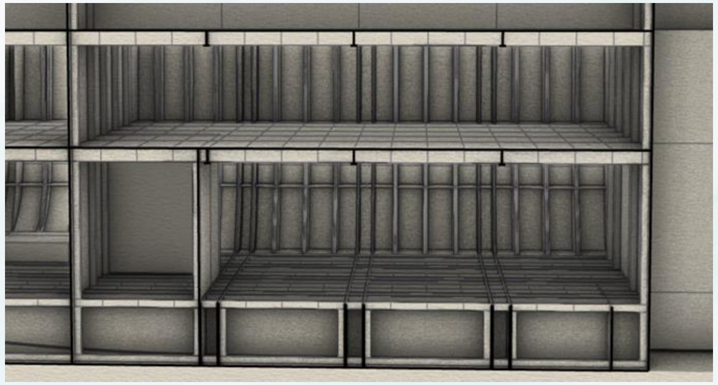
The approach during the structure definition is conditioned by the type of loads that the different elements have to bear:

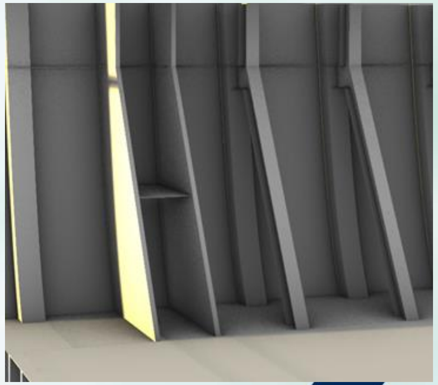
Hull girder bending moments: Longitudinal framing for bearing hogging and sagging bending moments. (Sandwich laminates)





Possible impact loads: Transverse framing for resisting possible impacts from other ships, containers, seabed, etc. (Monolithic laminates)

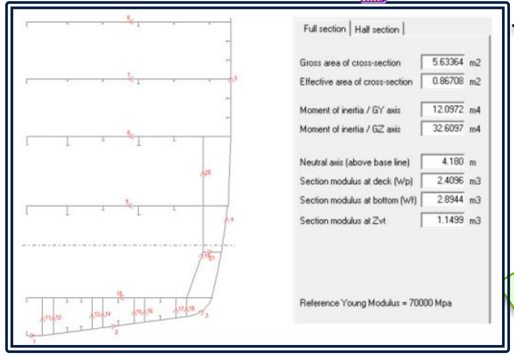


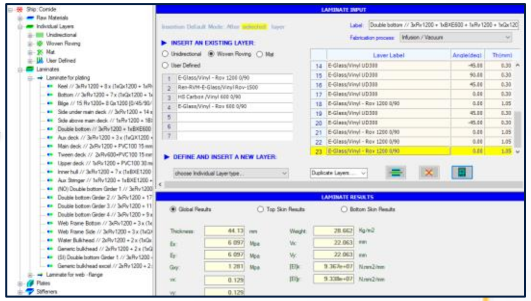


Structure Definition – MidShip Design Basis: Design Cycle & Scantling

MIDSHIP DESIGN

Mars 2000





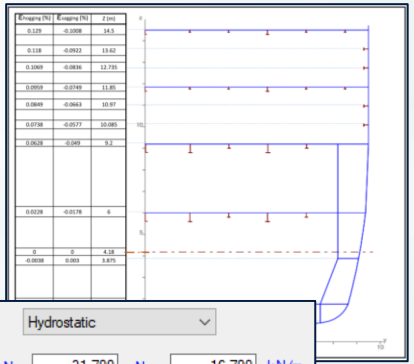
1st Scantling

2nd Scantling

ComposeIT

Midship Redesign

Mars 2000



Forces DF: Hydrostatic

Nx -180.900 Ny -31.700 Nxy 16.700 kN/m

ε - Deformations

$N_x = \varepsilon_x \times E_x \times thick. /100$

$N_y = \nu_y \times N_x$ in kN/m

Approach to Obtain Shear Deformations

$$Th_{equi\ steel} = Th\ comp\ x\ \frac{E_{composite}}{E_{steel}}$$

ComposeIT

LOADS

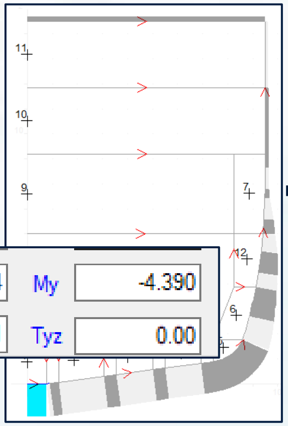
	TYPE	P
Pressure P1:	Side Shell Impact (Pssmin)	30.00
Pressure P2:	Hydrostatic	0.00
Pressure P3:	Hydrostatic	0.00
Pressure P4:	Hydrostatic	0.00

Forces DF: Bottom Slamming (Psl)

Nx	124.800	Ny	9.500	Nxy	88.800	kN/m
Mx	0.090	My	-0.463	Mxy	0.000	kN.m/m
Txz	2.02	Tyz	0.00			kN/m

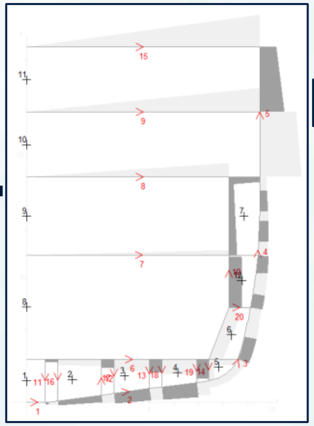
Loads Application

Mars 2000



Mx	1.094	My	-4.390
Txz	13.21	Tyz	0.00

Local Loads: Hydrostatic...

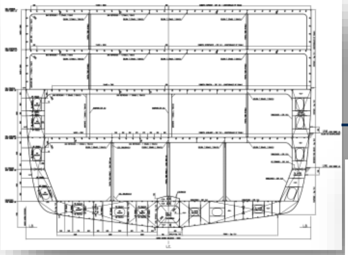


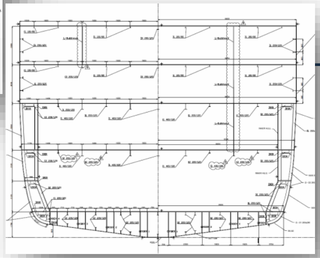
γ - Shear Def.

$N_{xy} = \gamma_{xy} \times G_{xy} \times thick. /100$

Structure Definition: Structure Weight Reduction

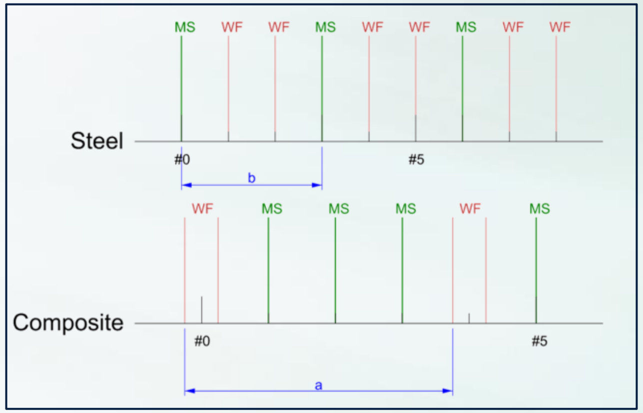
Preliminary analysis





Steel structural weight	26.38	t/m
Composite structural weigth	6.22	t/m

Composite weight less than steel	**76%**



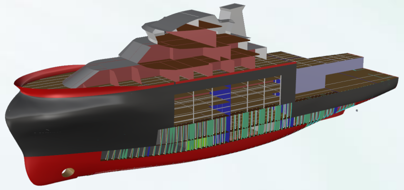
Detailed analysis

Once the structure has been modelled in FEM, the inertia matrix is obtained considering the insulation on board, extracting the **total structural weight** as well as the **CoG**.

As an important finding, a weight comparison between the steel-based reference vessel and the designed fibre-based vessel was carried out, reaching a **reduction of almost 70%** including the insulation of the composites elements.

CORNIDE DE SAAVEDRA - FEM Weight Estimation

DESCRIPTION	WEIGHT(tn)
Hull (Composite)	525.34
Insulation (Stone wool)	159.32
Total Weight	**684.66**



Steel Structural Weight	2252.08

Stone Wool density	0.07	tn/m3

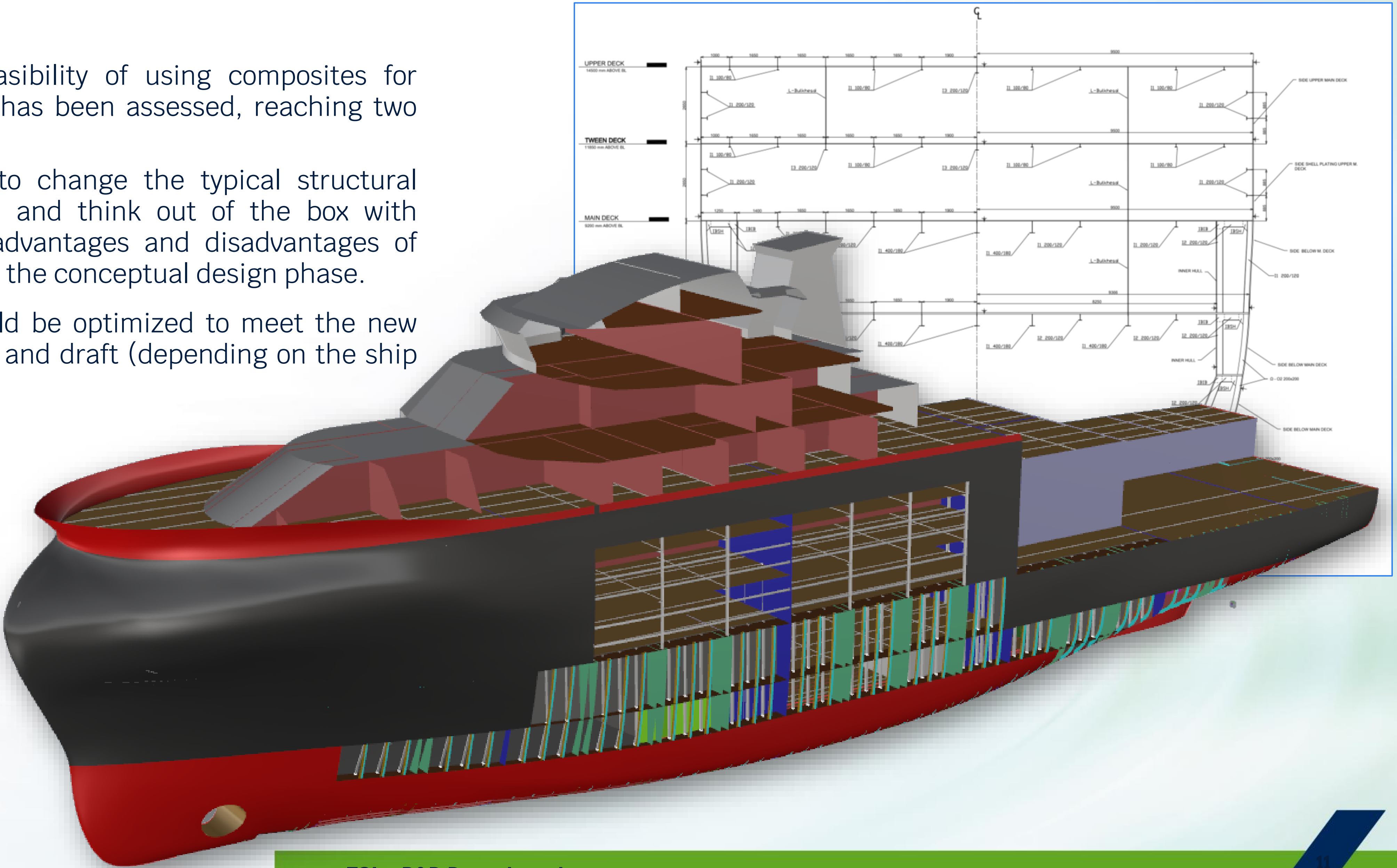
Structural Weigth reduction due to composites	76.7%
Structural Weigth reduction due to composites + Insulation	69.6%

Structure Definition - Conclusions

Structure - The feasibility of using composites for large-length vessels has been assessed, reaching two main conclusions:

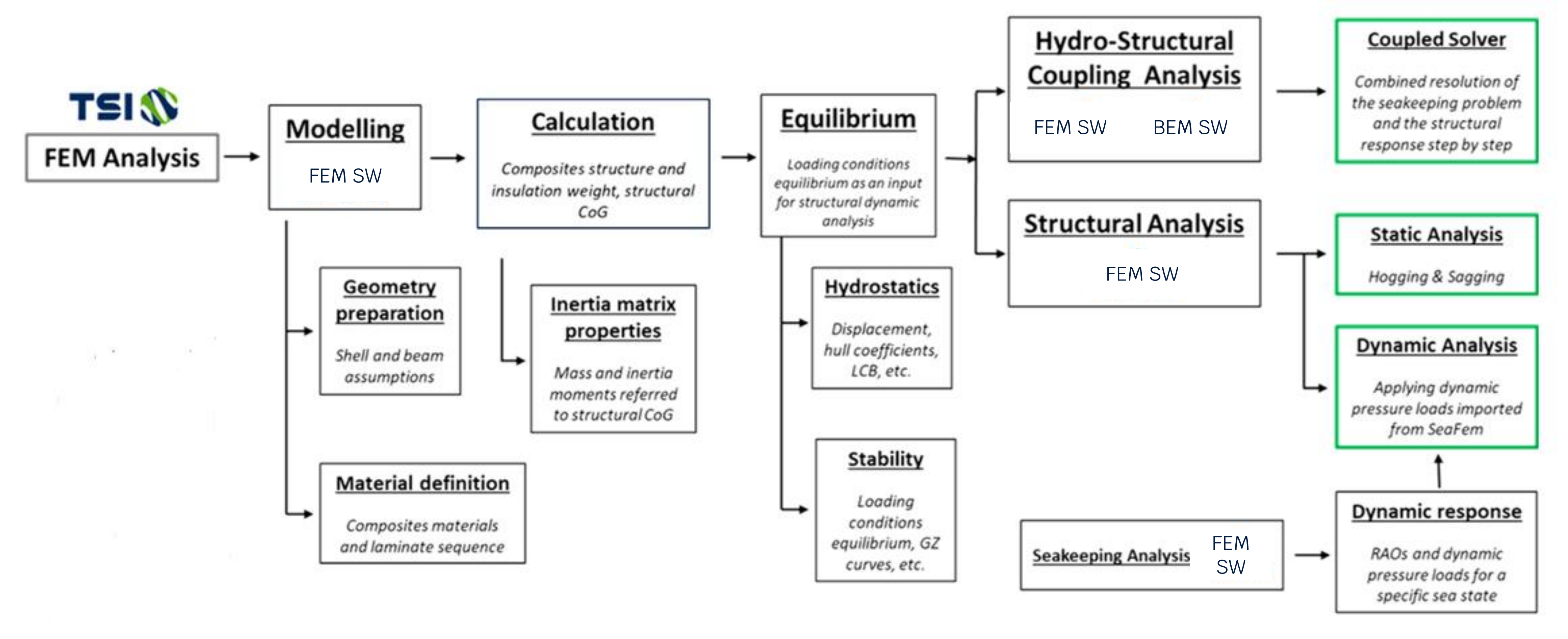
1. It is necessary to change the typical structural design approach and think out of the box with respect to the advantages and disadvantages of composites since the conceptual design phase.

2. The design should be optimized to meet the new weight condition and draft (depending on the ship mission).



FEM Analysis

FEM Analysis: Flowchart



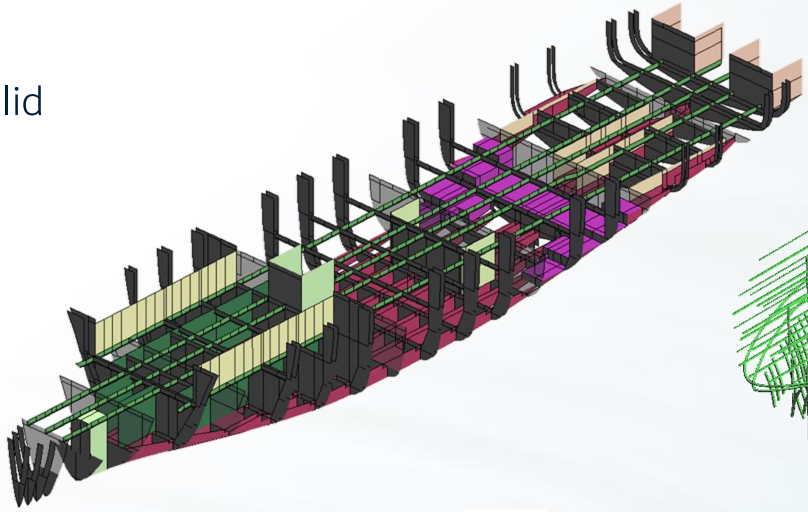
FEM Analysis: Model design - Concepts

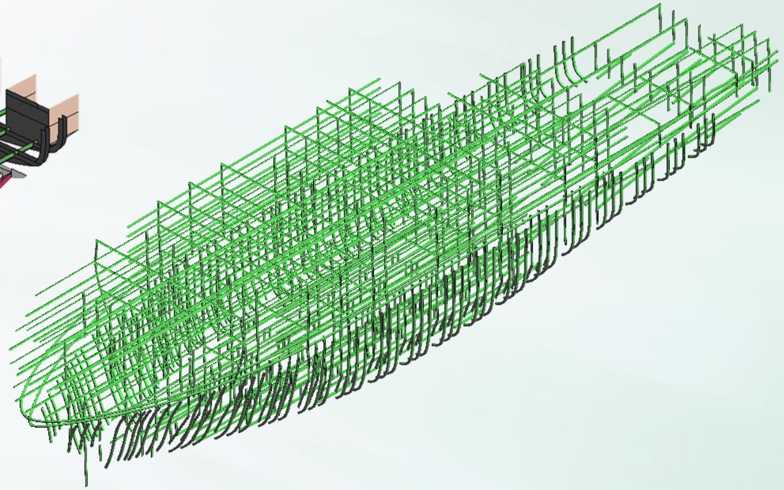
FEM Modelling Design

Geometry simplification

Beam and Shell elements, turning a complex 3D solid geometry into a simplified 2D and 1D model.

- Shell elements:
  - Structure plating, primary reinforcements.
  - Large secondary reinforcements (400x180)
- Beam Element: Rest of the reinforcements





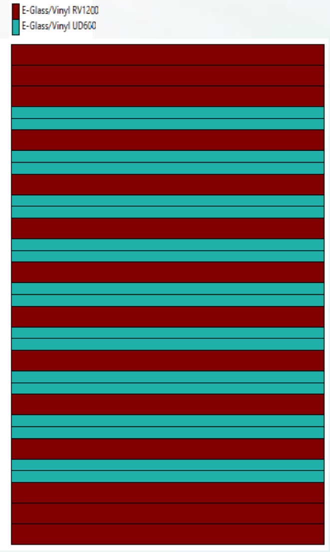
Material Assignment

Shell material: classical constitutive model

- Mechanical properties of a single layer are obtained from the combination of fibre and resin (%).
- Final composite material properties are given by the lamination sequence of these layers.

Beam Element: behaviour defined by the geometric section and modelled with isotropic properties (software requirement).

- The mechanical characteristics of the beam in the subjected direction will represent the material properties.



Symm

Material	Angle	Thickness	Layers
E-Glass/Vinyl RV1200	0.0	0.001054	3
E-Glass/Vinyl UD600	45.00	0.000597	1
E-Glass/Vinyl UD600	-45.00	0.000597	1
E-Glass/Vinyl RV1200	0.0	0.001054	1
E-Glass/Vinyl UD600	45.00	0.000597	1
E-Glass/Vinyl UD600	-45.00	0.000597	1
E-Glass/Vinyl RV1200	0.0	0.001054	1
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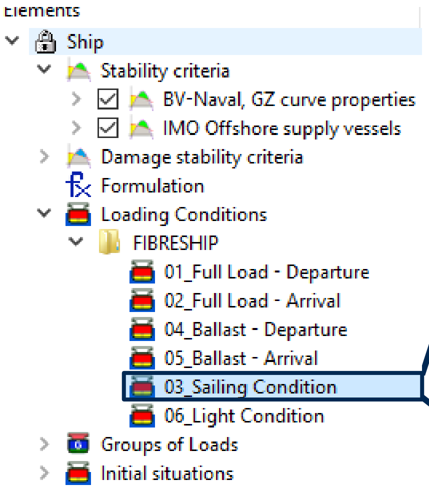
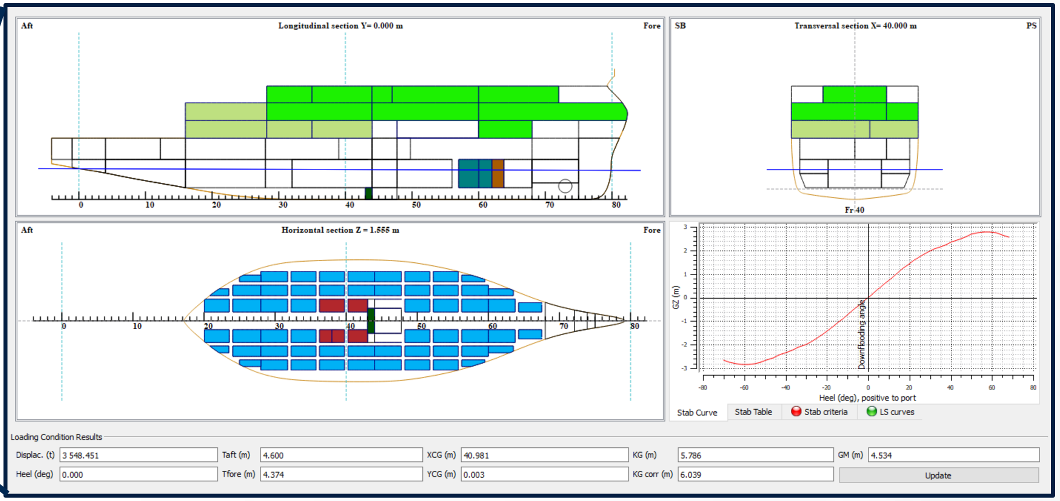
E-Glass/Vinyl UD600	45.00	0.000597	1
E-Glass/Vinyl UD600	-45.00	0.000597	1
E-Glass/Vinyl RV1200	0.0	0.001054	1
E-Glass/Vinyl UD600	45.00	0.000597	1

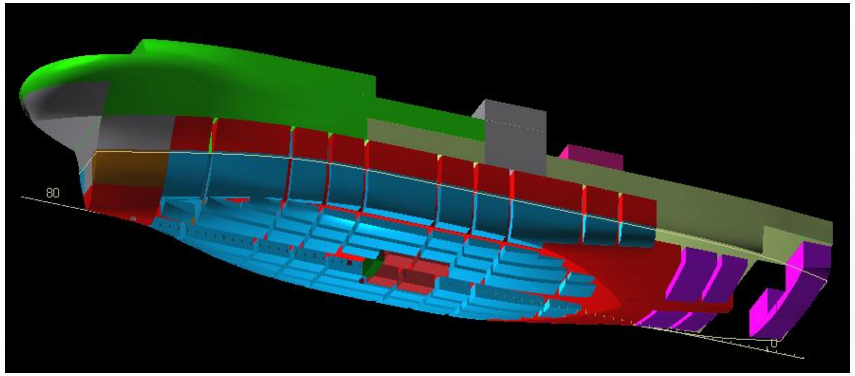
FEM Analysis: Loading Conditions, Stability, Balance & FRV's Internal Loads

Loading Conditions, Stability, Balance



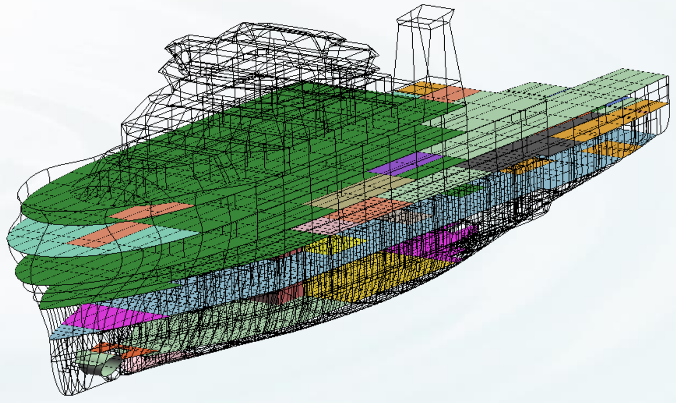


#	Loading Condition	Weight (t)	Displacement (m3)	GMt (m)	Drafts and trim		
					Taft (m)	Tfore (m)	Tm (m)
1	Full load - departure	3812.6	3719.6	4.2	4.9	4.6	4.7
2	Full load - arrival	3257.9	3178.5	4.6	4.7	3.7	4.2
3	Sailing	3548.5	3461.9	4.7	4.6	4.4	4.5
4	Ballast - Departure	3689.1	3599.2	4.7	4.7	4.5	4.6
5	Ballast - Arrival	3205.0	3126.8	5.2	4.7	3.7	4.2
6	Lightship	2308.9	2252.6	6.3	4.8	1.8	3.3

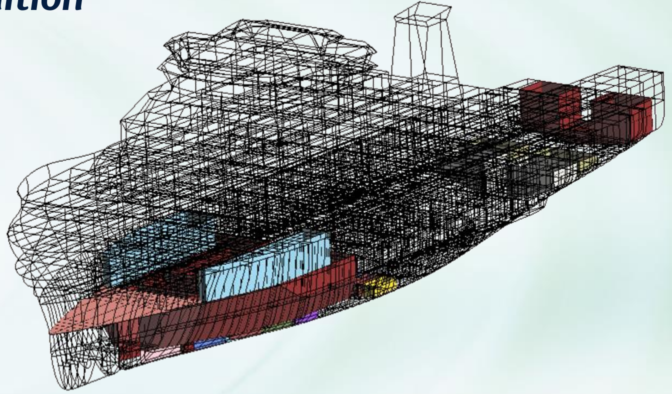


Name	scripti	num	Weight	XCoG	YCoG	ZCoG
COMPOSITE - F...	Lig...	--	2133.350 t	x 36873.0 mm	176.000 mm	6972.000 mm
Remainder		--	0.000 t	x 0.0 mm	0.000 mm	0.000 mm
Structure		--	684.660 t	x 40314.9 mm	165.199 mm	7514.633 mm
Machinery		--	274.400 t	x 33025.2 mm	-51.020 mm	3110.787 mm
Equipment		--	924.290 t	x 30563.1 mm	29.320 mm	6762.822 mm
Accommodation		--	250.000 t	x 55000.0 mm	1000.000 mm	10500.000 mm

Internal loads considered for sailing condition



Fixed equipment and other loads



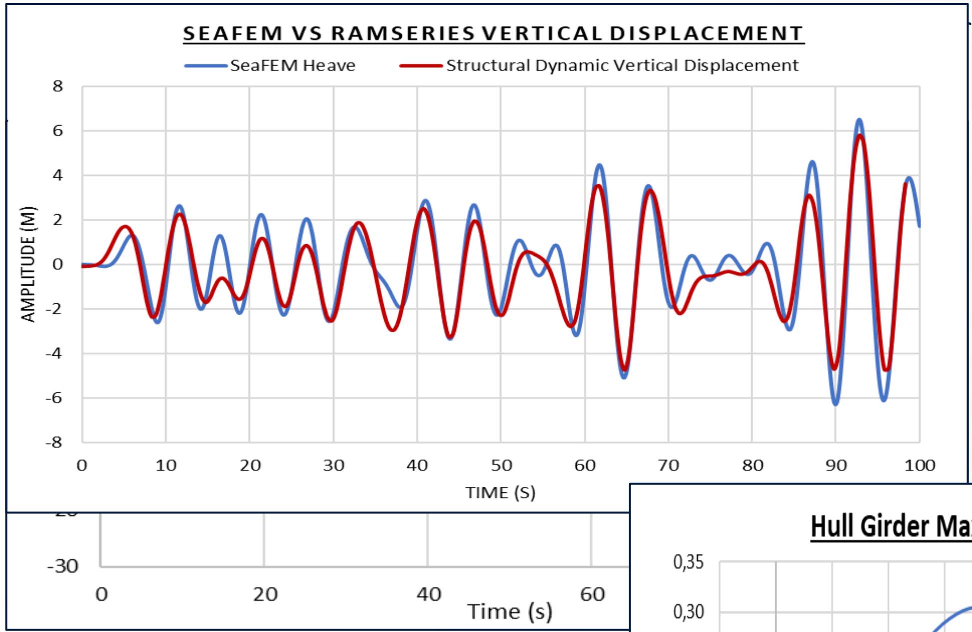
Ballast, anti-slamming, anti-heeling, fuel, oil and other tanks

FEM Analysis: Structural Dynamic Analysis (1/2)

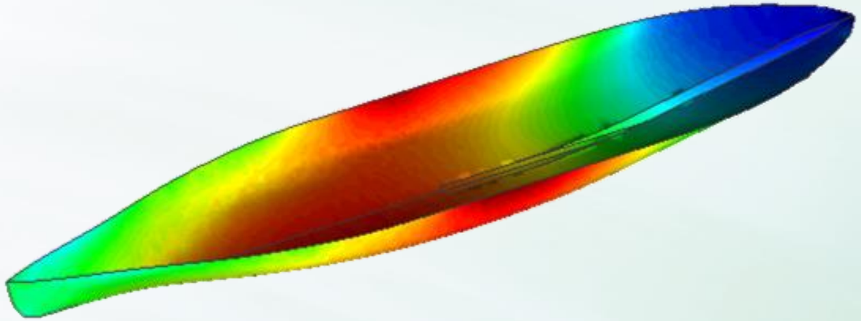
External loads for structural dynamic analysis, FRV'S movements and hull girder displacements

Jonswap spectrum

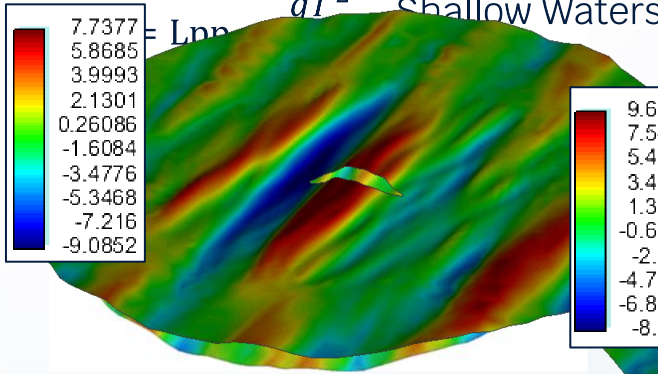
Magnitude	Value
Mean wave period (s)	7,2
Mean wave height (m)	10,17
Shortest period (s)	3
Longest period (s)	16
Nº of wave periods	20
Mean wave heading (º)	180
Spreading angle (º)	60
Nº of wave headings	10



nal forces time series are imported to the

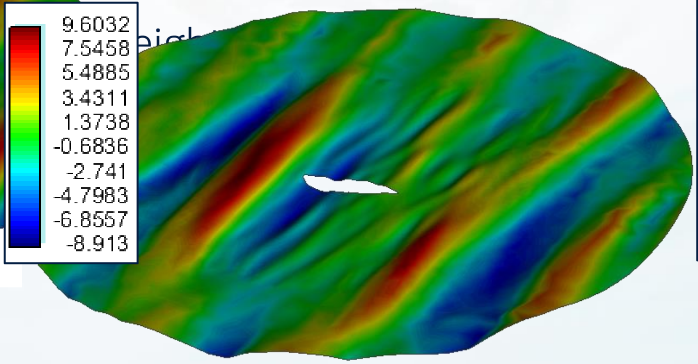


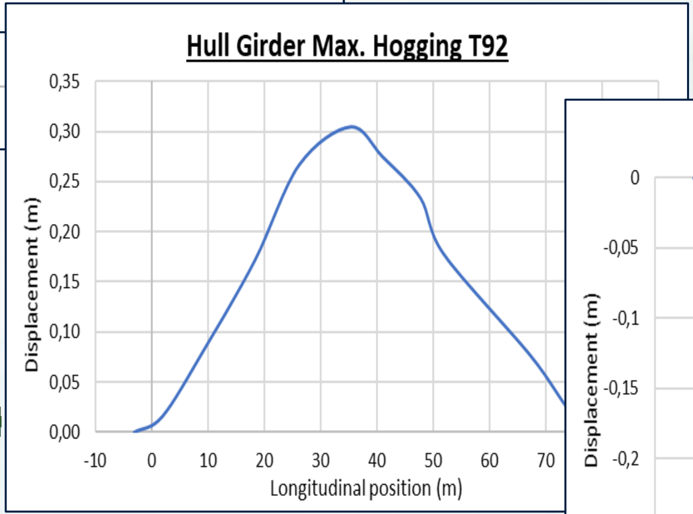
Max. Hogging (T92)

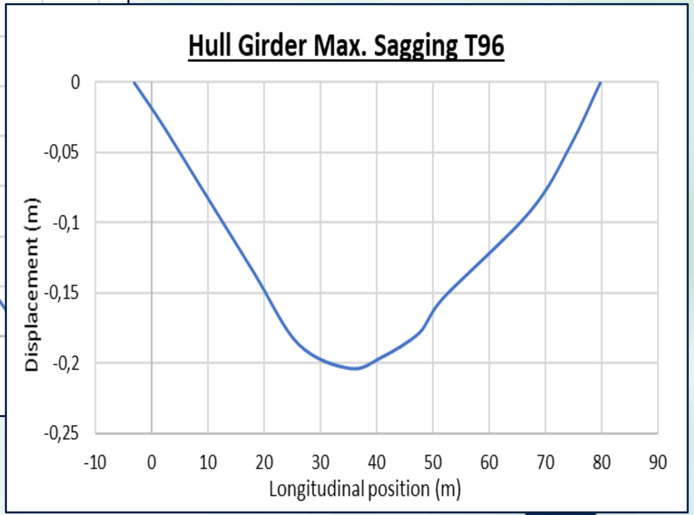


Shallow Waters dispersion

Max. Sagging (T96)

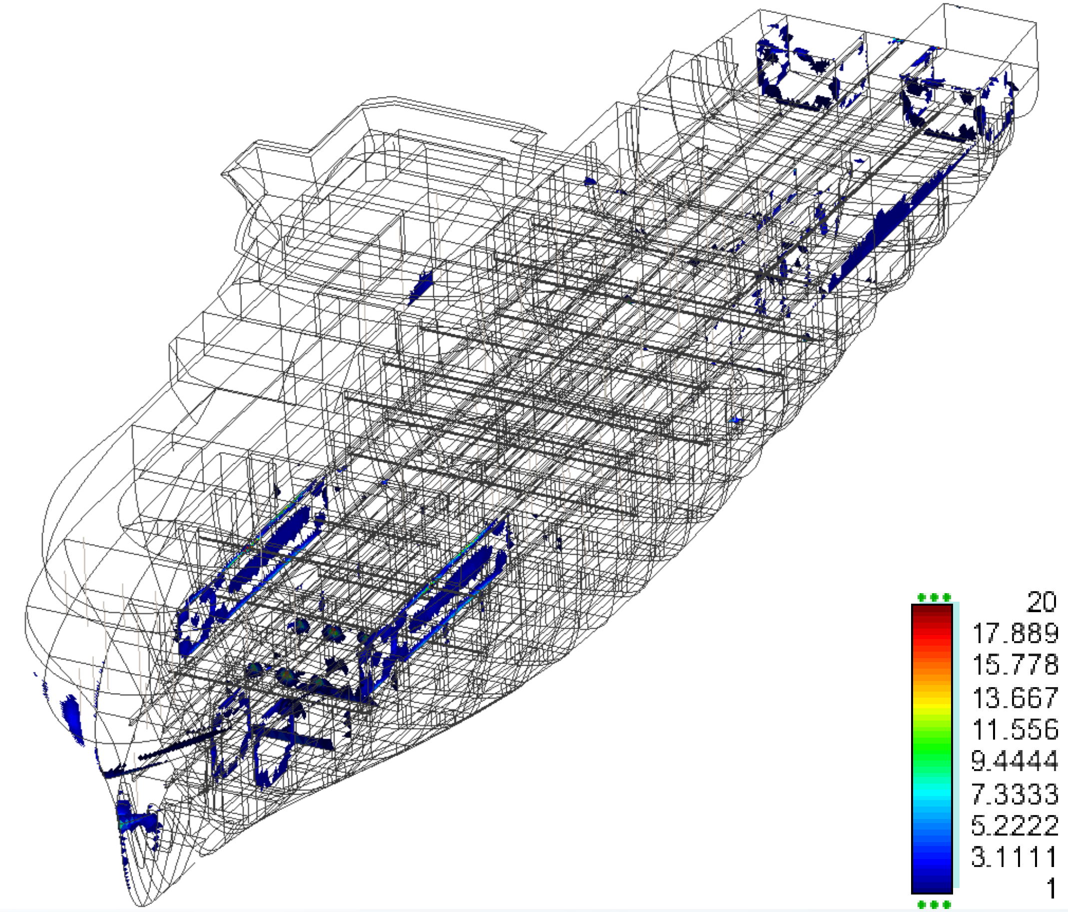




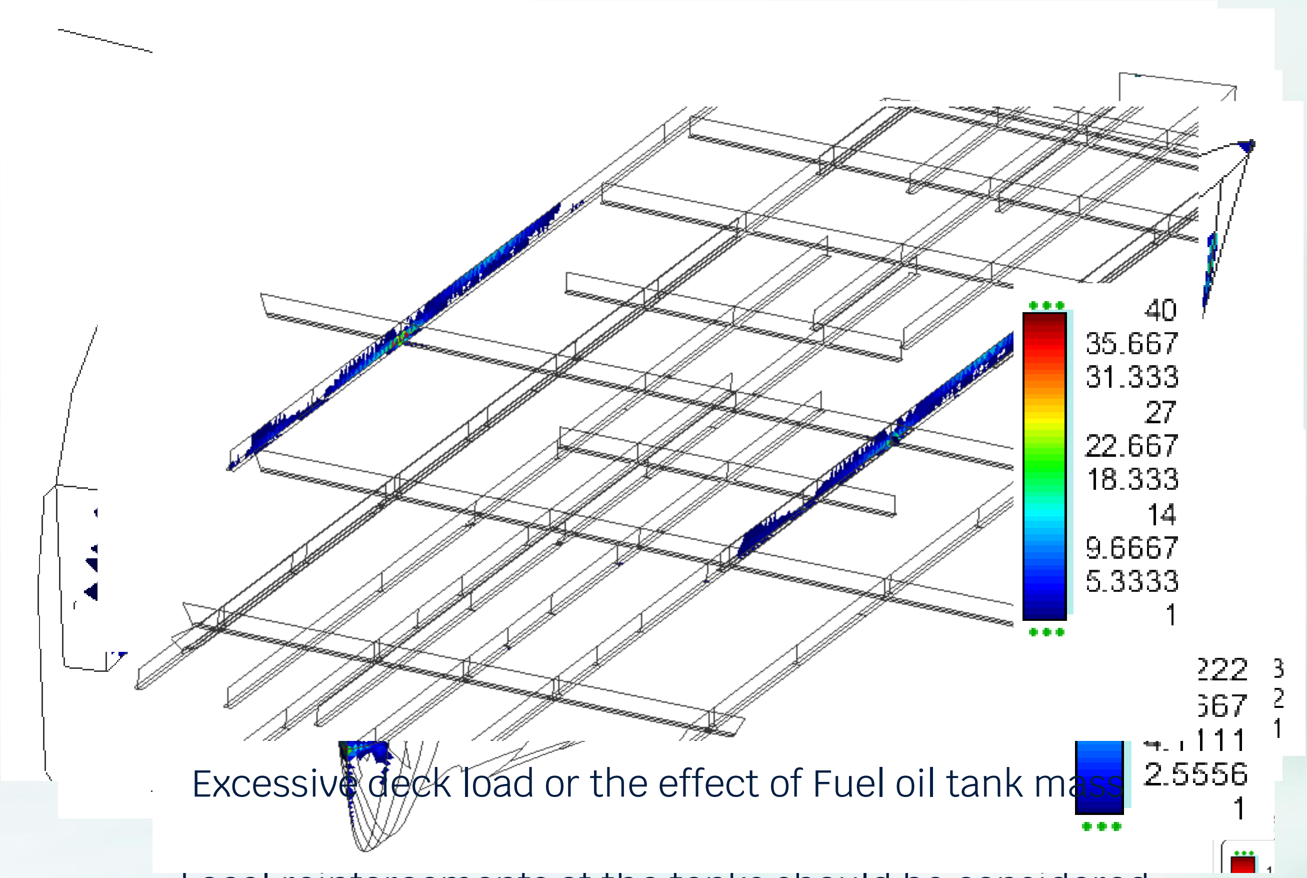


FEM Analysis: Structural Dynamic Analysis (2/2)

Tsai-Wu Criterion – Max all substeps



Tanks – Fresh water and fuel oil
Structure – Reinforcement 400x180



Excessive deck load or the effect of Fuel oil tank mass

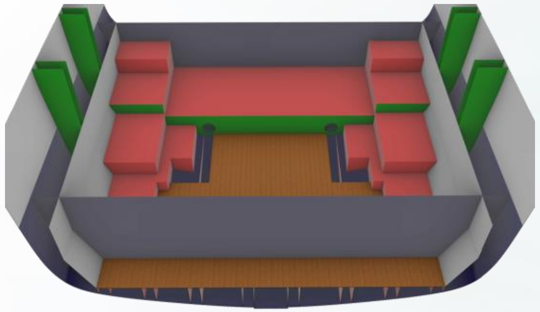
Local reinforcements of the tanks should be considered

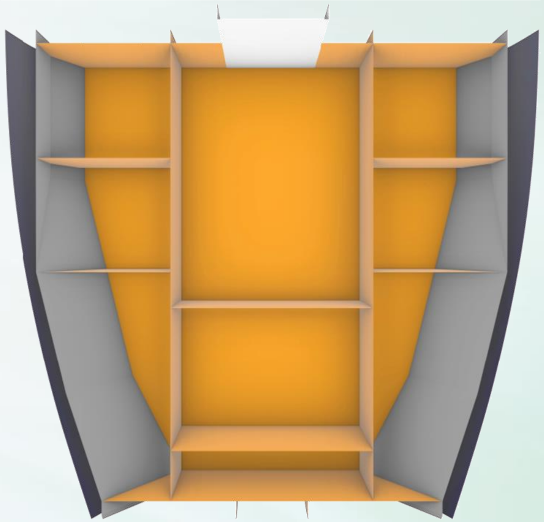
Likely due to waves local effect and the boundary conditions

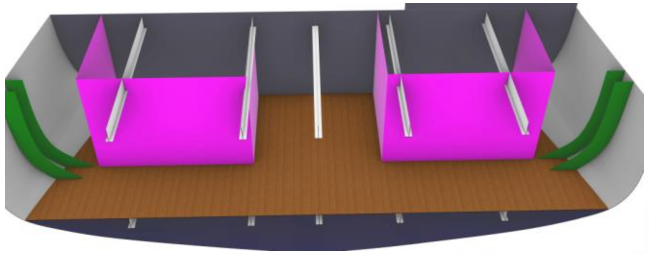
Conclusions

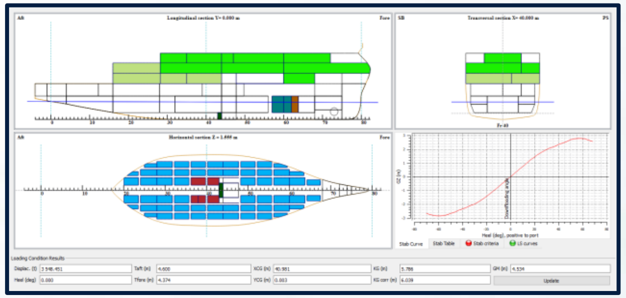
Conclusions: Summary

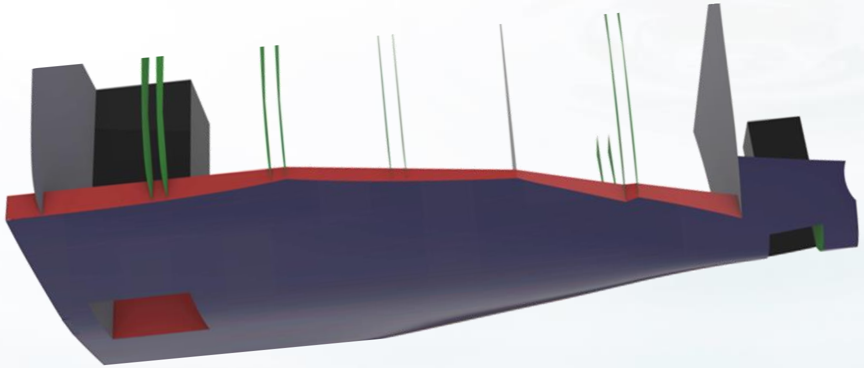
- ✓ Consider the **material type** from the very beginning of the design process.
- ✓ **Address an alternative approach of structural configuration** with respect to traditional steel-based vessels: keep in mind advantages and disadvantages of FRP materials, and make the most of them.











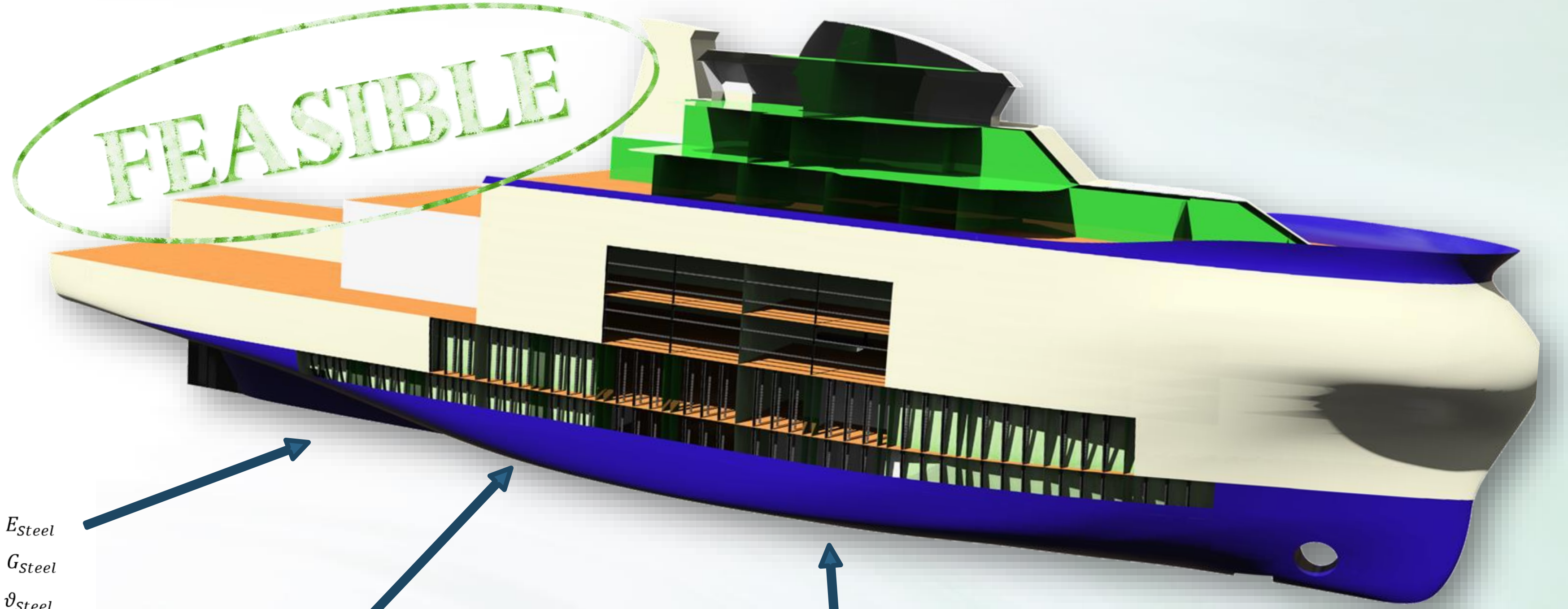
Thinking out of the box for an **effective design** of the **vessel as a whole:**

1. **Internal structure** design has to be entirely **focused on the cargo** to be transported according to the vessel operation profile.
2. **Spaces size and weight reduction** could **affect** in a significant way the draft of the vessel and therefore its **stability** and **seakeeping**.
3. Special attention has to be taken in the design to include the required **innovations** in the structure and internal spaces.

Conclusions: FIBRESHIP vessel comparative

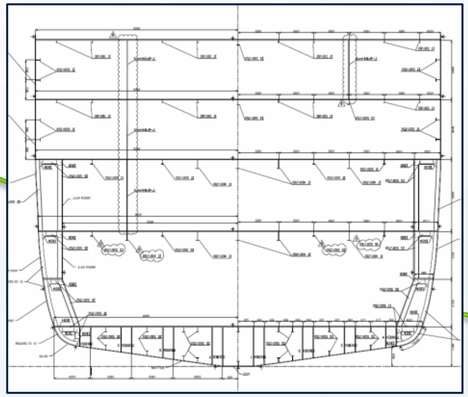
FIBRESHIP: Structural vessel design in FRP materials				
VESSEL TYPE		Containership	ROPAX	Fishing Research Vessel (FRV)
Vessel Category		Lightweight commercial vessels	Passenger transportation and leisure vessels	Special services vessels
Overall Length	(m)	260.0	204	86,4
Length between PP	(m)	244.8	185.4	79.9
Steel-based Structural Weight	(ton)	10952	8629	2252
Fibre-based Structural Weight w/o insulation	(ton)	4675	4232	525
Fibre-based Structural Weight insulation	(ton)	5925	5502	684
Average Composite Scantling	(mm)	35 (Torsion box 100)	41	32
Structural Weight Reduction wrt the reference steel-based vessel and considering insulation		**45,9%**	**36,2%**	**69,6%**
Steel-based Lightship displacement	(ton)	16535	13051	3701
Fibre-based Lightship displacement	(ton)	11508	9924	2133
Lightship Weight Reduction wrt a steel-based vessel		**30,4%**	**24,0%**	**42,4%**
Main conclusions		The FRP containership design fulfils all the requirements and reduces the stresses well below the acceptable limits. Only the maximum global deflection may be a limiting factor when considering extreme navigation conditions. Fire safety improvement is the next challenge to overcome.	Local Roll-On/Roll-Off areas have been checked. Significant local failure modes due to Roll-on/Roll-off cargo have identified. More structural optimization is needed. Fire safety improvement is the next challenge to overcome.	The FRV in composites fulfills all the structural requirements for all navigation conditions. It can be said that fibre-based vessels of up to 85 m length are feasible from the structural point of view. Fire safety improvement is the next challenge to overcome.

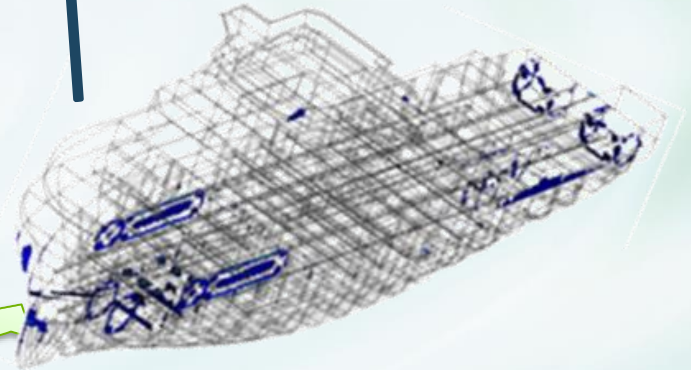
According to the results obtained in FIBRESHIP, it is FEASIBLE designing a structure in composite materials of a vessel larger than 500 GT



Generalized Hooke's law (orthotropic)

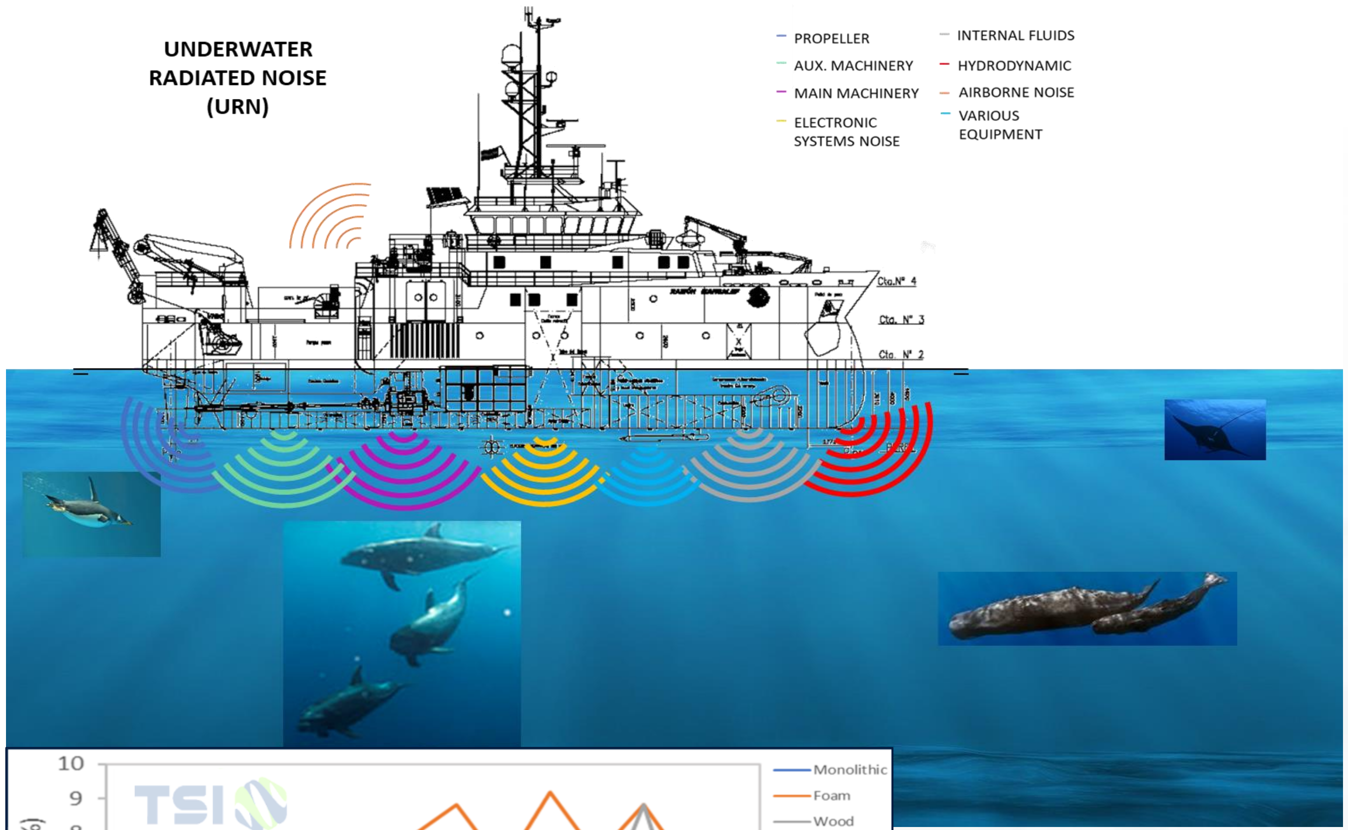
$$
\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{zz}\\ \gamma_{yz}\\ \gamma_{zx}\\ \gamma_{xy}\end{bmatrix} =
\begin{bmatrix}
\frac{1}{E_x} & -\frac{\vartheta_{xy}}{E_y} & -\frac{\vartheta_{xz}}{E_z} & 0 & 0 & 0\\
-\frac{\vartheta_{yx}}{E_x} & \frac{1}{E_y} & -\frac{\vartheta_{yz}}{E_z} & 0 & 0 & 0\\
-\frac{\vartheta_{zx}}{E_x} & -\frac{\vartheta_{zy}}{E_y} & \frac{1}{E_z} & 0 & 0 & 0\\
0 & 0 & 0 & \frac{1}{G_{yz}} & 0 & 0\\
0 & 0 & 0 & 0 & \frac{1}{G_{zx}} & 0\\
0 & 0 & 0 & 0 & 0 & \frac{1}{G_{xy}}
\end{bmatrix} *
\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{zz}\\ \tau_{yz}\\ \tau_{zx}\\ \tau_{xy}\end{bmatrix}
\rightarrow
\begin{cases}
E_{Composite} \ll E_{Steel}\\
G_{Composite} \ll G_{Steel}\\
\vartheta_{Composite} < \vartheta_{Steel}
\end{cases}
$$

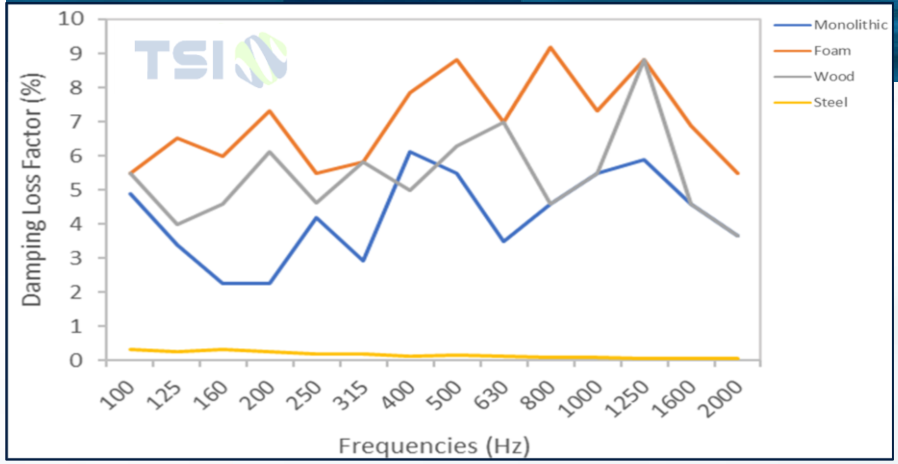


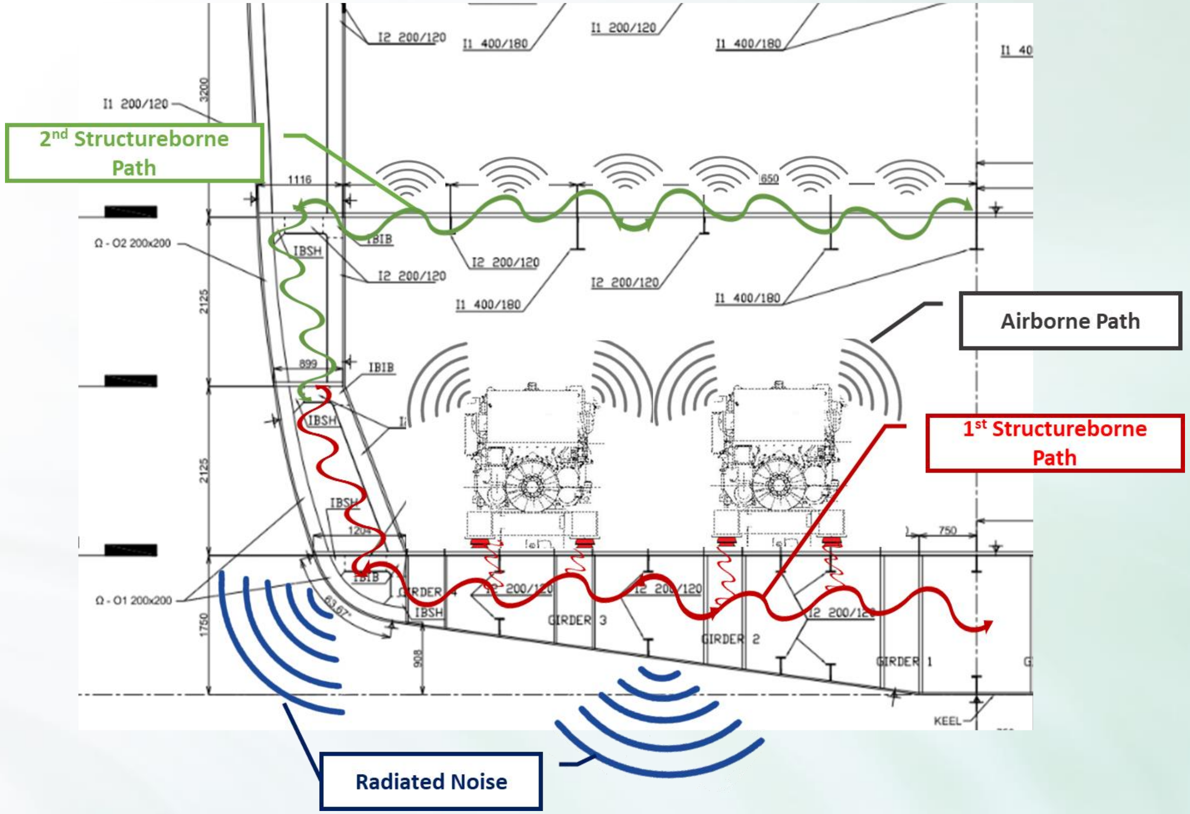


Influence of composite structures on URN

Underwater Radiated Noise (URN)





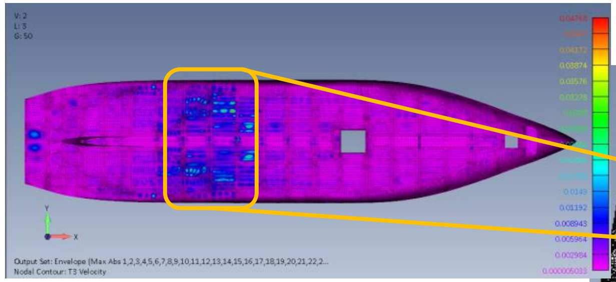


Acoustic signature of the ship consists of two frequency domains (it depends on the length of the vessel):

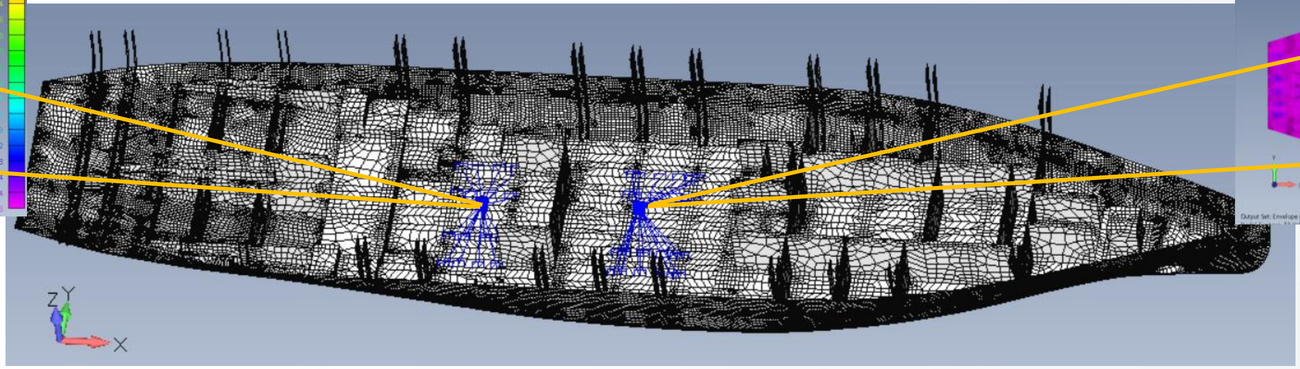
- Low-frequency domain (up to 150-200Hz):
- High-frequency domain (from 200-10000Hz):

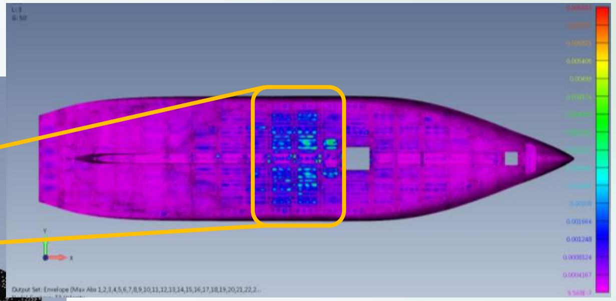
URN – Analysis & Prediction

Initial Conditions for URN Prediction



Electric Motor Pressure Pulse

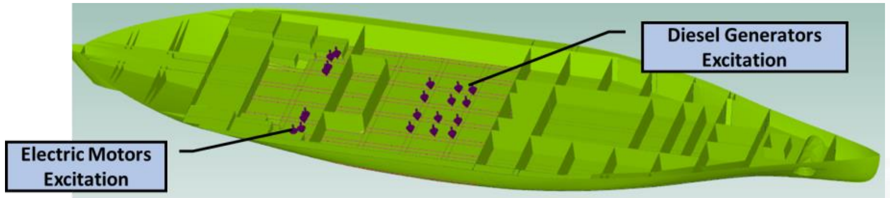


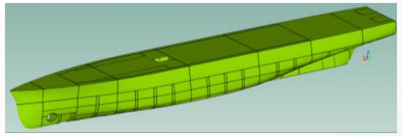


Diesel Generator Pressure Pulse

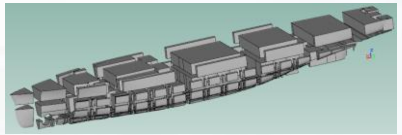
Low & High – Frequency Analysis Result

High frequency analysis: SEA



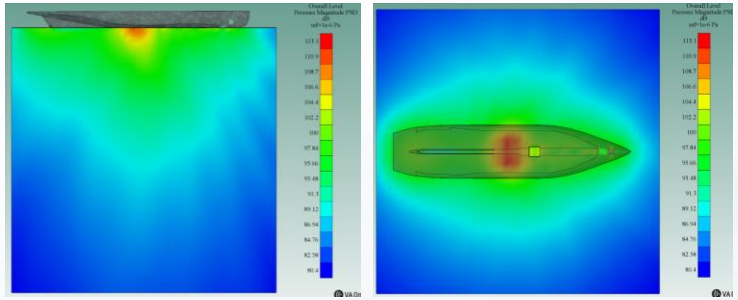


SEA panels of the vessel underwater structure

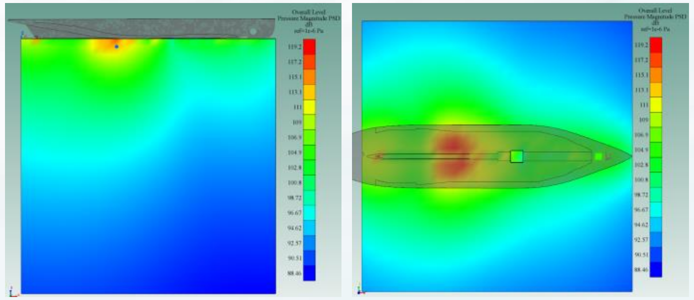


SEA Cavities of the vessel underwater structure

Low frequency analysis: FEM

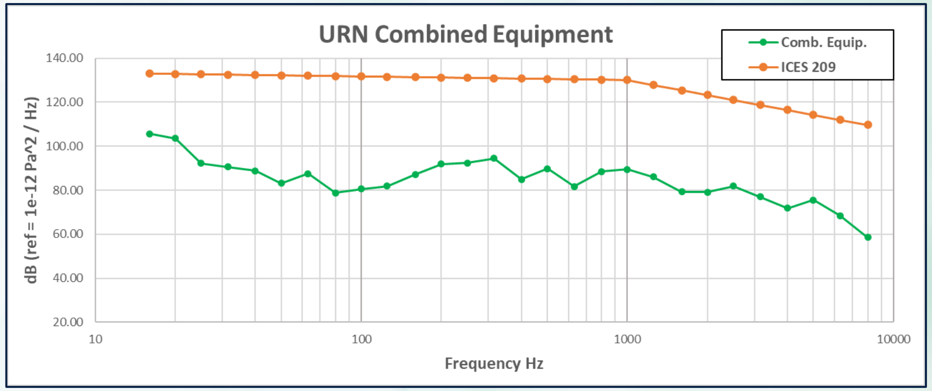


Diesel Generator Low Frequency Pressure Pulse



Electric Motor Low Frequency Pressure Pulse

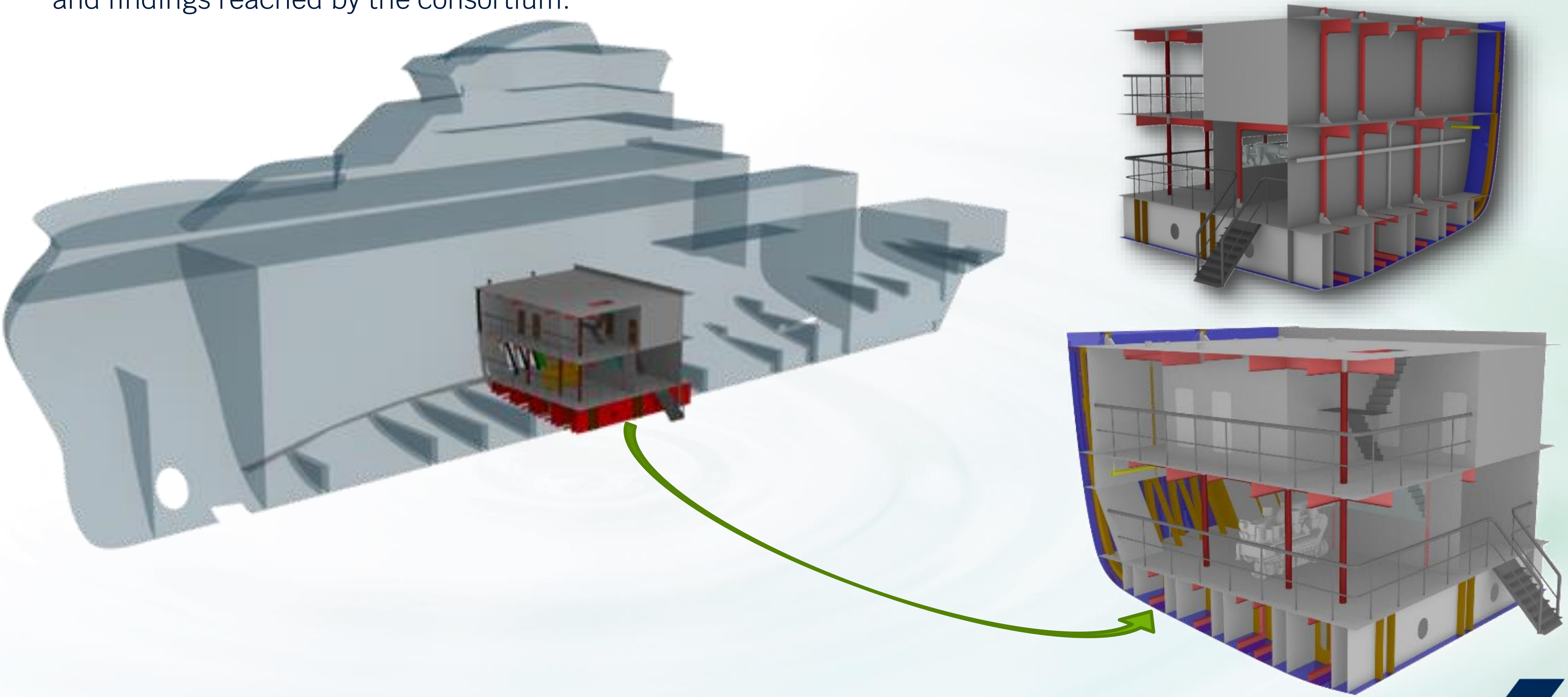
Radiated Noise from Combined Equipment



Demonstrator

Demonstrator: Demonstrator Design

The FIBRESHIP project contains the building a demonstrator including the advances and findings reached by the consortium.



Demonstrator: Manufacturing Process Findings

The hull lamination is carried out only once per block, using the infusion technique.

The huge size of blocks and complexity to work on them, is an important issue to address in the future as a research line.

The primary structure is added before unmoulding to give stiffness to the block, facilitating technicians and specialists the proper joining of the elements in the structure.

One of the researches made by iXblue shipyard it is the manufacturing of reusable moulds, allowing their use for different constructions.

Through demonstrator construction, several findings regarding shipyard adaptation to this new activity have been obtained, being all of them gathered in a document of the project.


FIBRESHIP

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