FIBRESHIP
INTEGRAL COMPOSITE SHIP

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Numerical tools for the design of fibre-based ships of large lengths

Participants: CIMNE, COMPASSIS, ULIM, VTT, TWI, LR, BV, RINA, TUCO, IXBLUE, TSI

Cartagena, 27th February 2019

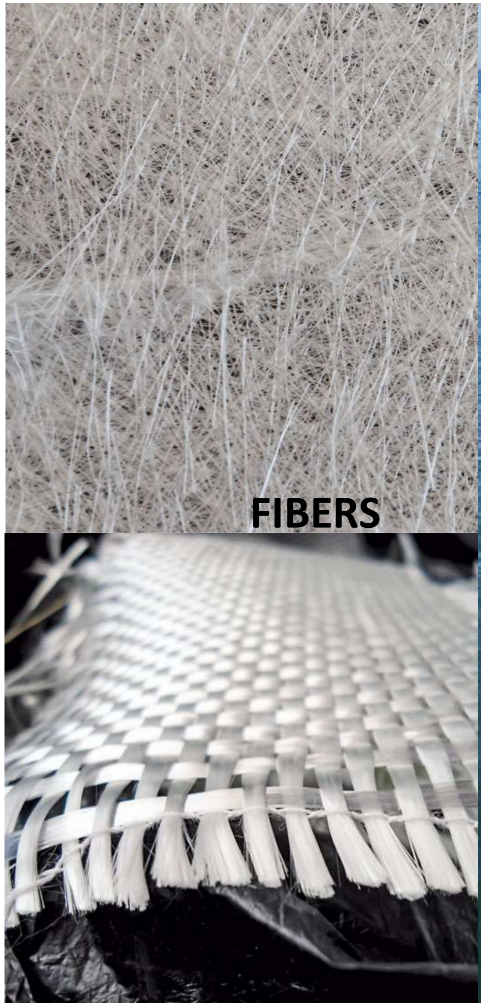
BRIEF DESCRIPTION

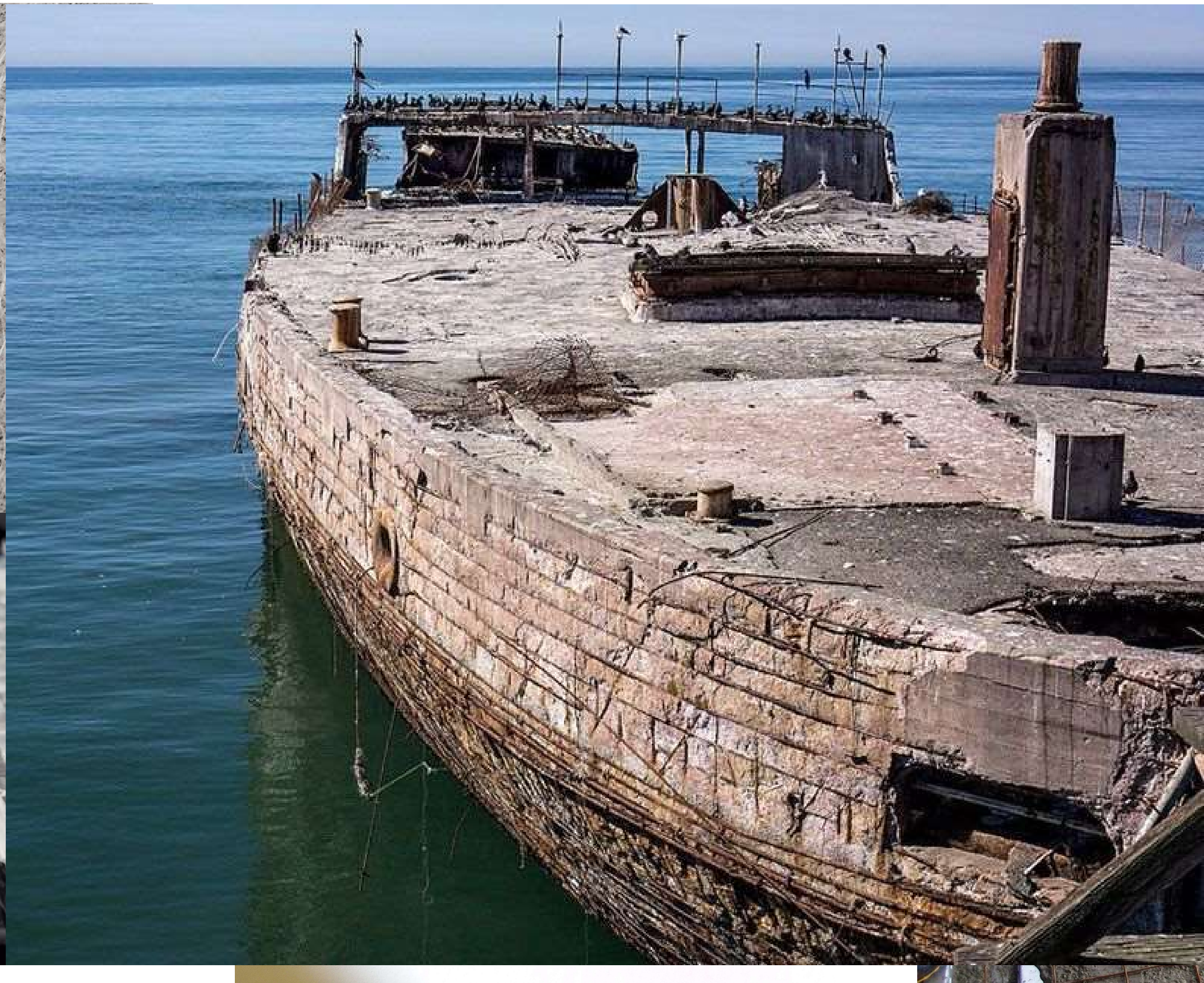
- **CHARACTERIZATION AND SIMULATION OF FIBRE-BASED MATERIALS**
  - Simulation of mechanical performance of composites.
  - Calibration process.
  - Fatigue performance of composites.

- **NUMERICAL TOOLS TO DESIGN AND ANALYZE FIBRE-BASED SHIPS OF LARGE LENGTH**
  - Coupled seakeeping-FEA tool
  - GUI for materials definition, hull girder analysis and collapse assessment.

CHARACTERIZATION AND SIMULATION OF FIBRE-BASED MATERIALS

INTRODUCTION. What's a composite material?



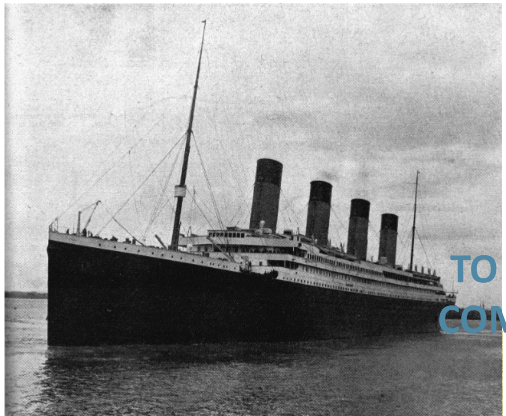


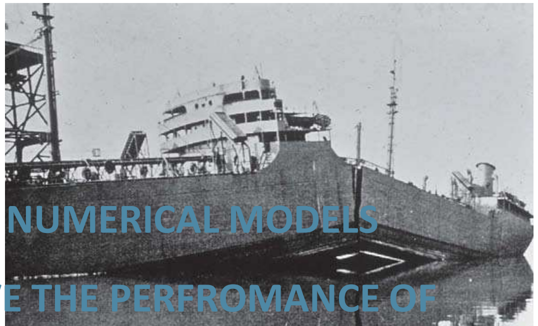
TASK: Development of numerical models

INTRODUCTION. Use of composite materials on naval industry

SOLUTIONS ON NAVAL INDUSTRY ARE BECOMING MORE SPECIFIC, AS WELL AS THE MATERIALS USED TO DEAL WITH ARE BECOMING MORE COMPLEX.

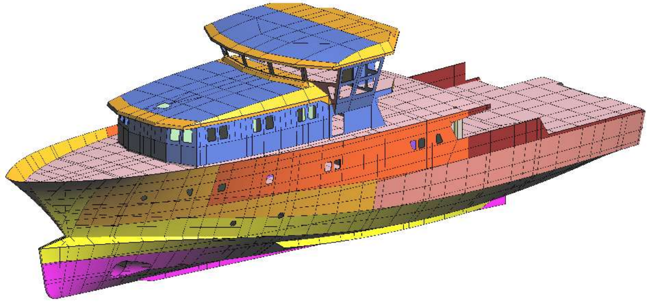
COMPLEX SOLUTIONS REQUIRE SPECIFIC TOOLS





USE OF NUMERICAL MODELS

TO RESOLVE THE PERFROMANCE OF COMPLEX MATERIALS AND COMPLEX STRUCTURES



TASK: Development of numerical models

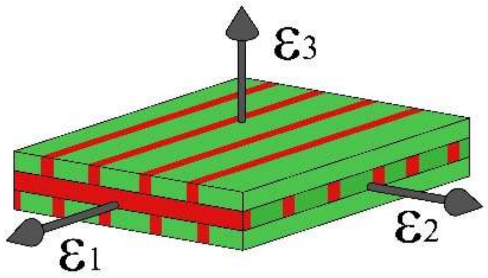
INTRODUCTION. Challenges with composites

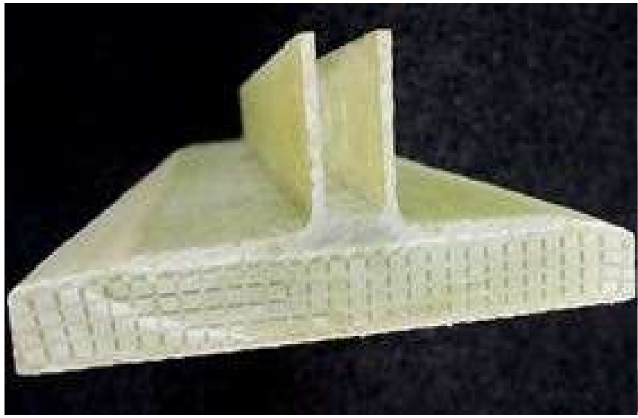
- Anisotropic behavior: material properties are orientation-dependency.
- Different failure modes (delamination, matrix cracking, fiber breakage,…)
- Lack of experimental data compared with other materials.

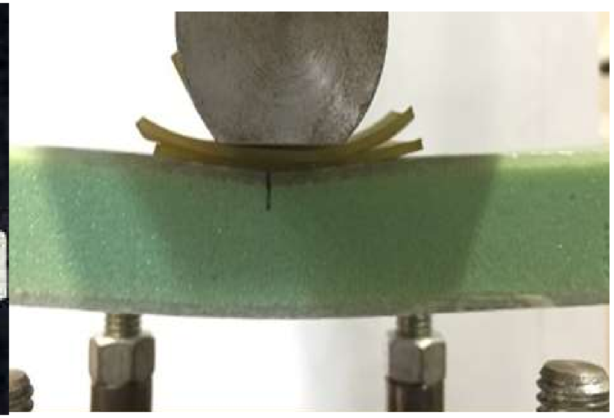
HOW TO DEAL WITH THESE CHALLENGES?

⇩

Standardization of tests and calibration methods

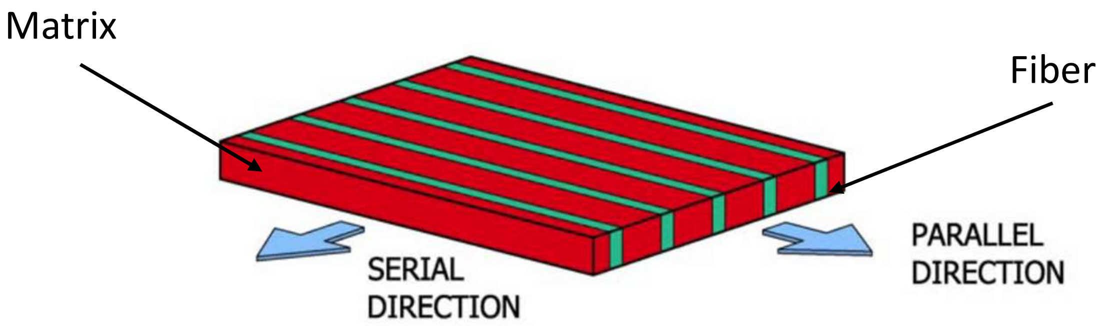






Serial/Parallel Mixing Theory

This formulation is a constitutive equations manager that provides the response of the composite by coupling the constitutive equations of its components.



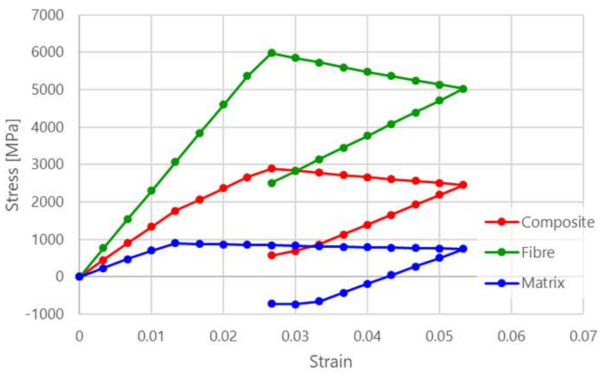
Compatibility equations

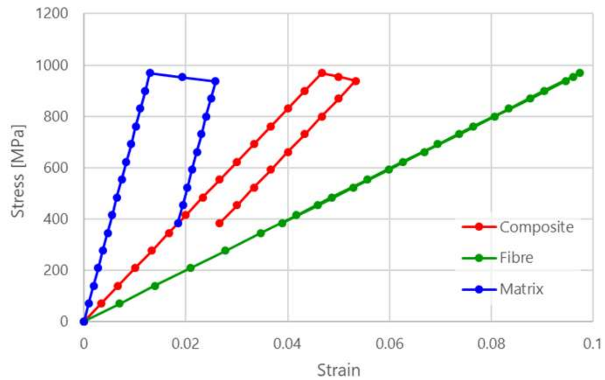
Parallel behavior

$$\begin{cases} {}^{c}\varepsilon_{P} = {}^{m}\varepsilon_{P} = {}^{f}\varepsilon_{P} \\ {}^{c}\sigma_{P} = {}^{m}k\,{}^{m}\sigma_{P} + {}^{f}k\,{}^{f}\sigma_{P} \end{cases}$$

Serial behavior

$$\begin{cases} {}^{c}\varepsilon_{S} = {}^{m}k\,{}^{m}\varepsilon_{S} + {}^{f}k\,{}^{f}\varepsilon_{S} \\ {}^{c}\sigma_{S} = {}^{m}\sigma_{S} = {}^{f}\sigma_{S} \end{cases}$$





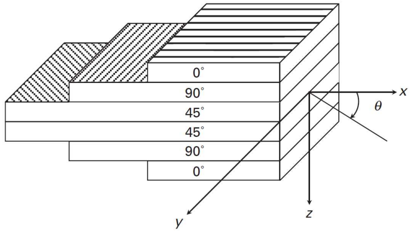
Check for convergence:

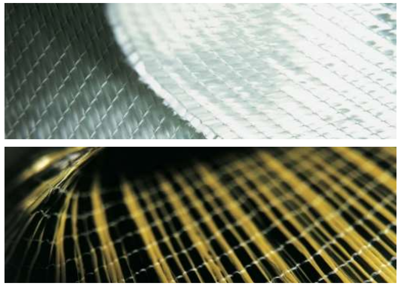
$$[\Delta\sigma_S]^k = [{}^{m}\sigma_S]^k - [{}^{f}\sigma_S]^k \approx 0$$

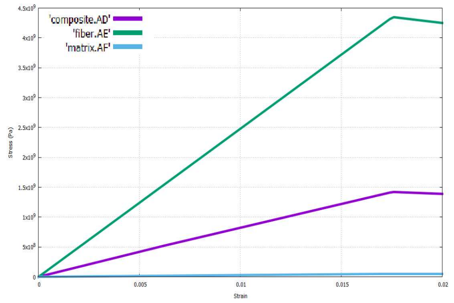
TASK: Development of numerical models

ADVANTAGES OF USE S/P MIXING THEORY

- **Any staking sequence, no matter fiber orientation or fiber volume fraction.**
- **Formulation is able to couple different fiber/matrix systems, different constitutive laws.**
- **Non-linear performance of the composite can be defined from its constituents.**





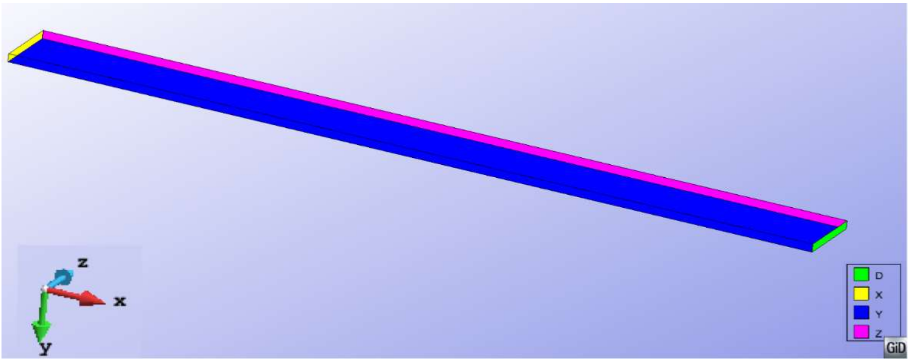


WHAT DATA DO WE REQUIRE?

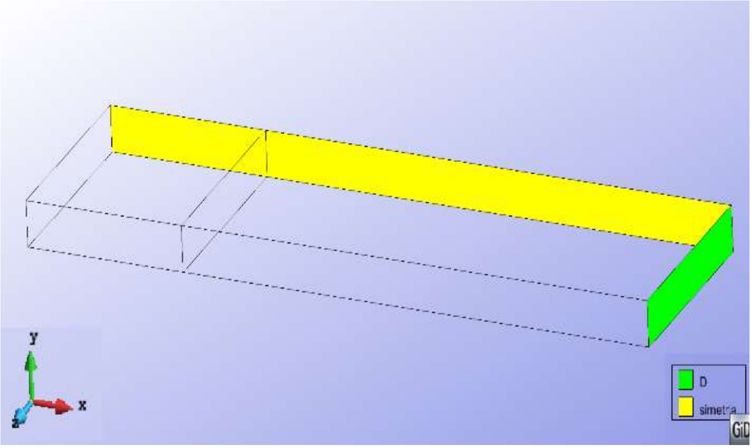
- **Stacking sequence of the laminate and volumetric participation.**
- **Elastic properties of the constituents.**
- **Non-linear properties of the constituents.**

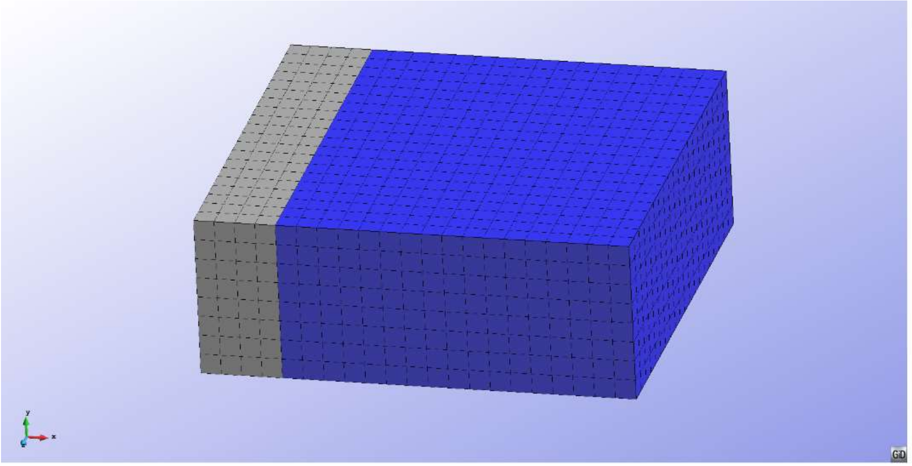
RESULTS. Numerical model

Tensile test model



Flexure test model



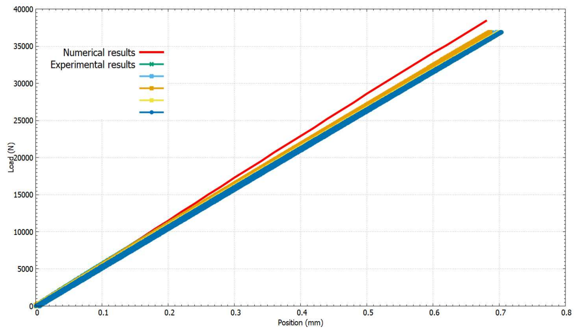


Shear test model

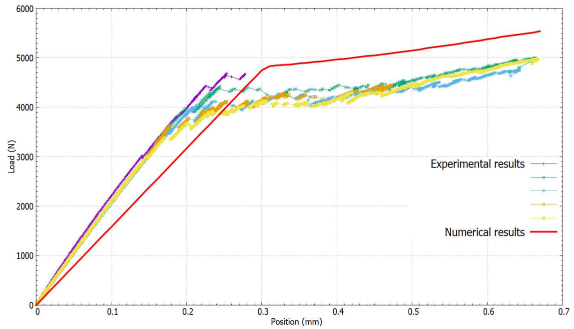
TASK: Development of numerical models

RESULTS. Load-Position curves.

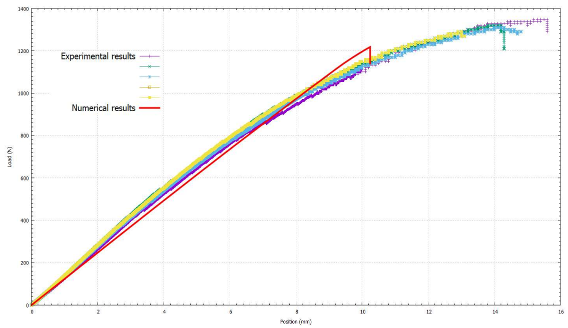
Longitudinal tensile test



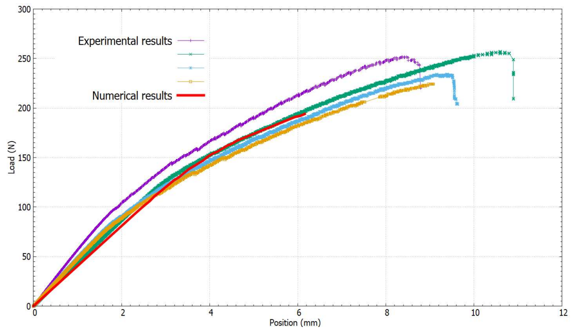
Transversal tensile test



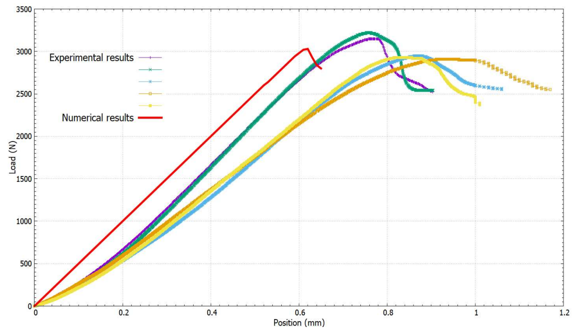
Longitudinal flexure test



Trasnversal flexure test



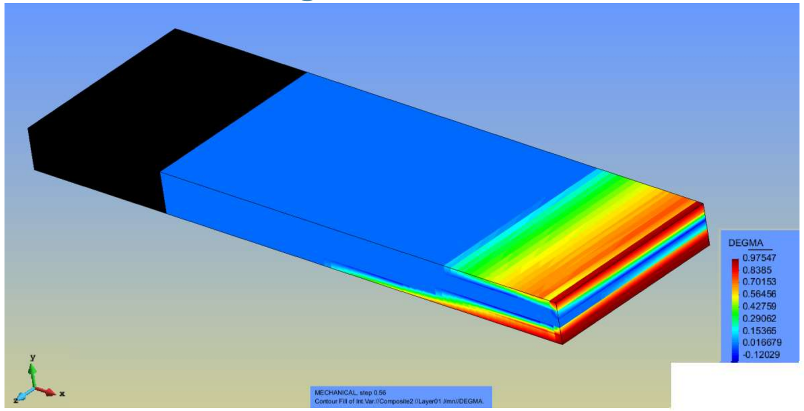
Shear test



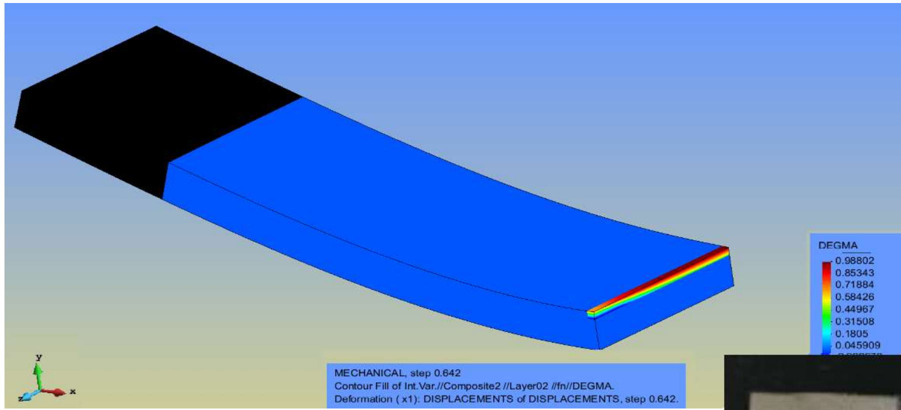
TASK: Development of numerical models

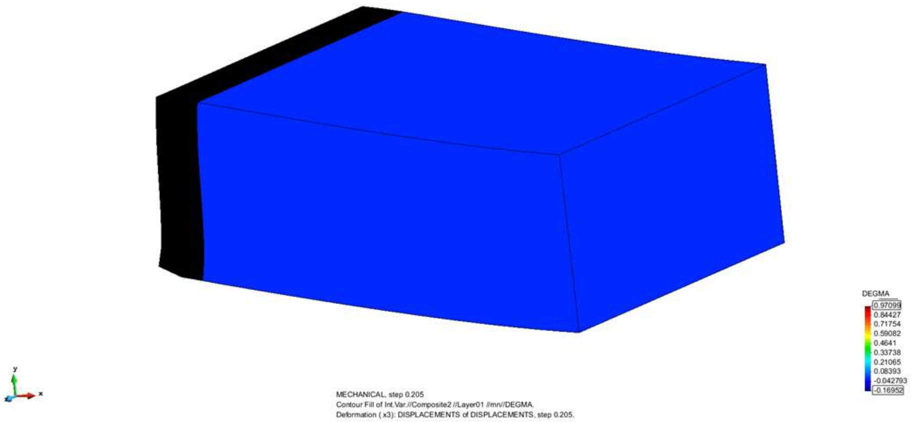
RESULTS FEM MODEL. Failure modes.

3P Bending in fibre direction



3P Bending perpendicular to fibre direction





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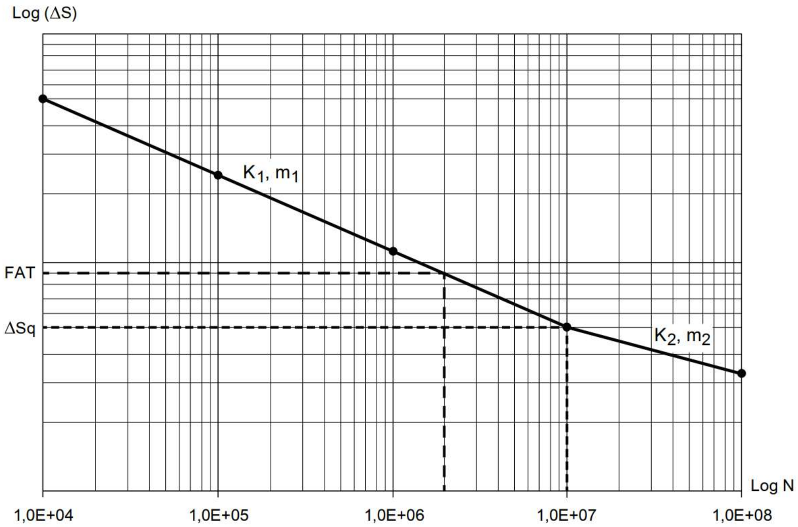
! A numerical simulation not only has to represent the global performance correctly, besides has to show the equivalent failure mechanism

FIBRESHIP INTEGRAL COMPOSITE SHIP

INTRODUCTION. Fatigue phenomenon

ASTM E1823 standard: *"The process of permanent, progressive and localized structural change which occurs to a material point subjected to strains and stresses of variable amplitudes which produces cracks which lead to total failure after a certain number of cycles".*



Importance of the fatigue in naval structures. Prove of it is the existence of specific rules on Class Societies

DNV-RP-C203 — DNV

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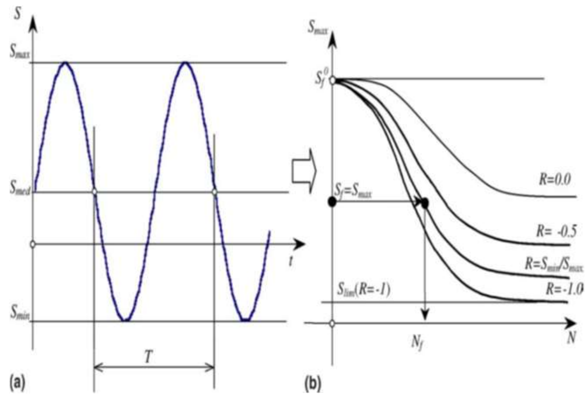
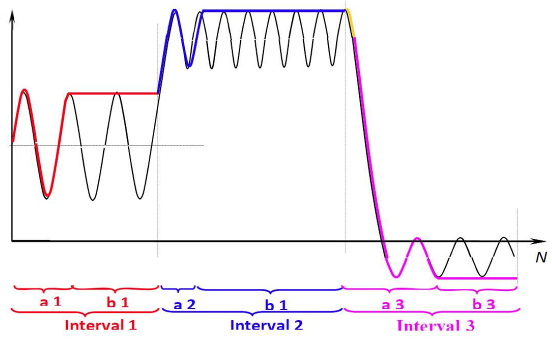
FATIGUE FORMULATION

- Fatigue damage formulation initially developed for metallic materials
- The constitutive law is modified by means of a reduction function, to account for the cyclic behaviour of the load.
- The formulation can take into account different block loading sequence.



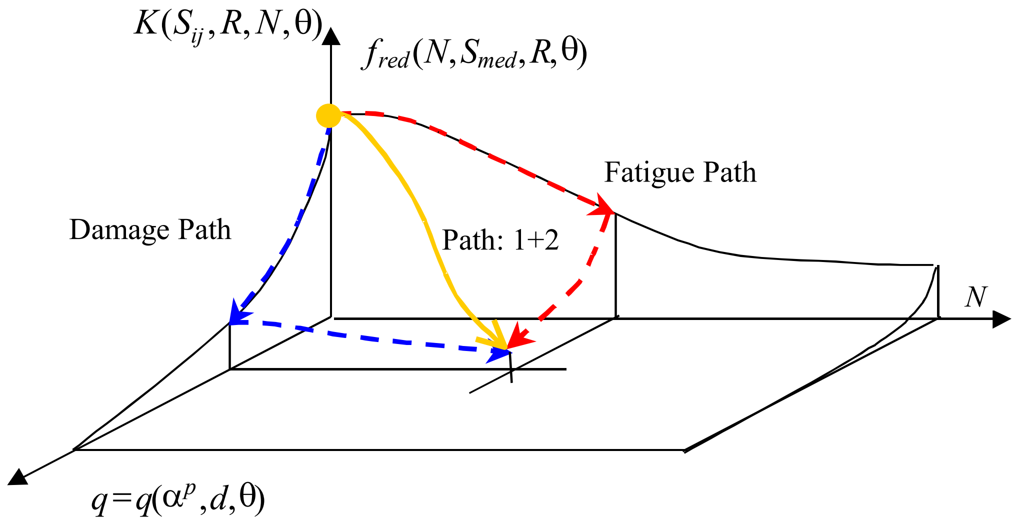


Non-fatigue constitutive equation: $f(\sigma) - K(\sigma_{th}) \leq 0$

Fatigue application: $f(\sigma) - f_N(N, \sigma_m, R) \cdot K(\sigma_{th}) \leq 0$

Influence of N_c strength reduction (HCF)

Influence of *Quasi-Static* strength reduction.



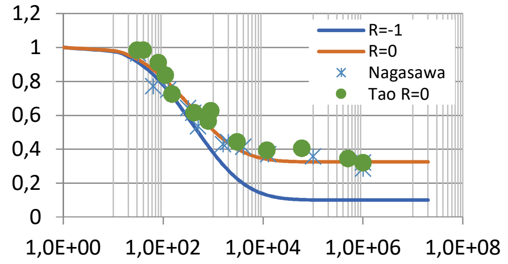
TASK: Fatigue performance of composites

ADAPTATION OF THE FORMULATION TO COMPOSITES

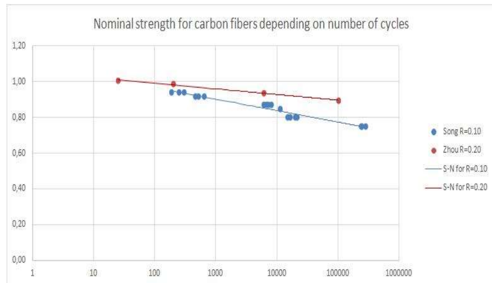
- Require to establish fatigue models for fibre and matrix.
- S/P Mixing Theory couples both materials to obtain fatigue behaviour of composite.
- **Fibre and matrix performance, both static and fatigue, are obtained by tests on UD laminates**.
    - UD loaded at longitudinal direction has a fibre-dominated performance.
    - UD loaded at transverse direction has a matrix-dominated performance.
- Failure of the laminate is supposed when damage appears on fibre for longitudinal ply.

FATIGUE MODELS

Constitutive law for matrix

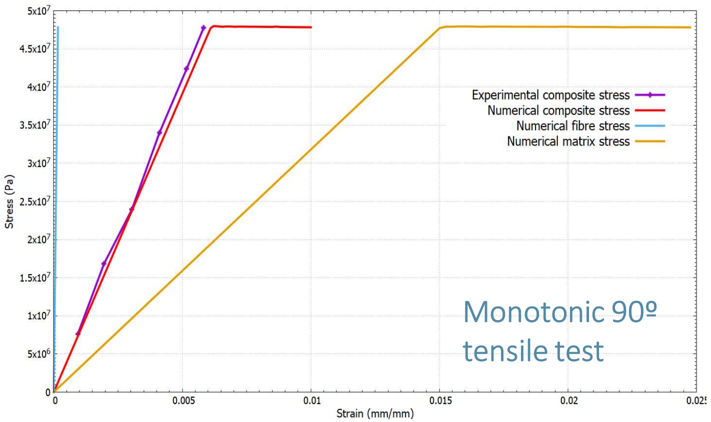


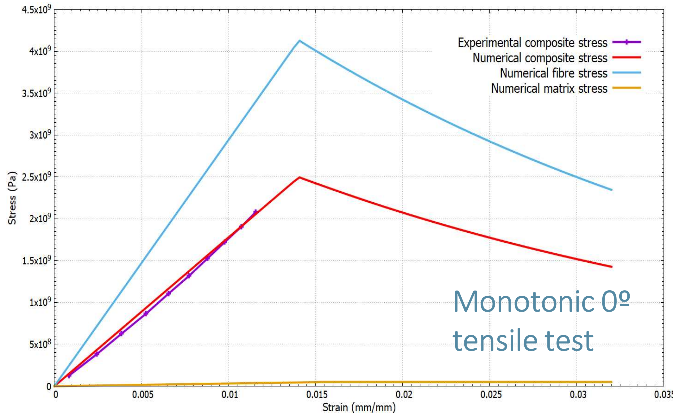
Constitutive law for fibers

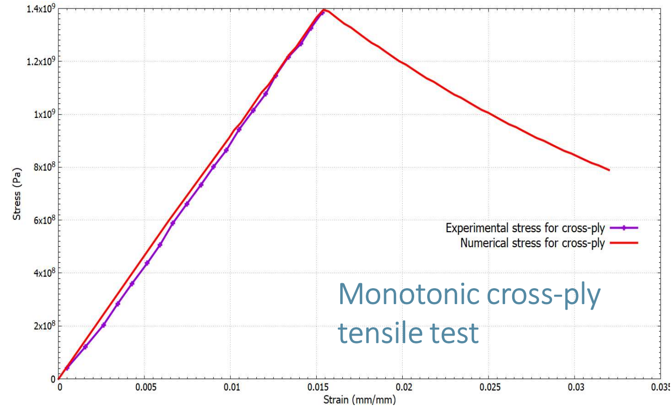


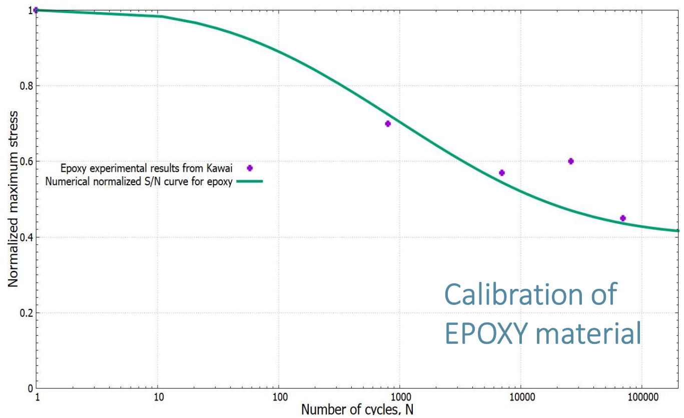
TASK: Fatigue performance of composites

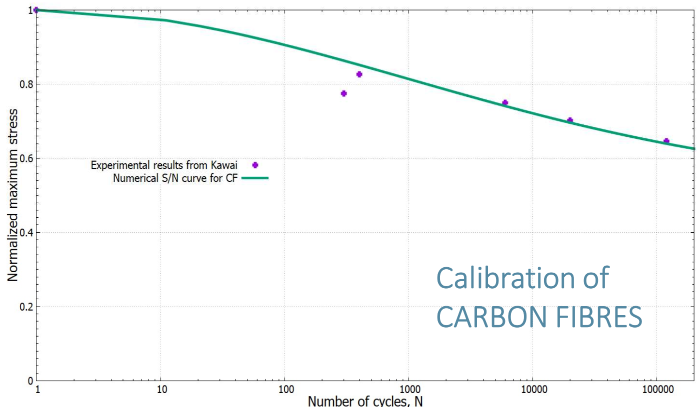
VALIDATION OF THE FORMULATION

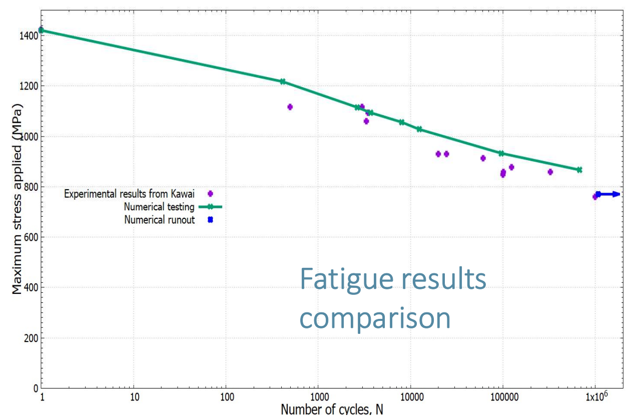








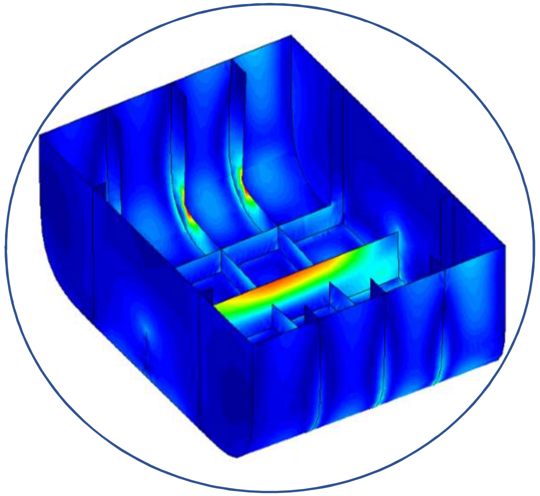


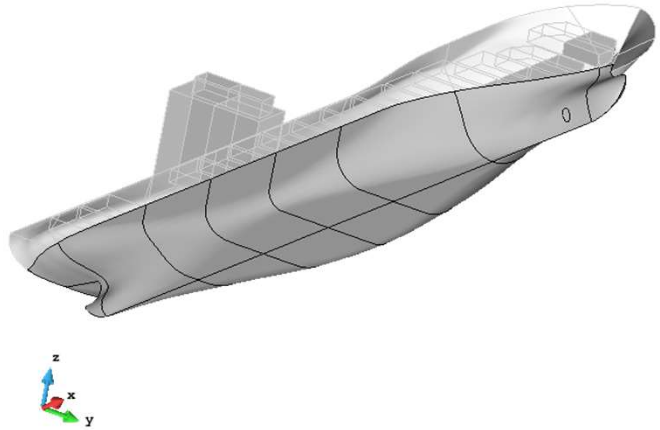


CONCLUSIONS ABOUT NUMERICAL MODELS

RELEVANT ASPECTS

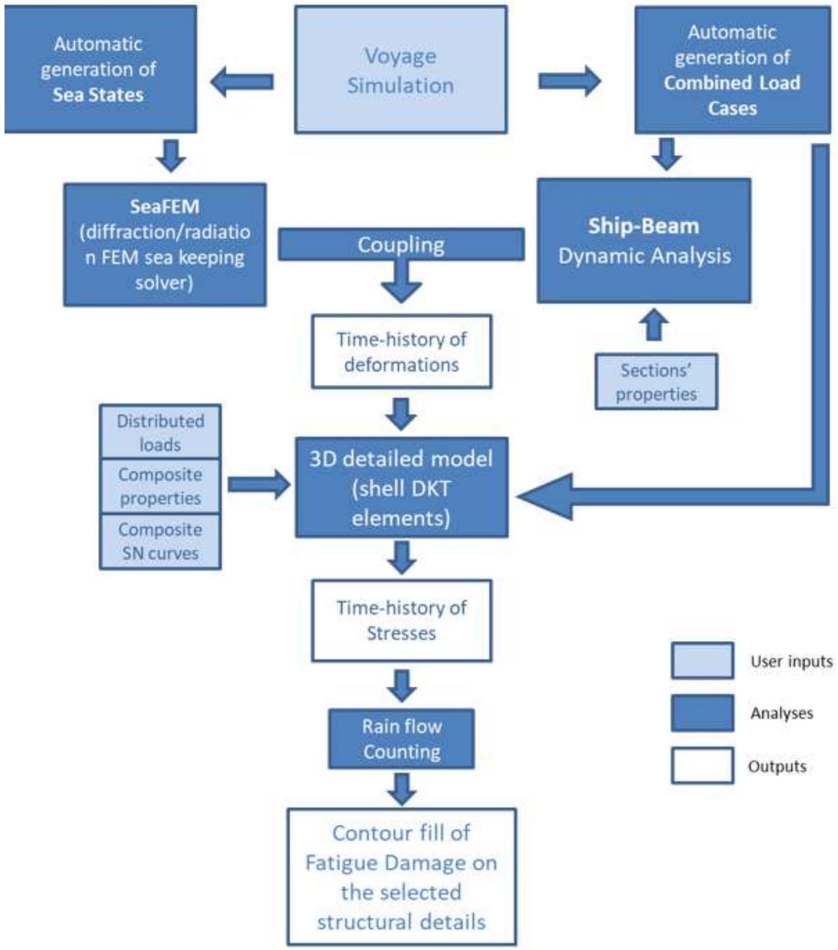
- Composite perfromance is obtained by means of fiber and matrix behavior, regardless fiber orientation or fiber participation, what reduces number of tests to be done.
- A process to calibrate the numerical model is constructed.
- Failure modes of the composite can be obtained.
- S/P Mixing Theory is compatible with known failure criteria (Tsai-Hill, first ply failure, etc).
- A composite fatigue model is introduced in order to simulate any kind of laminate.
- Better understanding of fatigue performance of composite structures.
- Reduction of uncertainty means structure optimization.

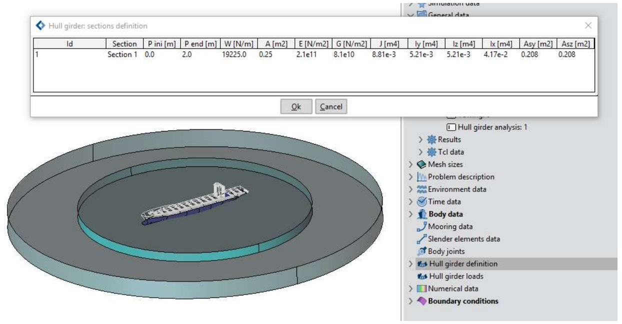


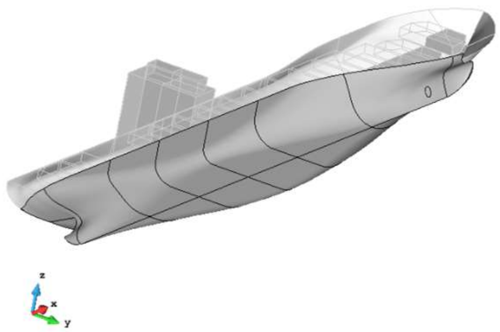


NUMERICAL TOOLS TO DESIGN AND ANALYZE FIBRE-BASED SHIPS OF LARGE LENGTH

Hull girder analysis tool

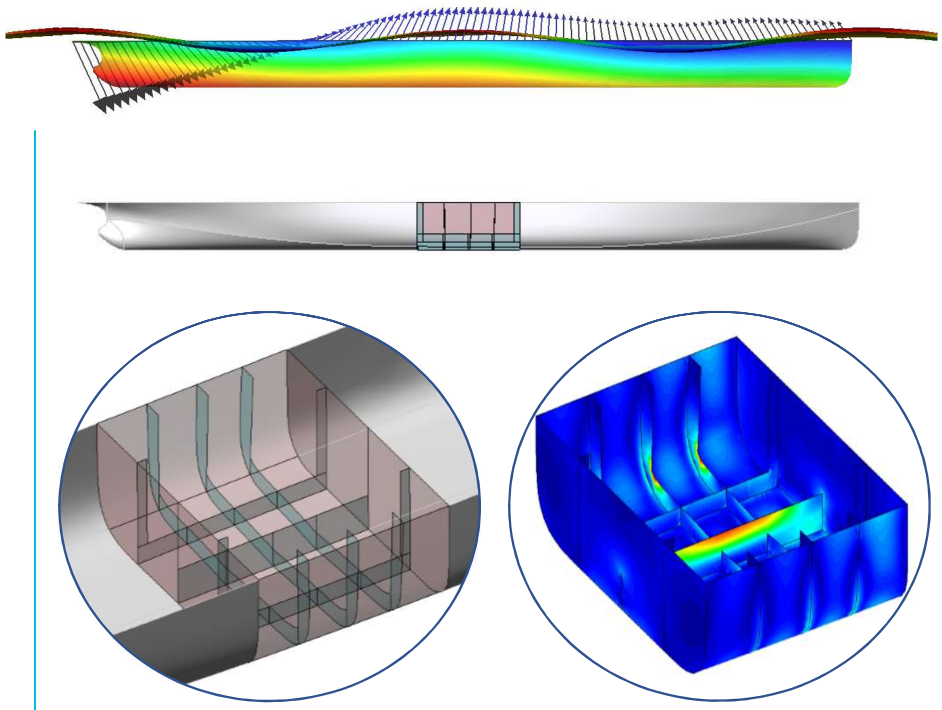






- ✓ **Hull girder model**: Simple 3D dynamic beam coupled with FEM seakeeping solver. It allows to analyse quickly long time series of the coupled problem.
- ✓ **3D detailed local model**: information from the hull girder model may be used to enforce the boundary conditions needed for a detailed analysis of a local ship structure.

Hull girder analysis tool



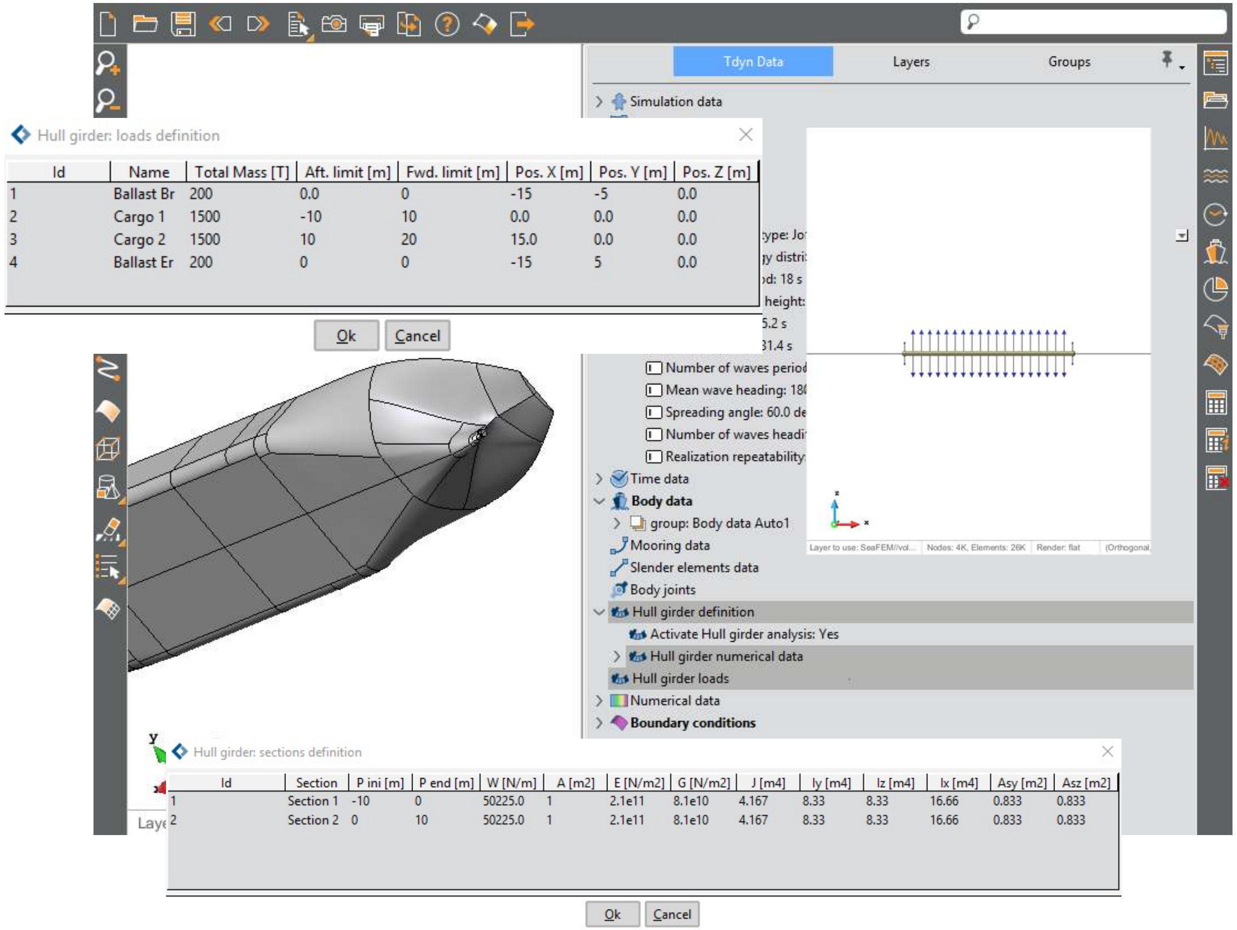
○ <u>Applied loads and boundary conditions</u>:

- Distributed cargo pressure loads must be specified
- Seakeeping wave load calculated during the hull girder analysis
- Enforce hull girder displacements at the end boundaries of the local section under analysis

○ <u>Results</u>:

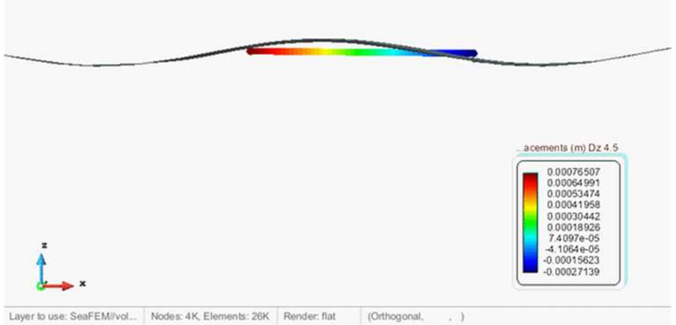
- Time history of local displacements and stresses in the detailed structure of the section under analysis

Hull girder graphic user interface

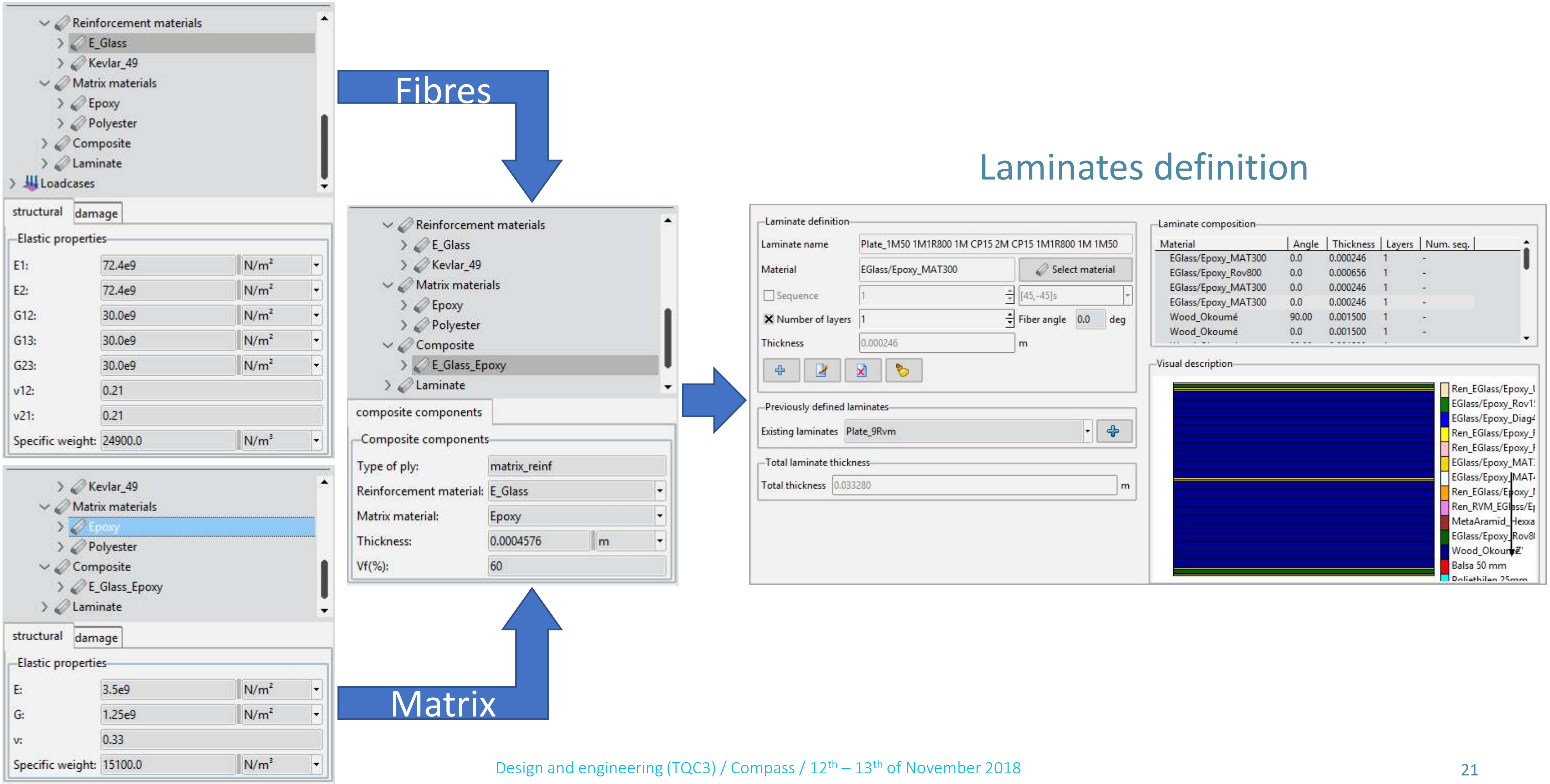


✓ A GUI has been implemented in RamSeries to allow for the definition of ship sections and cargo/ballast loads for the hull girder solver.

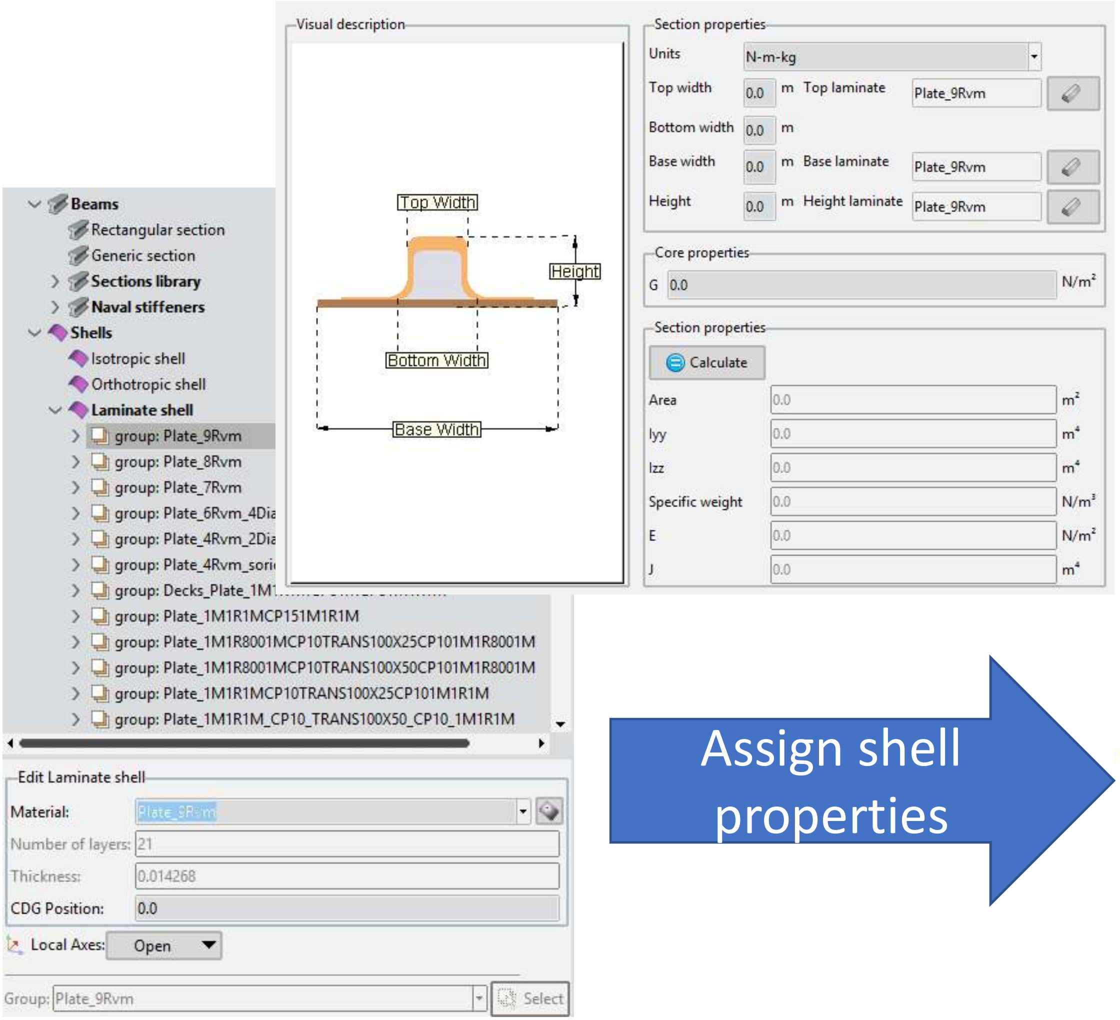
$$\left[\mathbf{M}\left[\frac{(1-\alpha_m)}{(\beta\Delta t^2)}\right]+\mathbf{C}\left[(1-\alpha_f)\frac{\gamma}{(\beta\Delta t)}\right]+\mathbf{K}(1-\alpha_f)\right]\Delta U = F_{ext}$$



GUI for the definition and assignement of laminates

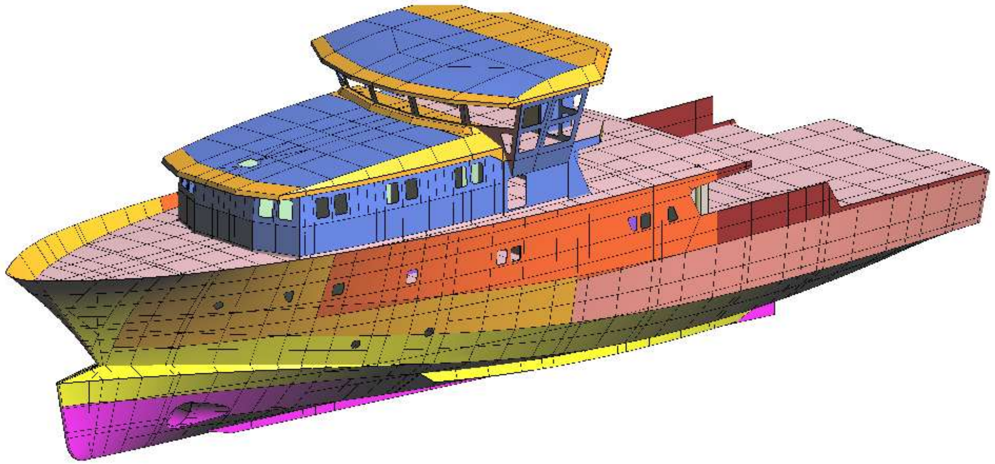


GUI for the definition and assignement of laminates



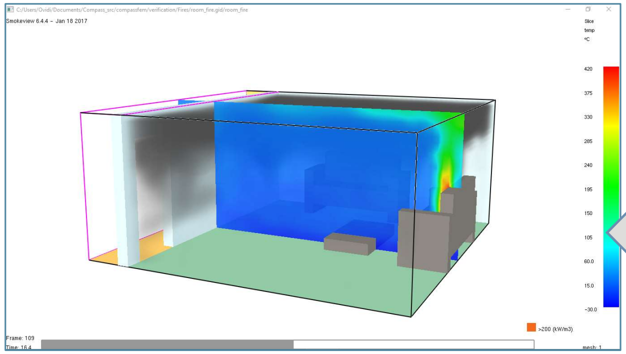
Assign beam

Assign shell properties



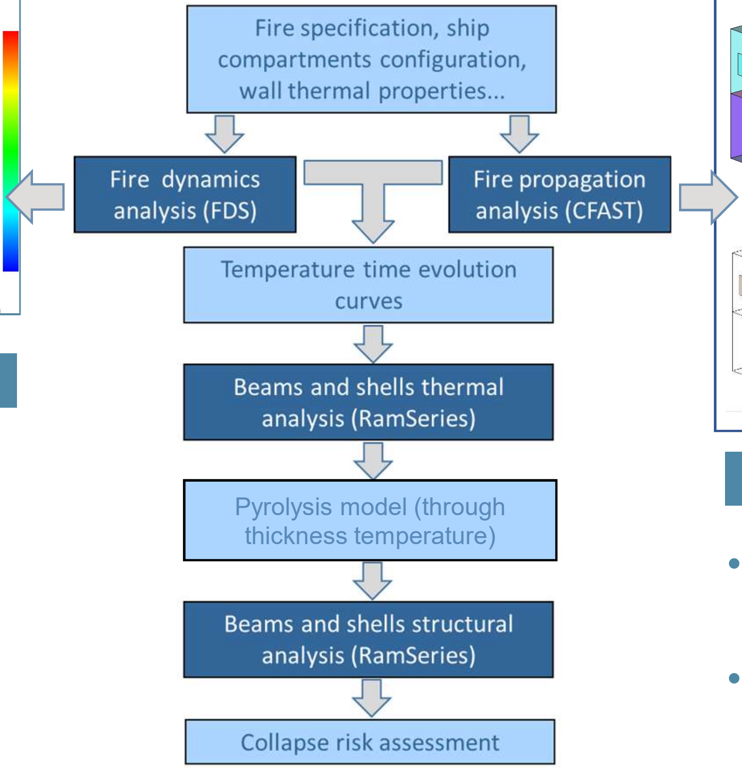
Coupled analysis for collapse assessment

- FDS GUI (based on GiD-Ramseries)

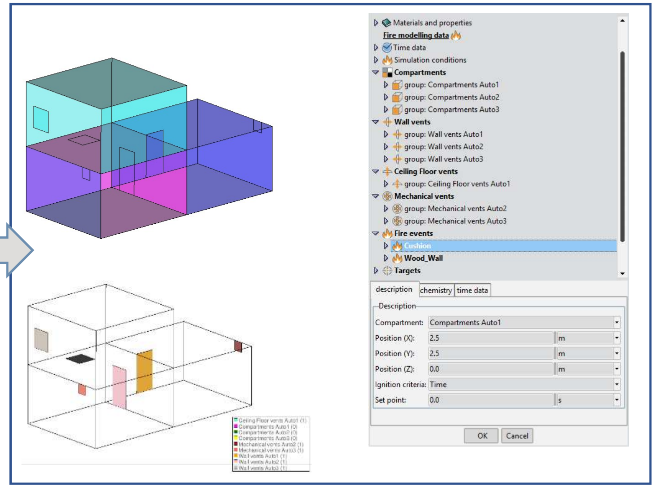


SOME CHARACTERISTICS

- New GUI tools allow to define the main namelist groups of FDS (obstacles, vents, reactions, fire events ...) directly in GiD-RamSeries and to run FDS solver.
- Geometrical information is shared with the structural model and can be used for the definition of the FDS model.
- Importation tools (STEP and IGES, including XML’s FORAN data)



CFAST GUI (based on GiD-Ramseries)

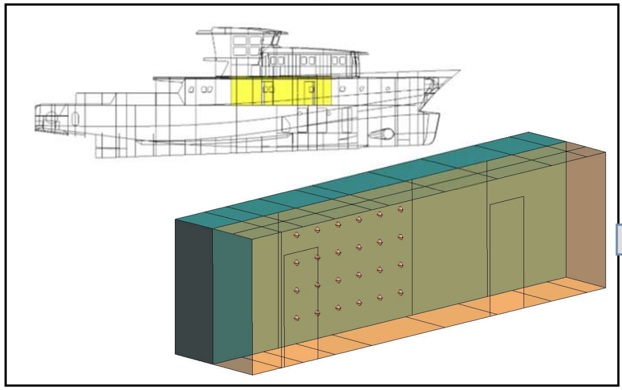


SOME CHARACTERISTICS

- New GUI tools also allow to define compartments, vents, fire events and targets directly in RamSeries and to run the CFAST solver.
- Geometrical information from the structural model can be used for the definition of the CFAST model if necessary..
- Importation tools (STEP and IGES, including XML’s FORAN data)

Coupled analysis for collapse assessment

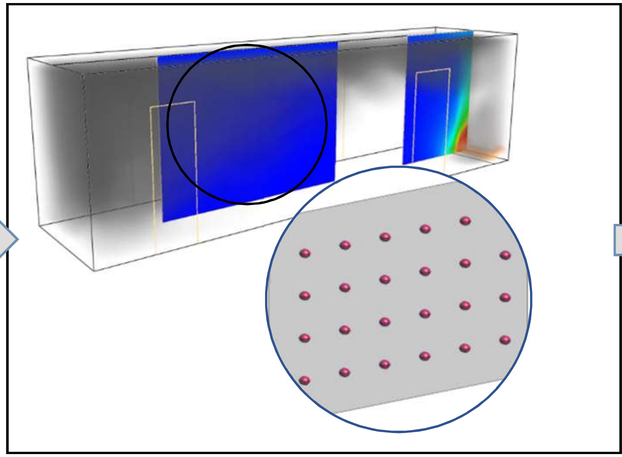
- FDS / CFAST GUI ()



SOME CHARACTERISTICS

- FDS: Temperature maps over structural components (beams, decks and bulkheads) are calculated
- CFAST: Two-zones temperature evolution is calculated.
- FDS/CFAST: Furthermore, time evolution of (adiabatic) temperature in a distributed network of control points

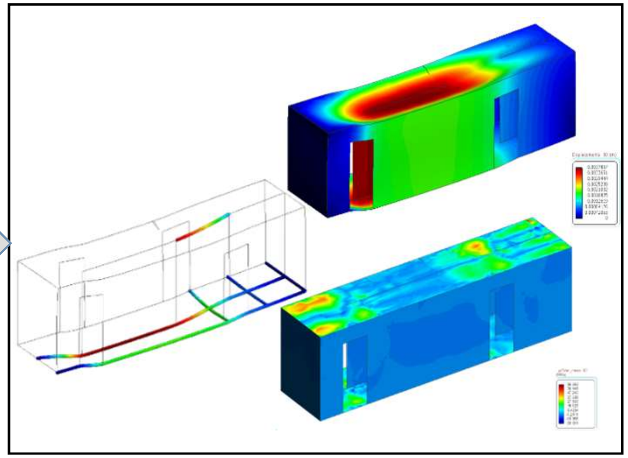
- 1D/2D Pyrolysis model



SOME CHARACTERISTICS

- Transfer temperature (heat flux) information from control points to the structural solver.
- The structural solver includes a pyrolysis model for composites (1D -through thickness- model for shell elements and a 2D model for beam elements), which calculated temperature distribution (per layer).

Thermo-mechanical analysis

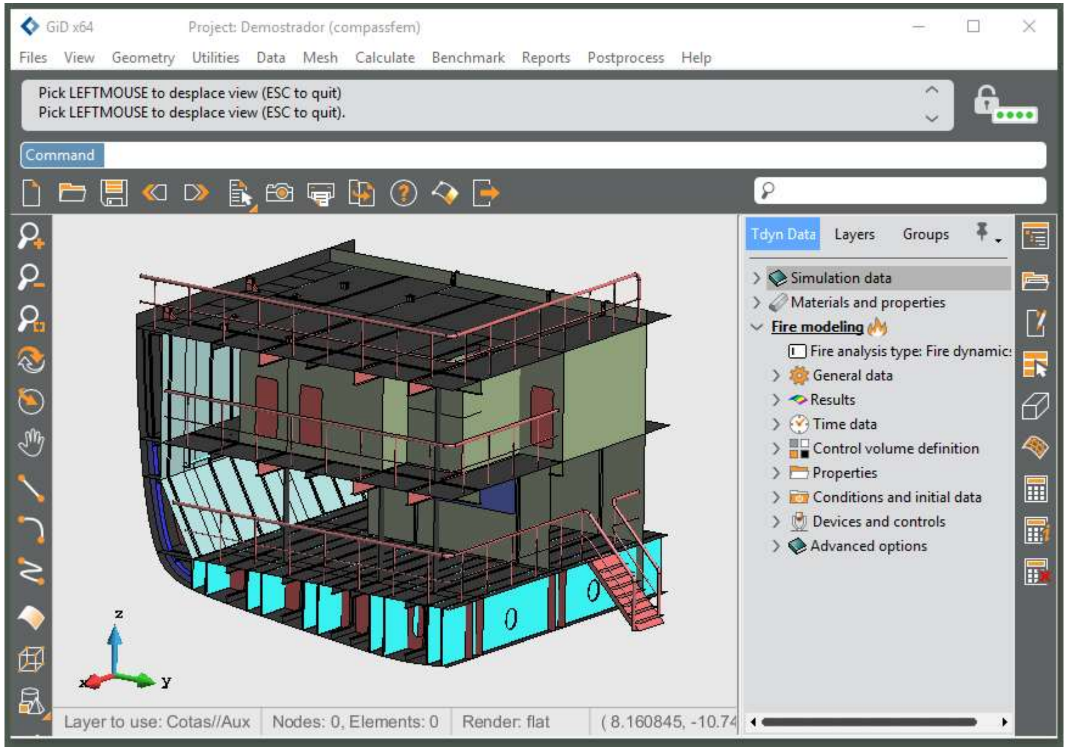


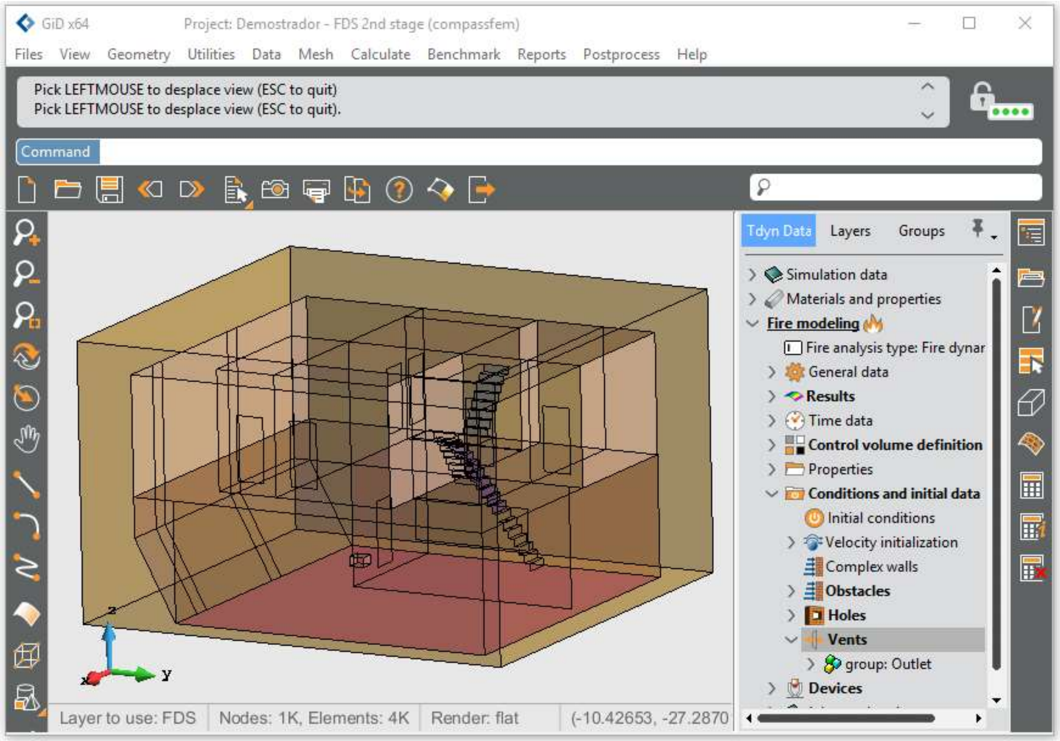
SOME CHARACTERISTICS

- Displacements, strains and stresses are calculated on structural components using a thermo-mechanical composites constitutive model (collapse of the structure is assessed).

Collapse assessment of complex and large structures

- Start the validation and demonstration of fire analysis tools by simulating a fire scenario in the FIBRESHIP's demonstrator of the fishing research vessel





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THANK YOU

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