Computational Analysis Tools

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## WP3 - Development and Validation of Numerical and CAE Tools

### Task 3.1: Development and tuning of a coupled Seakeeping-FEA analysis tool
- **Leader:** COMPASS
- **Foreseen Period:** M1-M24
- **Status:** Finished
- **Progress:** 100%

### Task 3.2: Implementation of the Inverse Finite Element Model Updating method
- **Leader:** CIMNE
- **Foreseen Period:** M1-M24
- **Status:** Finished
- **Progress:** 100%

### Task 3.3: Development of thermo-mechanical behaviour analysis and collapse assessment tools for laminated composite structures
- **Leader:** COMPASS
- **Foreseen Period:** M1-M24
- **Status:** Finished
- **Progress:** 100%

### Task 3.4: Validation and benchmarking for the software developments and applications
- **Leader:** COMPASS
- **Foreseen Period:** M13-M24
- **Status:** Delayed
- **Progress:** 60%

### Task 3.5: Demonstration of the developments and implementations
- **Leader:** COMPASS
- **Foreseen Period:** M13-M24
- **Status:** Finished
- **Progress:** 100%

### Task 3.6: Graphical user interface integration of the developments and implementations
- **Leader:** COMPASS
- **Foreseen Period:** M13-M24
- **Status:** Validation and testing
- **Progress:** 90%

### Task 3.7: Simulation tool version release, documentation and training
- **Leader:** COMPASS
- **Foreseen Period:** M13-M24
- **Status:** Validation and testing
- **Progress:** 90%
Constitutive model for FRP materials

Solution: Implementation of a new constitutive model for FRP materials (basic component)

Objectives: Integrate (within a FEM GUI) an advanced constitutive model for FRP materials based on the Serial/Parallel mixing theory (SP-RoM) & isotropic Kachanov-type damage (including model implementation and validation) & thermo-mechanical model & fatigue assessment model.

Components: GiD, Tdyn-Ramseries, SP-RoM model (new development).

Other characteristics: Usability (easy definition, local axes management, new groups management tools, ...).

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Constitutive model for FRP materials

Definition of FRP laminates

Laminates definition

Materials database (catalogue)

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Constitutive model for FRP materials

Definition of structural FEM model

Beam properties

Pre-processor (GiD-Ramseries)

CAD/CAM import tools (IGES / STEP + FORAN XML)

Definition of local axes

Shell / Solid properties

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• Wöhler (S-N) experimental curves are defined for parallel and serial directions (matrix and fiber).
• Rainflow counting-type algorithm (Miner’s Rule) is used to estimate the damage per ply.
• Damage estimate of the composite is evaluated based on the per-ply value.

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Solution: Fire simulation & collapse assessment tool

Objectives: Coupled computational analysis solution for fire and smoke propagation (fire dynamics and fire propagation) and collapse assessment of FRP composite structures (thermo-mechanical + pyrolysis + isotropic damage FEM).

Components: CFAST, FDS, GiD, Tdyn-Ramseries / Abaqus, S/P thermomechanical model + isotropic damage (new), 1D-2D pyrolysis model (new).

Other characteristics: Usability (included integrated GUI), Import/Export tools, Practicability (Fire propagation vs Fire dynamics).

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FDS GUI (based on GiD-Ramseries)

• 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)

• 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)
FDS / CFAST GUI

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.

Fire Dynamics

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

Displacements, strains and stresses are calculated on structural components using a thermo-mechanical composites constitutive model.

An isotropic damage model is used to assess the collapse risk of the structure.
Fire simulation & collapse assessment tool

La Ciotat / 24-26th May 2019

Example of application: Fire-resisting division test

Fire Dynamics

Pyrolysis model

The heat fluxes/adiabatic temperature are calculated in a set of control points on the bulwark deck.

An 1D/2D model calculates the temperature evolution through the panel/stiffener thickness and the pyrolysis of the polymer matrix.

\[ \rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} \right) - \frac{\partial}{\partial x} \left( \mu \frac{\partial T}{\partial x} \right) + \alpha (Q_e + h_e) \]

\[ \rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) - \rho_e C_{pe} \nabla \cdot \nabla T + \alpha (Q_e + h_e) \]

Characterization of materials properties is based on experimental tests (carried out by VTT)

Validation will be based on experimental tests (to be carried out by VTT and RINA)

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Solution: Full 3D hydroelastic (& non-linear) solver.

Objectives: To implement a coupled time-domain radiation/diffraction seakeeping analysis solver (2nd order) and dynamic FEM structural solver based on the SP-RoM constitutive model.

Components: GiD, Tdyn-Ramseries, Tdyn-SeaFEM, SP-RoM model (new), monolithic algorithm (new).

Other characteristics: Integrated GUI, Monolithic coupling, Import/Export tools.
Full 3D hydroelastic solver

La Ciotat / 24-26th May 2019

FEM structural solver data
- Linear / Non-linear dynamic solver
- SP RoM constitutive model

Hydroelastic solver
- Monolithic coupling

Importation tools
- STEP and IGES, including XML’s FORAN data

FEM seakeeping solver data
- Time domain
- 1st and 2nd order

Validation
- Validation to be done with the data gathered onboard Zim Luanda container ship (carried out by TSI)
Hull girder model + 3D FEM analysis

Solution:
- Hull girder model (basic component for fatigue assessment and health structural monitoring tools) + 1D to 3D FEM interface.

Objectives:
- To implement a time-domain coupled hull girder – seakeeping analysis tool (linear/non-linear – 1st order/2nd order) and a 1D to 3D FEM interface.

Components: GiD, Tdyn-SeaFEM, Tdyn-Ramseries, fatigue damage model (new), hydro-elastic model.

Other characteristics: Hull girder to 3D FEM model interface, Reduced computational cost, Usability (new GUI), Practicality.
Hull girder model

Definition of FRP laminates

- Automatic generation of Sea States
- Voyage Simulation
- Automatic generation of Combined Load Cases
- SeaFEM (diffraction/radiation in FEM seakeeping solver)
- Coupling
- Ship-Beam Dynamic Analysis
- Time-histories of deformations
- Sections’ properties
- Detailed 3D FEM model

3D Hydroelastic analysis

- Strength assessment

Hull girder model definition

- 1D to 3D interface
  - Transfer of (time-domain) seakeeping wave loads
  - Hull girder stresses / displacements are imposed at the boundaries of the 3D section under analysis
  - 3D FEM model offers local displacements and stresses using SP-RoM model

Coupled hull girder – seakeeping analysis

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Fatigue damage is estimated using a rainflow counting-type algorithm (Miner’s Rule) based on the SP RoM model.
Solution:

- Inverse Finite Element Updating Method (basic component).
- Structural health monitoring solution.
- Non-destructive testing tools.

Objectives:

- To implement an Inverse Finite Element (iFEM) Updating Method based on the SP-RoM + explicit Kachanov-type damage model.
- To develop a Structural Health Monitoring system for large-length FRP-based ships.
- To develop a non-destructive testing (inspection) for structural elements.

Components: RMOP optimization platform, GiD, Tdyn-Ramseries, SP-RoM model (new), monitoring system (new).
Inverse Finite Element Updating Method

Problem statement

• Damage zones: FEM model topologically / heuristically divided into zones
• Design variables: Average damage on the different zones
• Objective functions: weighted differences between measured and calculated frequencies:
  \[ f_{obj} = w_i \cdot (f_{ref,i} - f_i) \]
• Strategy: Minimization of the objective functions by means of Newton-based methods
• FEM solver: SP-RoM + explicit Kachanov-type damage model
• The iFEM model can be also applied to estimate damage maps based on different objective functions (such as displacements in control points)
Fire simulation & collapse assessment tool

Example of application: Quality assessment of a composite panel

Modal testing

- The natural frequencies of the structure are measured.

iFEM CAE model

- The iFEM model is created: FEM panel model + reference modal frequencies + a set of control points, defining the area of interest.

iFEM analysis / Quality assessment

- The model offers as a result an estimation of the damaged area of the panel.
Inverse Finite Element Updating Method

Structural Health Monitoring (SHM)

- Consist on:
  - A modal monitoring (testing) system
  - A model of the structure (global hull girder and local detailed models)
  - A processing unit (iFEM model)
- The collected data is used to feed the iFEM model, which estimates the damage map on the structure for the local detailed models
- The system is conceived to support decision making on maintenance plans

Non-destructive testing tools

- Consist on:
  - A portable modal monitoring (testing) system, including impact hammer.
  - A local model of the structural element (i.e. bulkhead)
  - A processing unit (iFEM model)
- The collected data is used to feed the iFEM model, which identifies possible defects in the structural element
- The tool is conceived for quality control and inspection on structural elements
### Computational Analysis Tools

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- Beta version of the different computational solutions already available.
- First training course scheduled.
- Final versions (validated tools) to be delivered by September 2019.
- Validation based on a three-tier approach: small, medium and large scale experiments.
- Demonstration on the three targeted vessels by January 2020.
THANK YOU

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