Application of the Global Influence Superposition (GIS) Method for High-Speed Structural Assessment of Floating Wind Turbines

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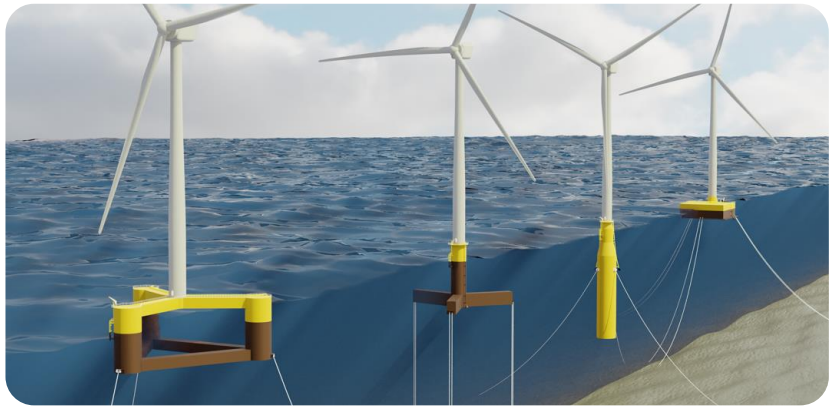
EERA DeepWind 2025

RAMBØLL

Floating Wind

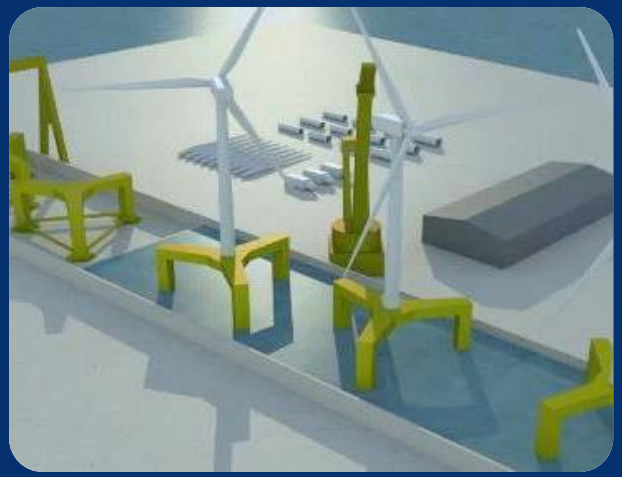
18,500 employees
700+ Wind Experts
Offshore since 1989
Involved in **70%** of all OFW projects

- Consultancy (Technical, Commercial, Strategic)
- Design and Engineering
- Owner's Engineer & Technical Due Diligence TDD+
- Logistics, T&I, Ports Assessments and Studies
- Asset and Structural Integrity Management
- Site Screening, Surveys, Investigations



- Since 2007, Ramboll provided consultancy services in 100+ commercial and R&D floating wind projects in engineering and advisory.
- Ramboll is an **independent engineering consultancy**, not focussed on a single concept or technology.
- Ramboll is **not developing an own proprietary floating substructure** design but has full design capabilities to support clients.

Ramboll combines independent detailed offshore knowledge of floater, moorings, cables with an in-depth understanding of wind turbine dynamics and project development, logistics, T&I, financing, strategy and risk experience from large offshore wind projects.



Why do we need highly efficient structural design processes in floating wind?

- Increased **complexity** in floating wind projects.
- The **foundation package** and related engineering activities are often on the **critical** path.
- For the **design works** it is key to:
  1) minimize durations
  2) minimize design risks

Early Design Stages:

- Good accuracy in analysis and pricing to **de-risk** project.
- Tight schedule.

Efficiency required

FEED/Detailed Design stages:

- High accuracy **required by Rules** & Contractually binding pricing
- Large number of DLCs and checks.

Efficiency required

How to get efficiency?

Analyses chain in 3 steps:

1. Global response analysis (ILA)

- Mios of time steps
- Efficient tools exist
- No structural model

2. Load transfer to FE (Load mapping)

- Mooring, interface loads
- Wave pressures
- Tank loads

3. Structural verification

- FE model
- Code checks: ULS, FLS, Buckling, etc.

- Different approaches to 2+3 have been proposed.
- Methods based on **Unit Load Cases** (ULCs) offer best balance between **speed and accuracy**.
- Allow to calculate stresses for **all time steps** in the **entire structure**.

Unit load methods, re-cap

FEA: **Unit loads in FEA** (global model) → **Unit responses** (e.g. stress tensor) *one small set, independent on time step and DLC*

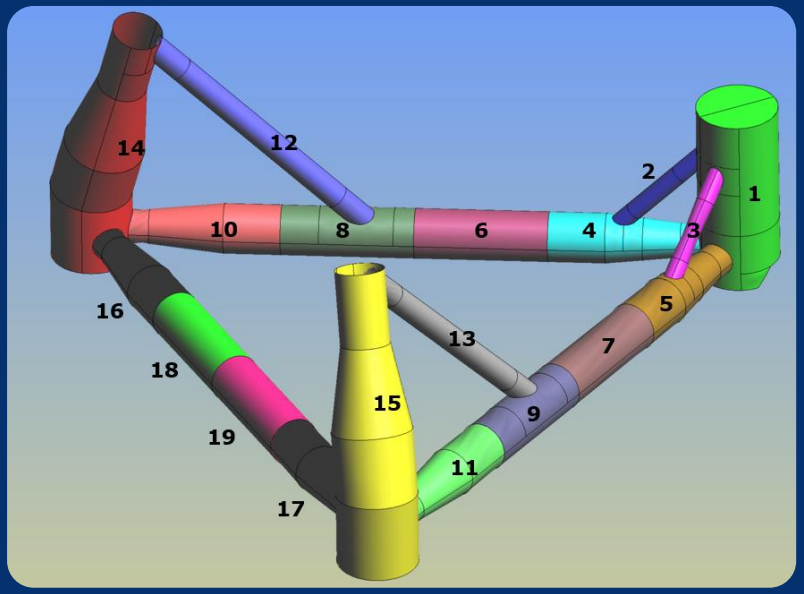
ILA: **Multiplicators** (scaling factors) *time series over all time steps of all DLCs*

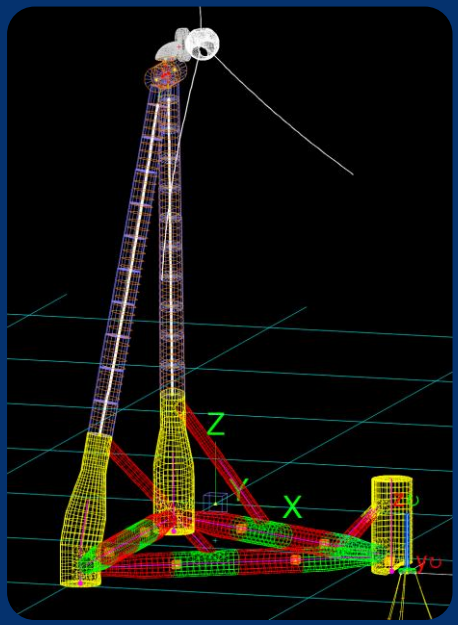
Structural response at any time step = **Σ Unit responses · Multiplicators**

GIS principles

- **GIS**: Global Influence Superposition.
- Developed by Ramboll over several years and applied in ongoing FEED/DD projects.
- Combination of OrcaFlex + ANSYS/LUSAS + In-house tools.

- **OrcaFlex segmented model:**
  - Multi-body model of hull with fine segmentation.
  - Allows to directly extract integrated hydrodynamic loads on each segment.
  - Provides good understanding of how the hydrodynamic loads are distributed.





Example model of the Brunel structure.

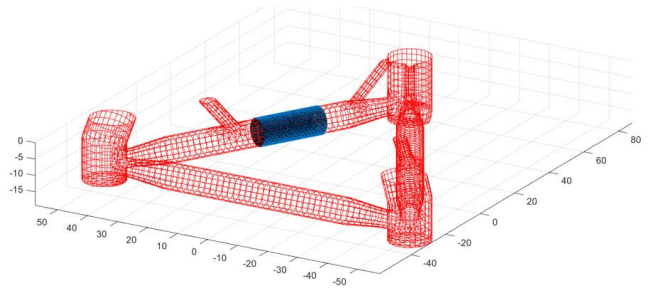
GIS principles

From integrated segment loads to pressures (load mapping)

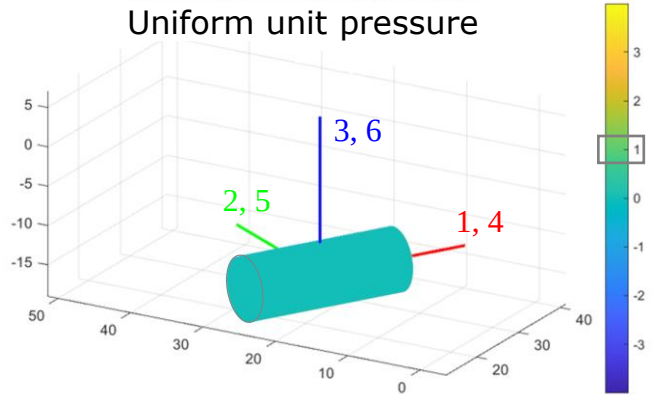
- Generalized pressure patterns on hull segments.
- Simplified way but good accuracy through superposition of:
  - pressure fields with uniform pattern
  - pressure fields with gradient pattern

These pressure ULCs cover:
- 1st order diffraction loads
- 2nd order wave loads
- Drag loads
- (Radiation loads)

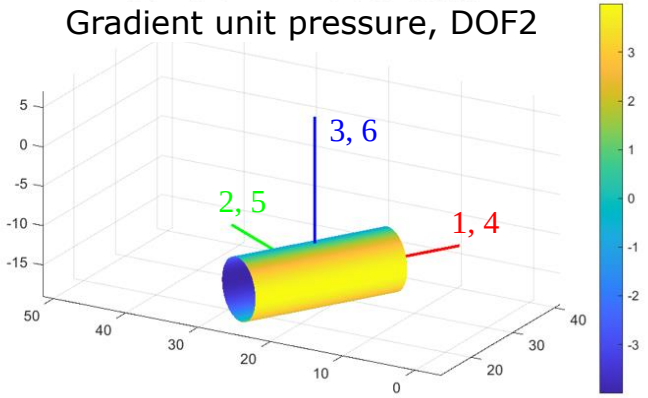
Segment



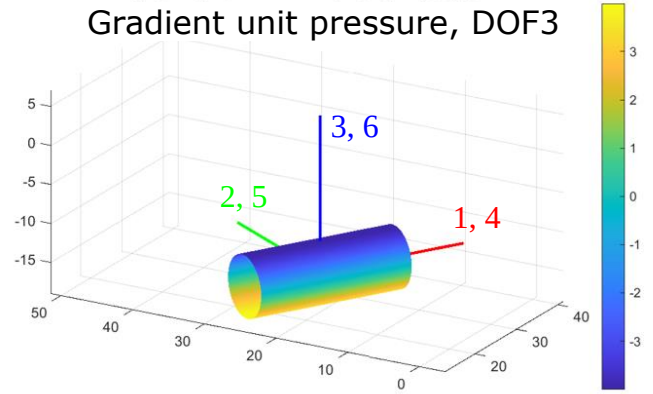
Uniform unit pressure



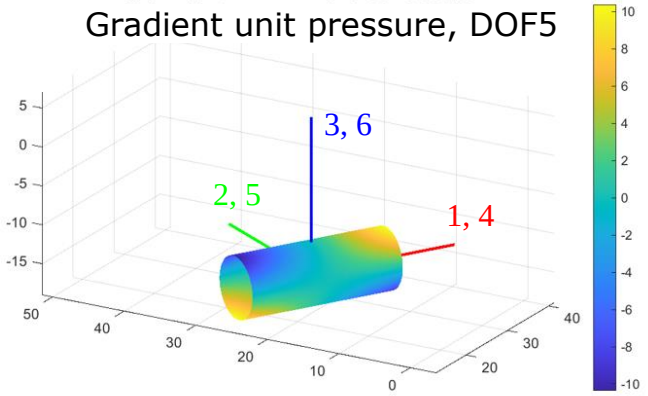
Gradient unit pressure, DOF2



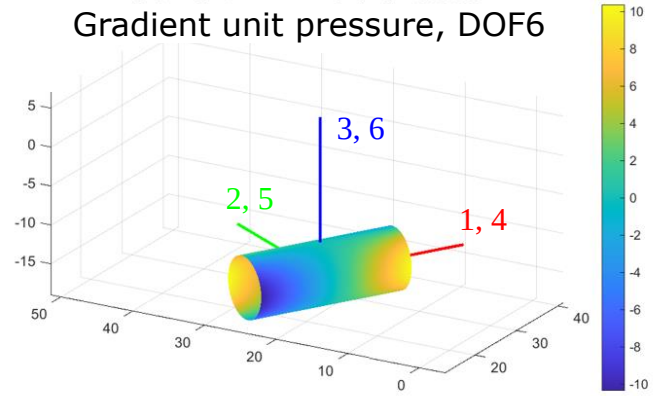
Gradient unit pressure, DOF3



Gradient unit pressure, DOF5

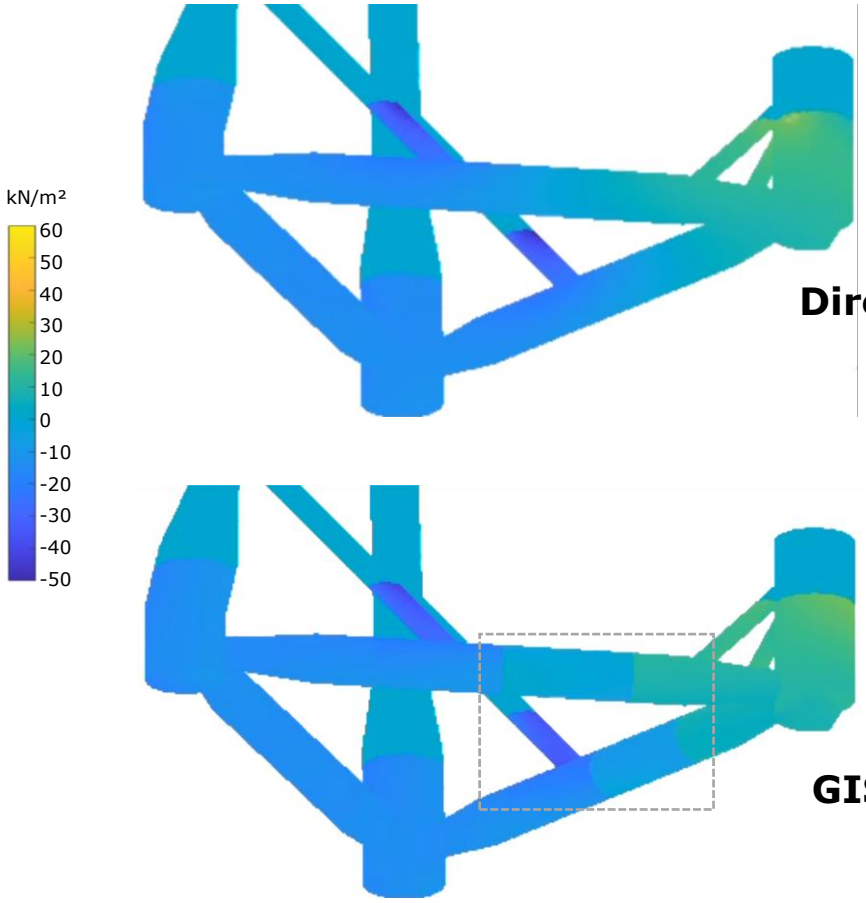


Gradient unit pressure, DOF6



GIS verification

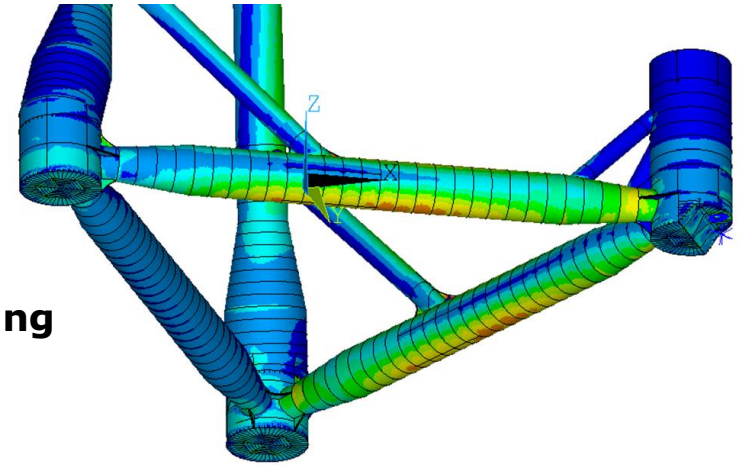
Pressure pattern verification
(diffraction + radiation pressures)



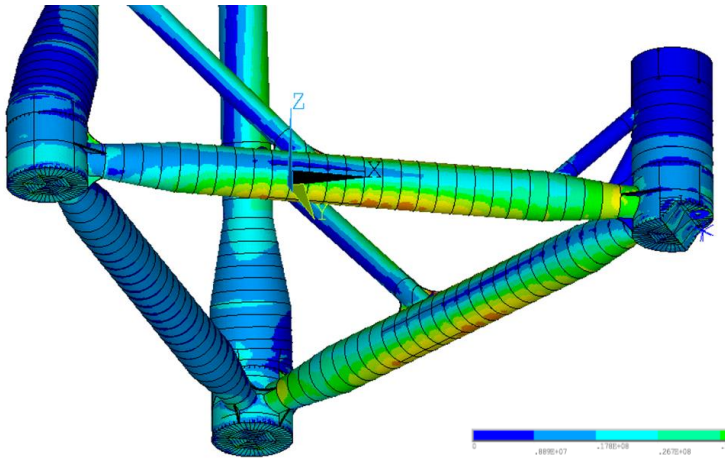
Direct Load Mapping

GIS method

Stress verification



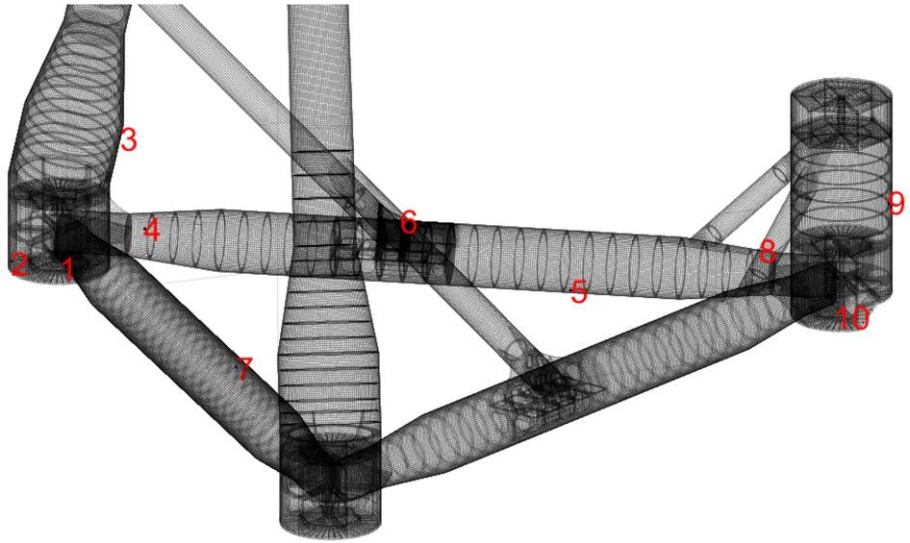
Von Mises stress based on loads from Direct Load Mapping



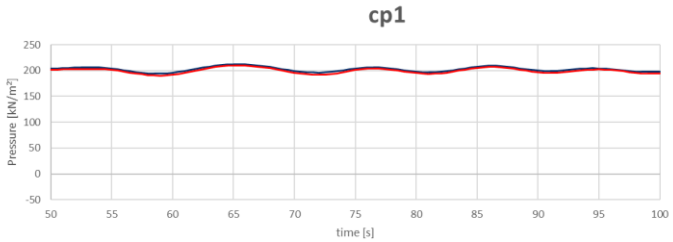
GIS method:
Von Mises stress calculated by superposition of unit stresses, multiplied with scaling factors (multiplicators).

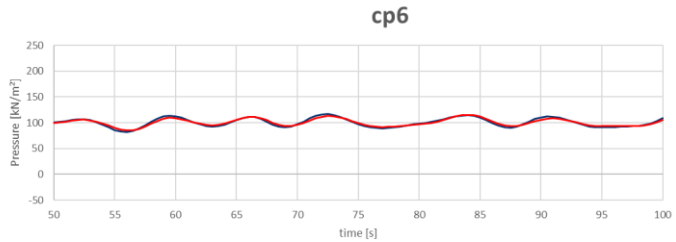
GIS verification

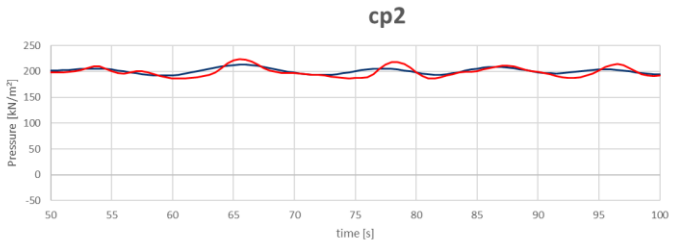
Pressure time series at control points

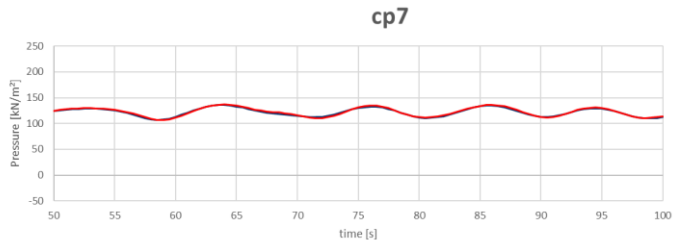


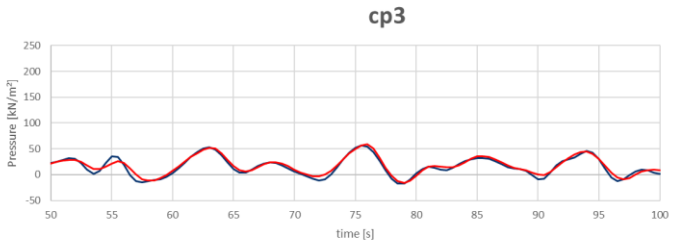
Direct Load Mapping
GIS

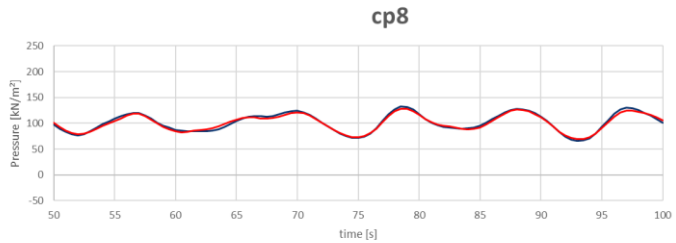


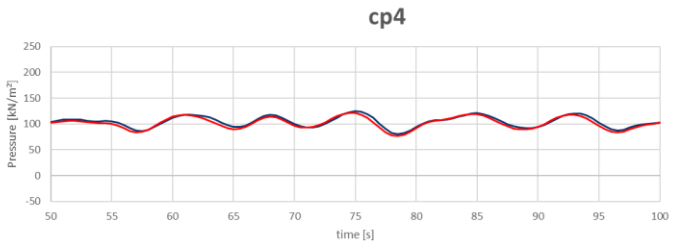


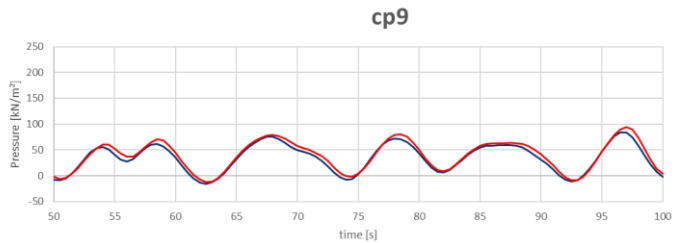


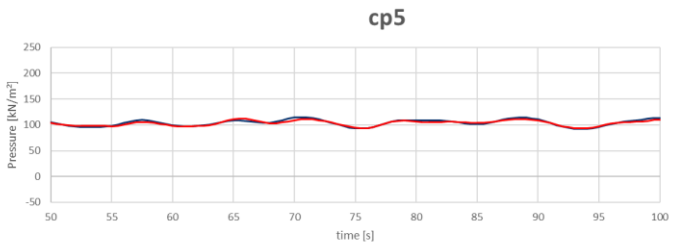


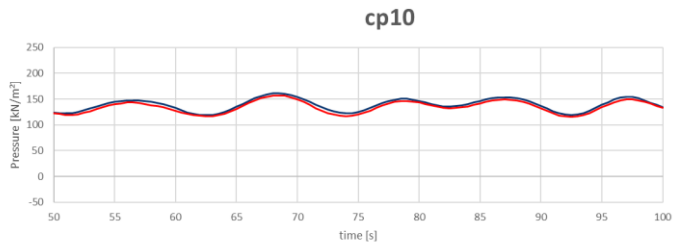












On the importance of load balance

1. ILA > **2.** Load mapping > **3.** Structural verification

- In the ILA (1) all the forces are in balance by nature of dynamic simulation.
- During load mapping (2) it is crucial to **transfer all the loads** from ILA to FE.
- Easy load balance check: **support reactions in FE = 0**

ILA: Relevant load contributors:

- Hydrodynamic pressures: diffraction + radiation + 2nd order + drag
- Hydrostatic pressures
- Wind pressures
- Interface loads: tower bottom + mooring
- Tank pressures
- Accelerations: gravity + rigid body dynamics + (structural dynamics)

Dynamic load balance > FE: Zero support reactions

Good load mapping

- All available load components captured
- Holistic view: sufficient accuracy in **all** components

GIS performance

Due to **limited number of ULCs** the reconstruction of stresses is **very fast**.

Example:

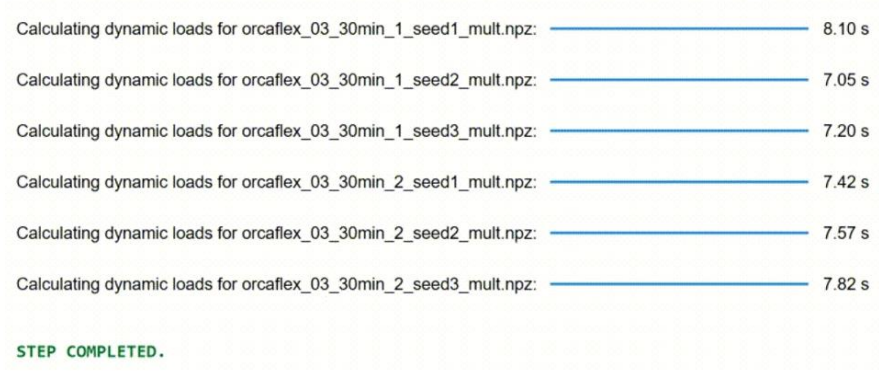
- FE mesh: **360742 elements**
- Envelope **von Mises stress** at top layer
- Calculation based on **160 ULCs**
- 6 simulations, **30 mins** each
- Time step: **0.1 sec**
- Average calculation time: **7.5 sec**
- **0.0004 sec per time step**

FEED ILA

*2000 simulations, 3h each, would take **25 h***

Machine

- *CPU: Intel® Core™ i7 2.50 GHz*
- *RAM: 64.0 GB*
- *GPU: Nvidia RTX A3000*
- *OS: Windows 10*



Overall process efficiency

1. Global response analysis (ILA)

- Mios of time steps
- Efficient tools exist
- No structural model

2. Load transfer to FE (Load mapping)

- Mooring, interface loads
- Wave pressures
- Tank loads

3. Structural verification

- FE model
- Code checks: ULS, FLS, Buckling, etc.

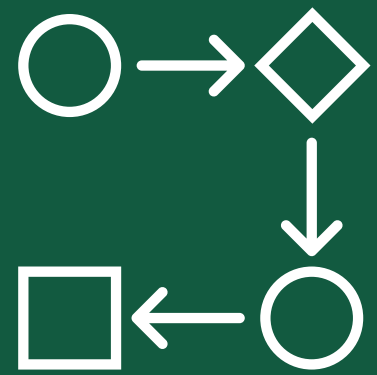
- Post-processing must be **time efficient** to not create a bottle neck in the overall performance.
- Post-processing must be **integrated** into the stress calculation process.

Efficient post-processing tools are key

GIS post-processing

- **Envelope solutions** for ULS checks, e.g.:
  - von Mises stresses for steel yield check.
  - principal stresses, stress components, for different concrete checks.
  - stress components in certain areas (plates) as input to steel buckling checks.
  - partial load factors and seed-averaging included.

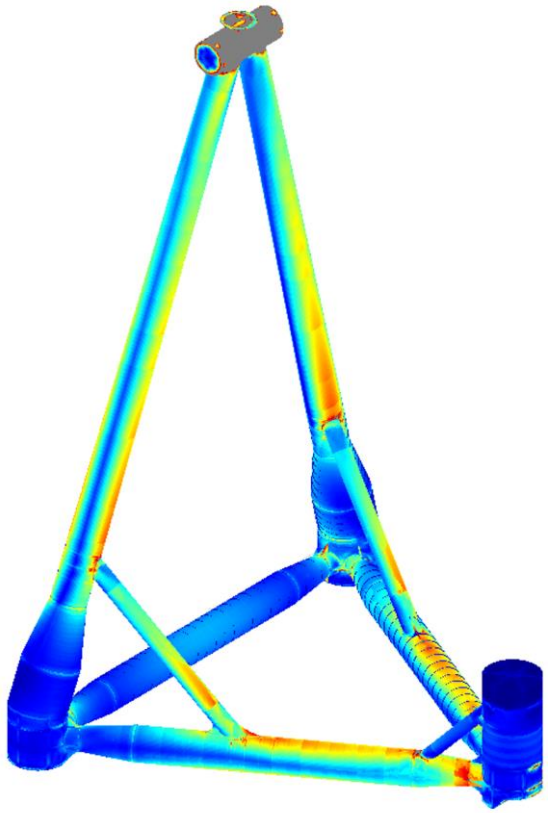
- Stress **time series** and rainflow counting for FLS checks.



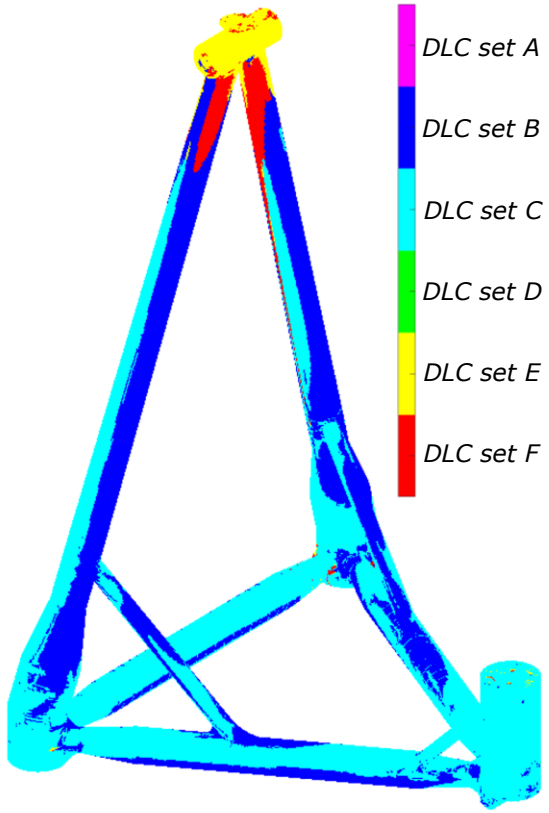
GIS tools

GIS post-processing: steel structure (Brunel example)

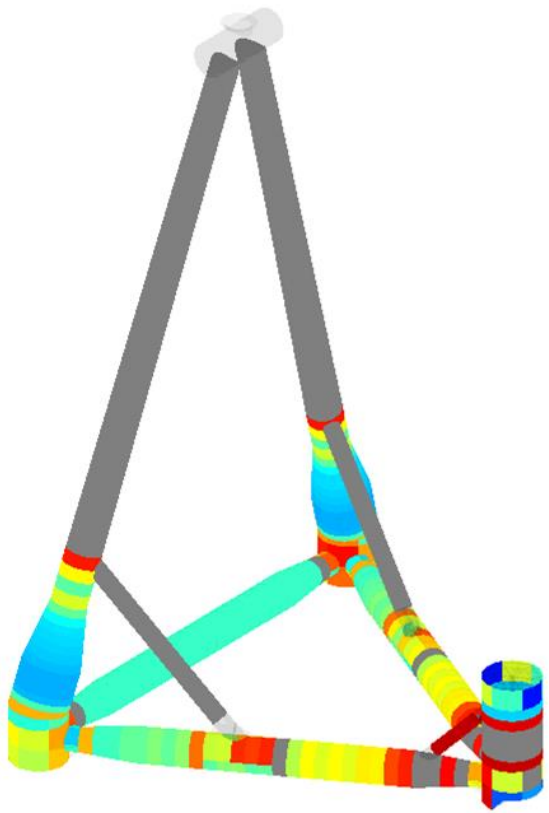
Envelope von Mises Stresses incl. load factors and seed-averaging



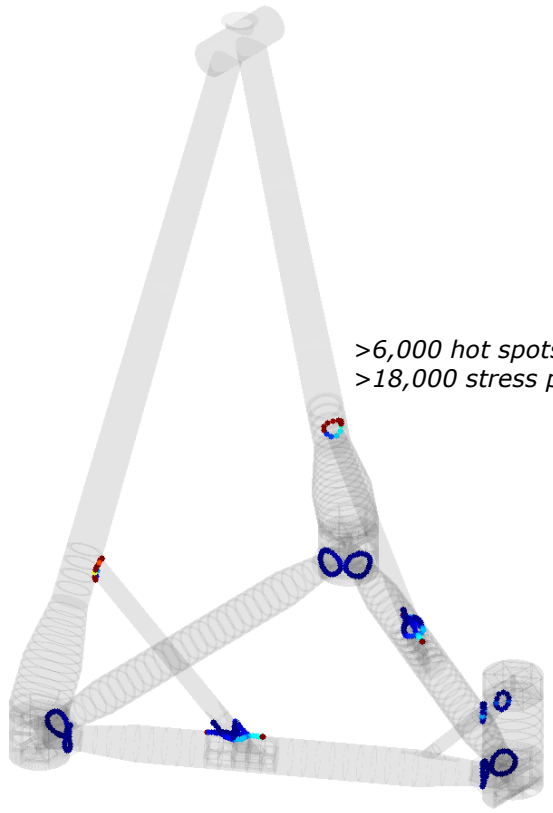
Governing DLCs



Shell/plate buckling check



Fatigue damages



Example results, not necessarily representing the final Brunel FEED structure.

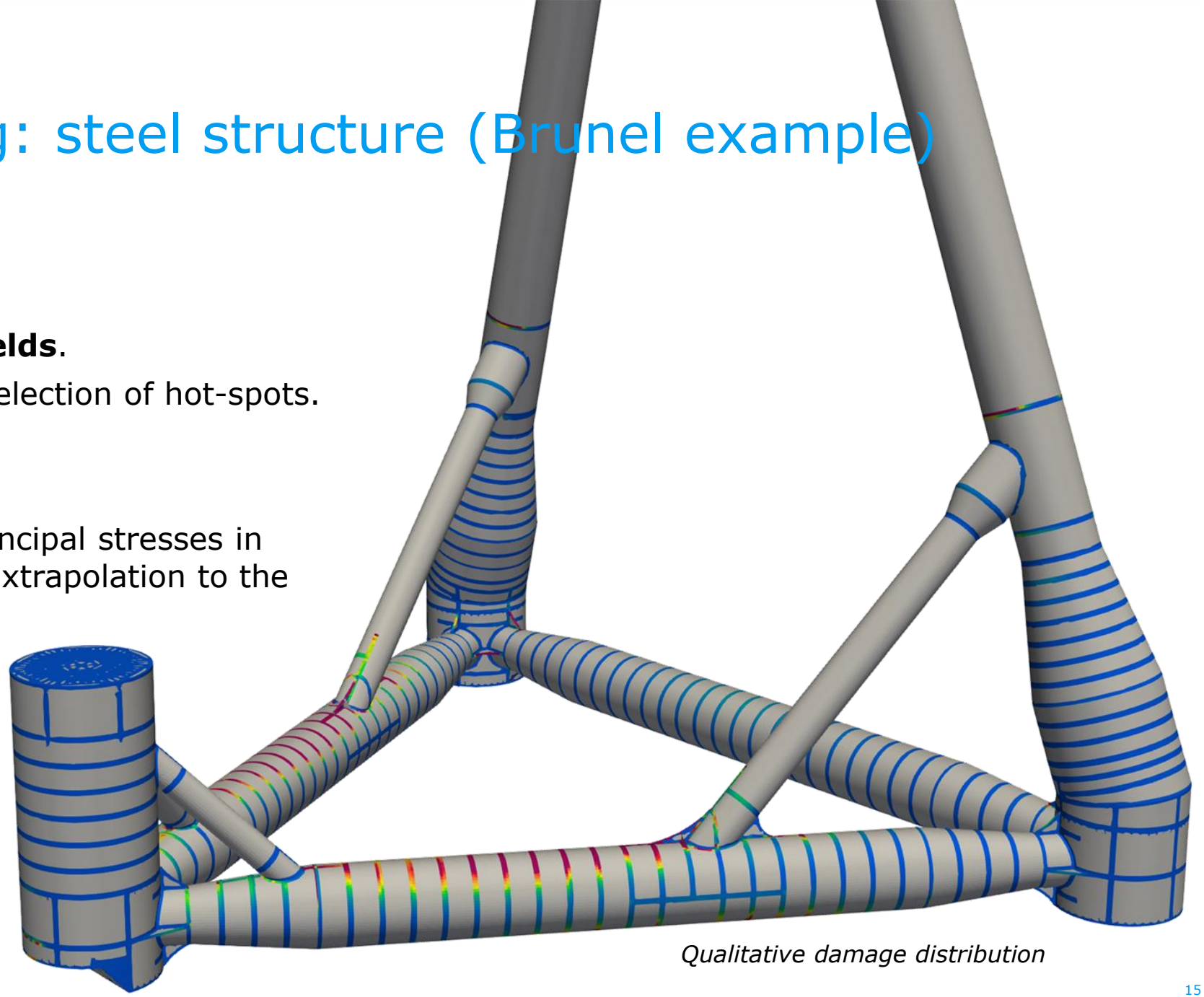
GIS post-processing: steel structure (Brunel example)

Fatigue screening

- Simplified FLS analysis for **all welds**.
- For qualitative assessment and selection of hot-spots.

Simplifications:

- Based on rainflow counting of principal stresses in elements adjacent to welds (no extrapolation to the weld).
- One representative SN curve.



Qualitative damage distribution

GIS post-processing: concrete structure

ULS/SLS

Envelope solutions:

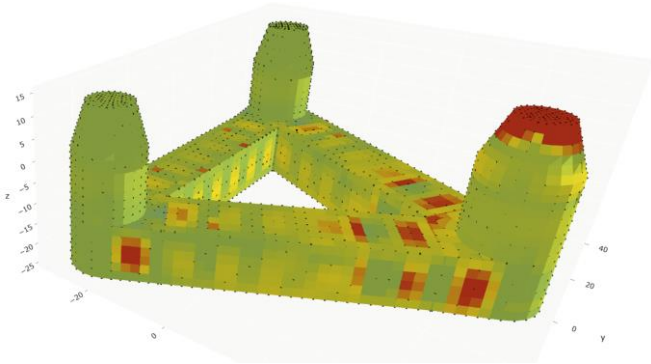
- Min/max minor/major principal stress (top/bottom layers).
- Min compression of x/y stress components (mid layer).

Identify most critical time instants and reconstruct the associated load conditions.

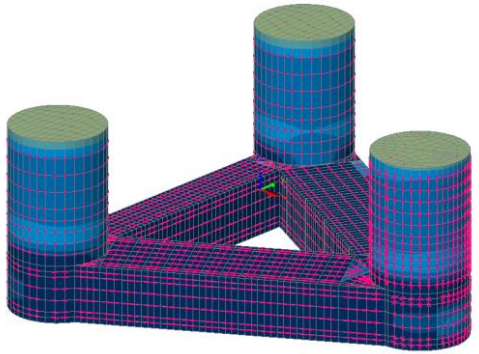
Structural verifications:

- Section capacity,
  concrete & reinforcement strength (ULS).
- Watertightness checks,
  section compression (SLS).

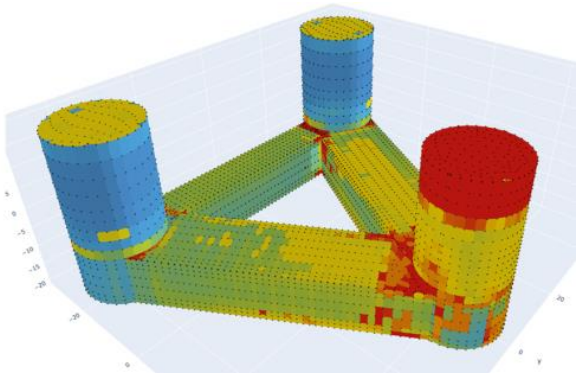
sigp2max (bottom)



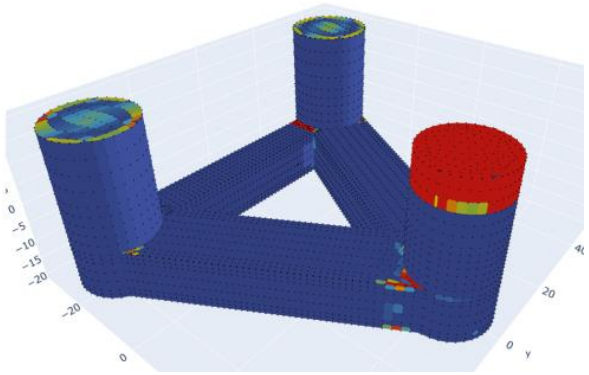
Principal stress directions



ULS utilization



Crack widths



Example results, not necessarily representing the final structure.

What do we gain?

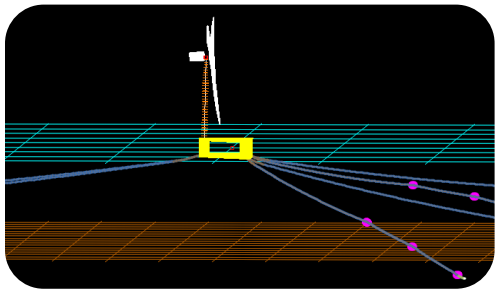
Methods such as the GIS methodology presented are:

- A **streamlined process**,
  all based on **one ILA** and **one FE model**.
- Same processes for global performance and structural design.
- **Quick and scalable**,
  no need to restrict the number of simulations.

Greater confidence

Delivery in time

Reduced risks

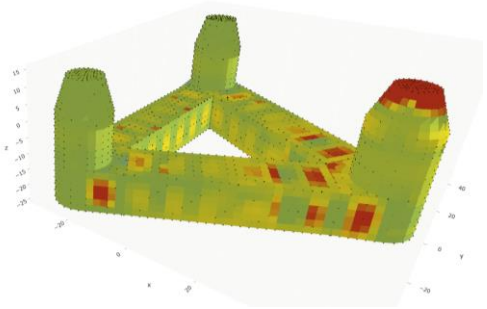


Coupled Analysis (ILA)

GIS based Load Mapping and Structural FE Verification

Design Updates

Structural Checks



Bright
ideas.
Sustainable
change.

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