Approaches and Challenges in the Structural Design Process of Floating Substructures

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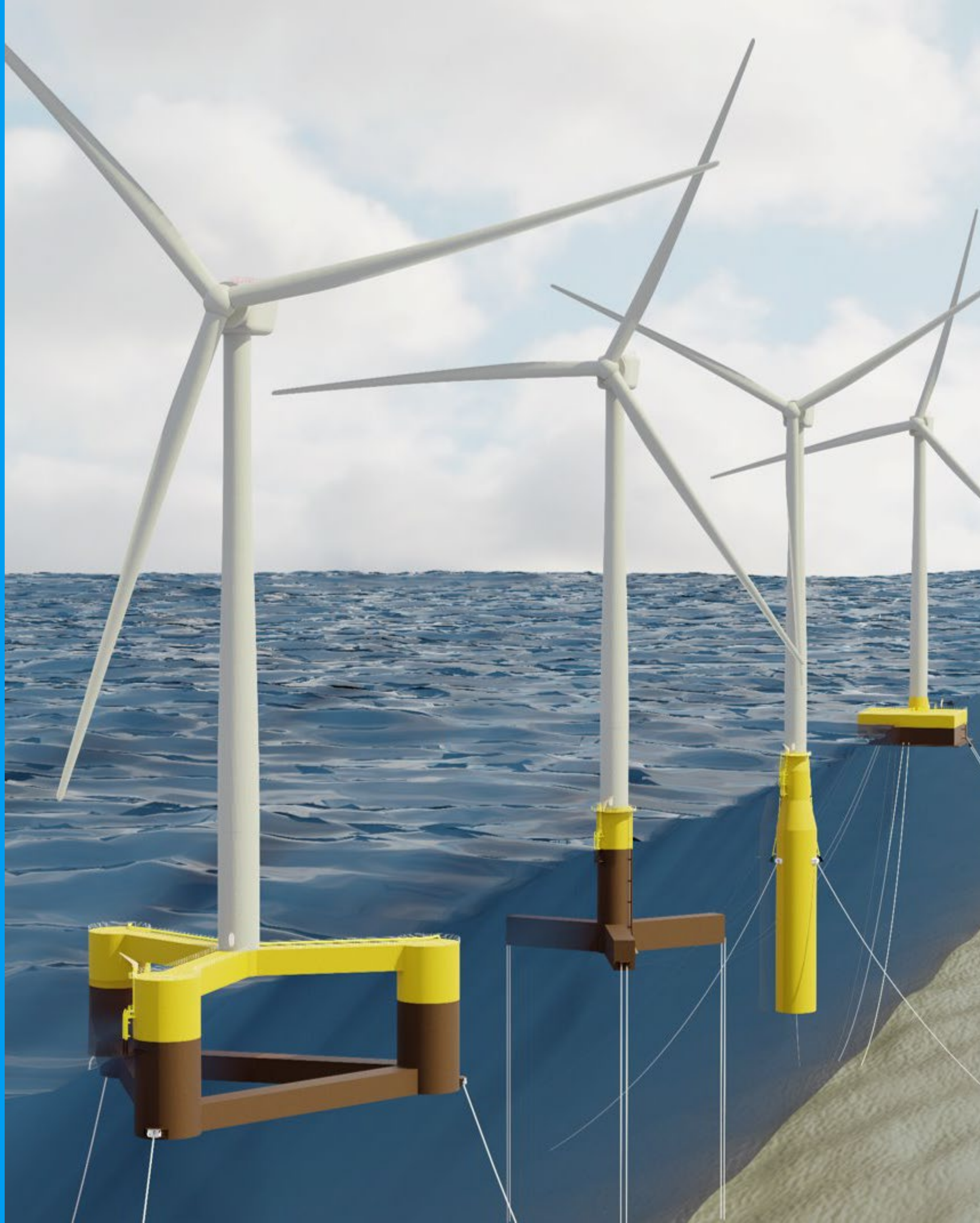
Bright ideas.
Sustainable change.

Michael Karch

EERA DeepWind 2024

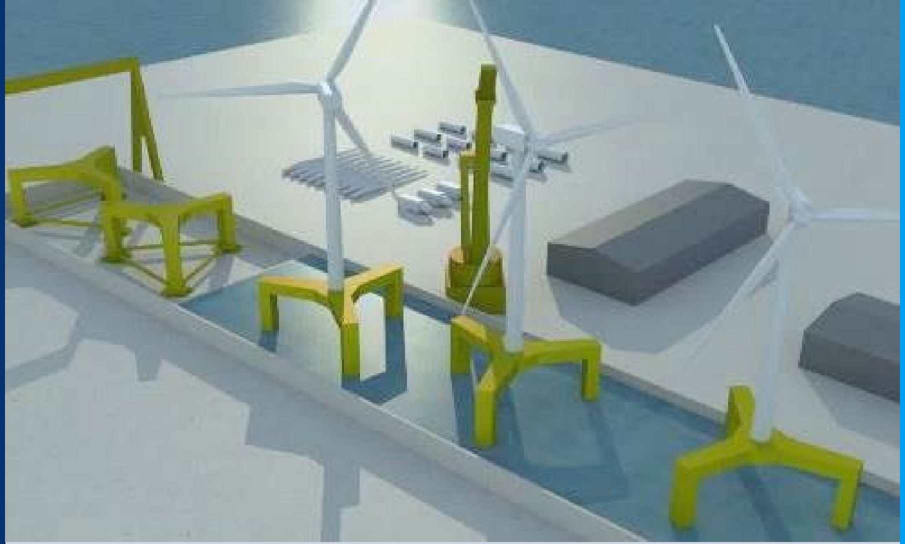


Floating Wind

RAMBOLL

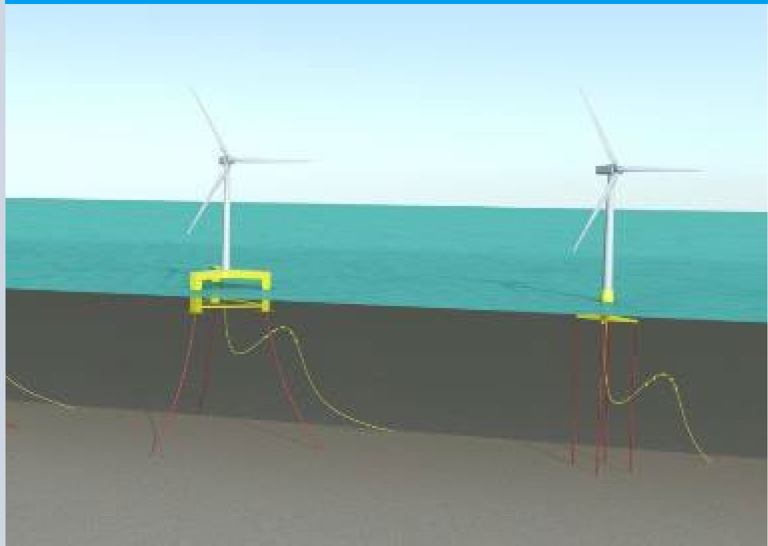
17,500 employees
500+ Wind Experts
Offshore since 1989
50% of all substructures

- Design and Engineering
- Consultancy (Technical, Commercial, Strategic)
- 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 more than 80 commercial and R&D projects related to floating wind in **engineering and advisory**
- Ramboll is approaching the market as 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.



Motivation

How to perform structural verification on a FEED or Detailed Design level?

Method Requirements:

Acceptance: Compliant with Certification/Class requirements

Accuracy: Sufficient for FEED or Detailed Design Level

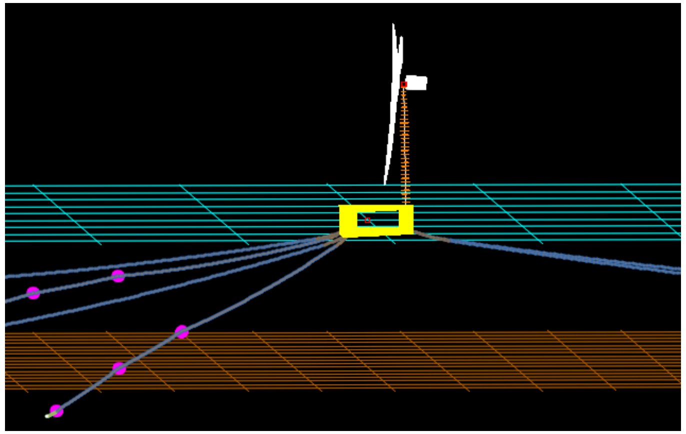
Efficiency: Allowing for design iterations within commercial project timelines at reasonable cost

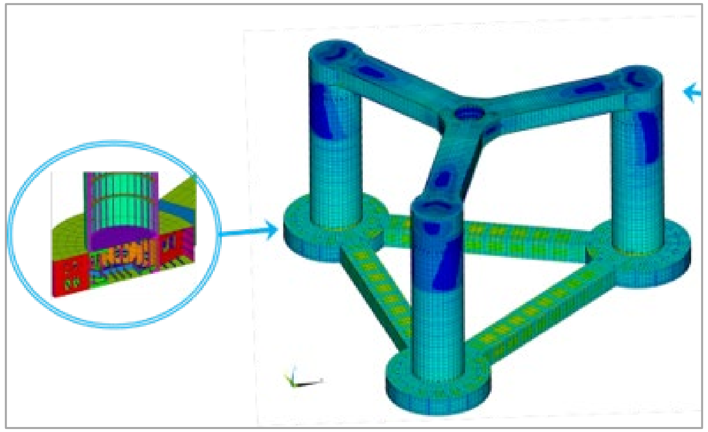
Flexibility: Applicable for different types of substructures (steel/concrete, SPAR/TLP/Semi/Barge)

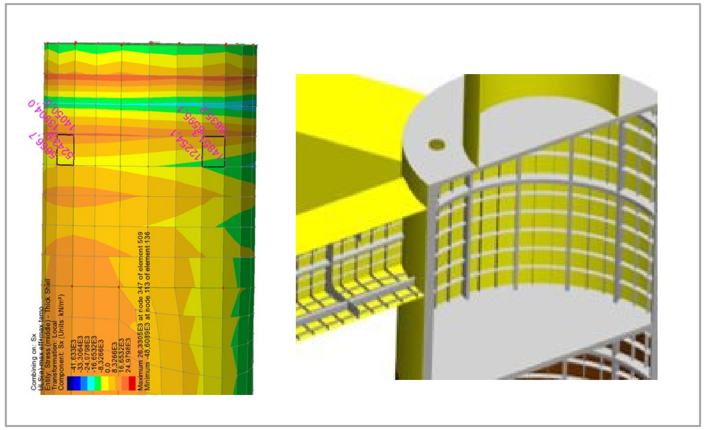
Ability to handle different types of analyses:

ULS/ALS/SLS	FLS
• Large sets of DLCs in time domain, fully coupled (10s-100s of millions of single time steps)	
• Stresses in entire structure • Critical loads may occur at any time instant of any DLC	• Large number of hot-spots (thousands) • Fine FE mesh near hot-spots (mm) • Analysis in time domain

Structural Analysis process







Challenges	Coupled analysis	Load and pressure mapping	Structural analysis

	• Representation of aero-servo-hydro-elastic coupled FOWT model incl.: WTG, Ctrl, Substructure, Mooring
	• **No detailed structural model**
	• Results do not include:
	  • **Accurate stresses**
	  • Pressures on the hull
		• **Reconstruction** of wave pressures
		• **Efficient** implementation of mapping in the actual design flow (large number of time steps)
		• Correct physics (e.g. tank loads, 2nd order wave loads, drag loads etc.)
			• **Large number of time steps** (calculation time, data handling)
			• Post-processing requires good tools (stress envelopes, seed averaging, critical DLCs, etc.)
			• Code check integration, e.g. yield, buckling checks, FLS

Key Challenge: Ability to handle large number of time-steps

Approaches (1/3)

Obtain sectional loads directly in coupled analysis

Idea:

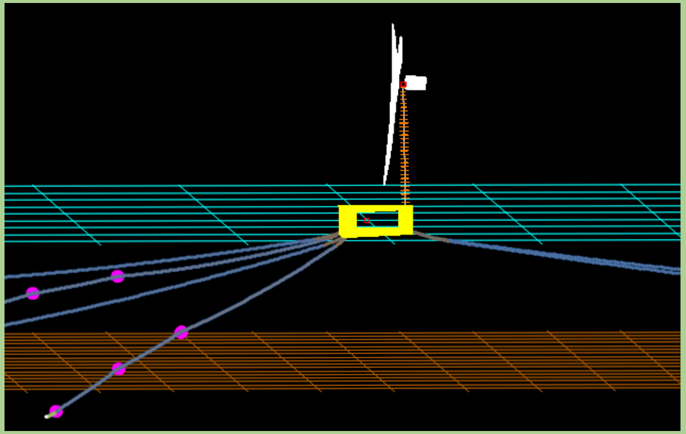
- Sectional loads in ILA help to identify most critical time steps for ULS.
  No need to analyse all time steps in FE for ULS.
- Coupled analysis model with simplified structural representation, for example:
  - Beam elements.
  - Segmented (multi-body) radiation/diffraction model.

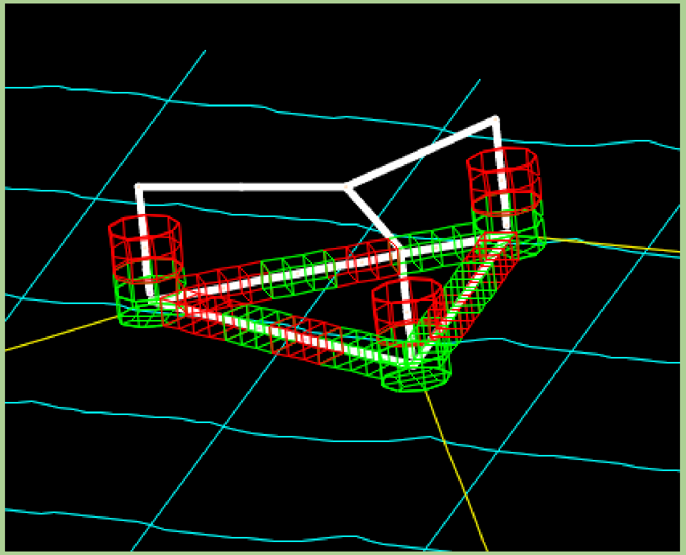
Pros:

- Only few time steps to analyse for ULS.
- Post-processing (buckling, yield checks) can potentially be done "by hand".
- Consideration of structural dynamics possible, as included in the coupled analysis.

Cons:

- Lends itself to lattice type structures.
- Sectional loads are in practice very difficult to calculate accurately:
  - Equivalent beam properties.
  - Hydrostatics of the segments.
- Are selected time instants most critical?
- Only for ULS. FLS must be addressed with different methodology.





Approaches (2/3)

Perform load mapping and FE calculations <u>fast</u>

Idea:

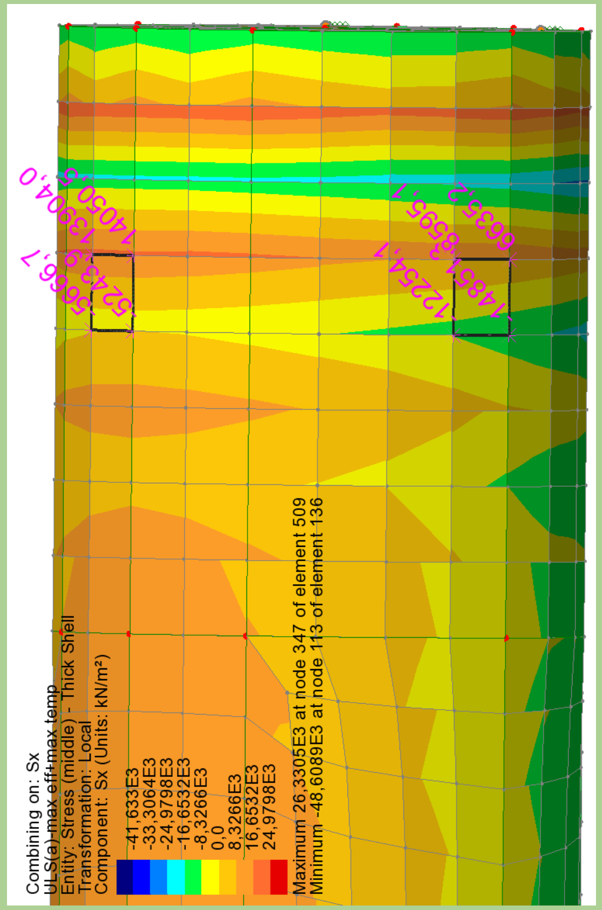
- Analyse <u>all time steps, one-by-one</u>
- To make it manageable, increase the speed by:
  - Relatively coarse FE mesh
  - Cloud computing & Parallel calculation

Pros:

- Accurate load modelling
- All time steps considered
- Consideration of structural dynamics possible

Cons:

- Coarser FE mesh required for efficiency:
  - Stress calculation in ULS accurate?
  - Number hot-spots in FLS has to be limited
- Despite cloud computing: Calculation time, storage capacity, costs are challenging



Approaches (3/3)

Methods <u>reducing computational effort</u> for mapping & FE.

Example: IM (Influence Matrix) method *(other methods exist)*

Idea:

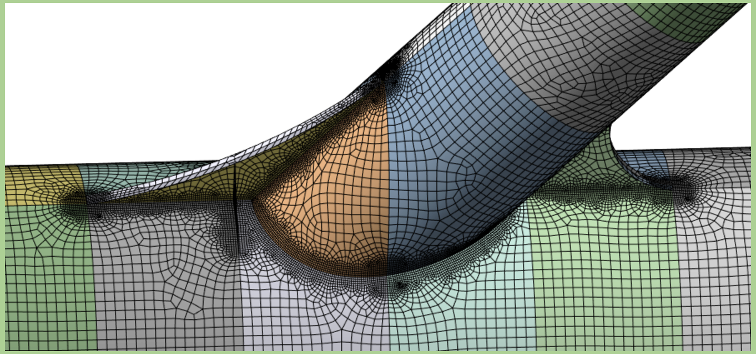
- Analyse in FE a <u>limited number</u> of Unit Load Cases (ULCs) for all types of loads and get Influence Matrix (IM) of stresses in all FE elements.
- From coupled analysis obtain time series of load multipliers for each ULC.
- Stress IMs · Multipliers = Stress (available for all time steps in all FE elements).

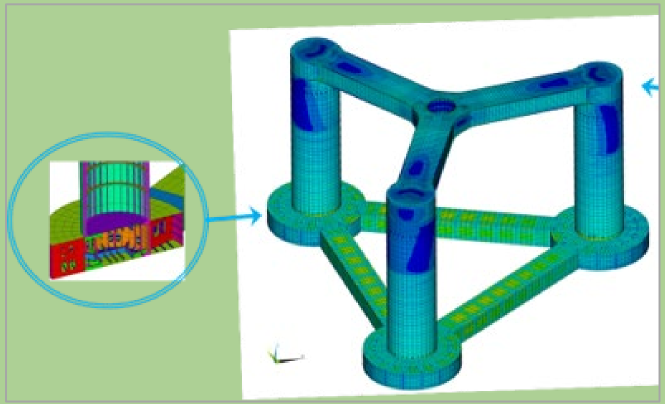
Pros:

- Stress calculation very efficient (only matrix multiplication).
- Large FE meshes with fine discretization possible.
- Consideration of structural dynamics is possible, if included in the coupled analysis.

Cons:

- Accurate load modelling and stress calculation <u>only with appropriate ULCs and multipliers.</u>
- Wave loads only up to Still Water Line.





This approach has been developed by Ramboll over several years and is applied in ongoing FEED/DD FLW projects.

We apply a combination of OrcaFlex + ANSYS + In-house tools.

NOTE: Presented approaches are only a selection – many others exist

Example project illustrating method application: Brunel

Project

Brunel FEED

Client

Fred Olsen 1848

Scope

DNV Basic Design Certification

Coupled analyses:

- **~50 Mio time instants**

FE model:

- **~400k to ~1m elements**
- **>6,000 hot-spots**

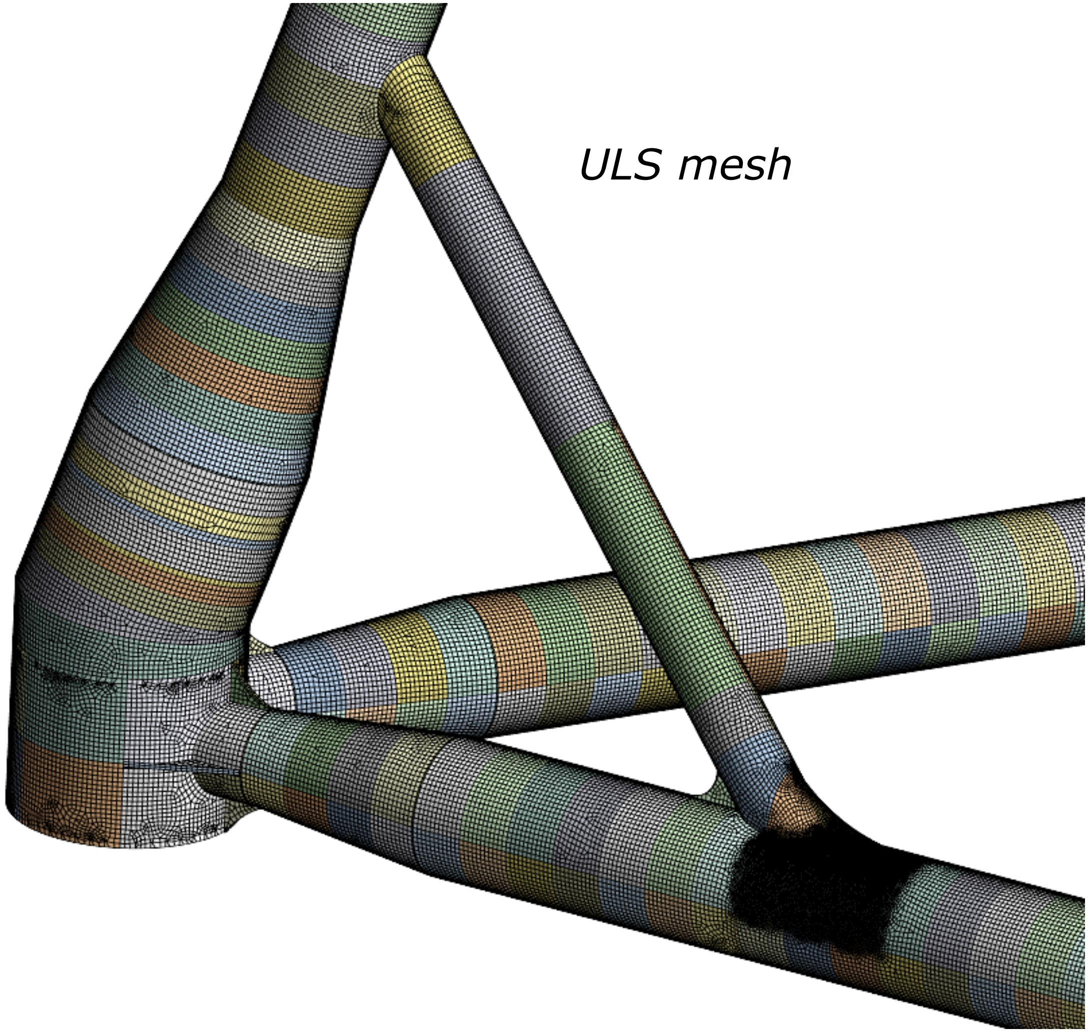
Full stress calculation & checks for yield, buckling, fatigue:

- **Very efficient process, even possible on local PC**

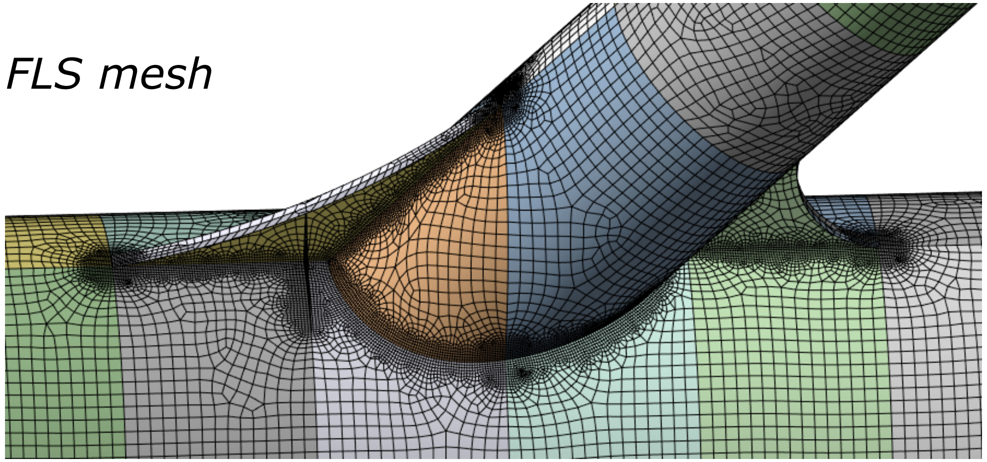
In 2023 Ramboll was selected by Fred Olsen 1848 as independent engineering consultant to support the Basic Design of their patented Brunel Foundation. All rights related the foundation concept are with Fred Olsen 1848. Results shown with friendly permission by FO1848.

Example Brunel: FE Meshes

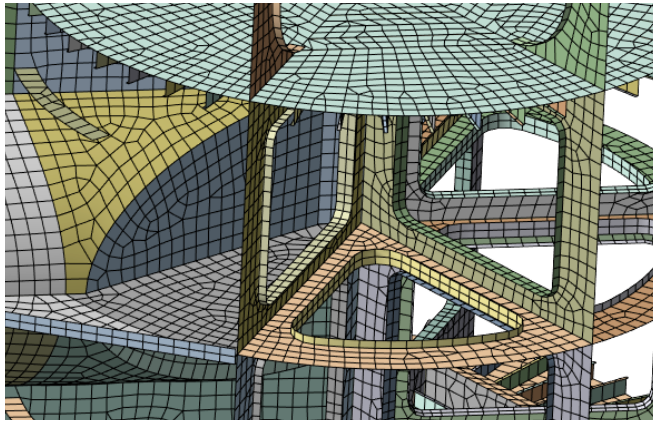
ULS mesh



FLS mesh



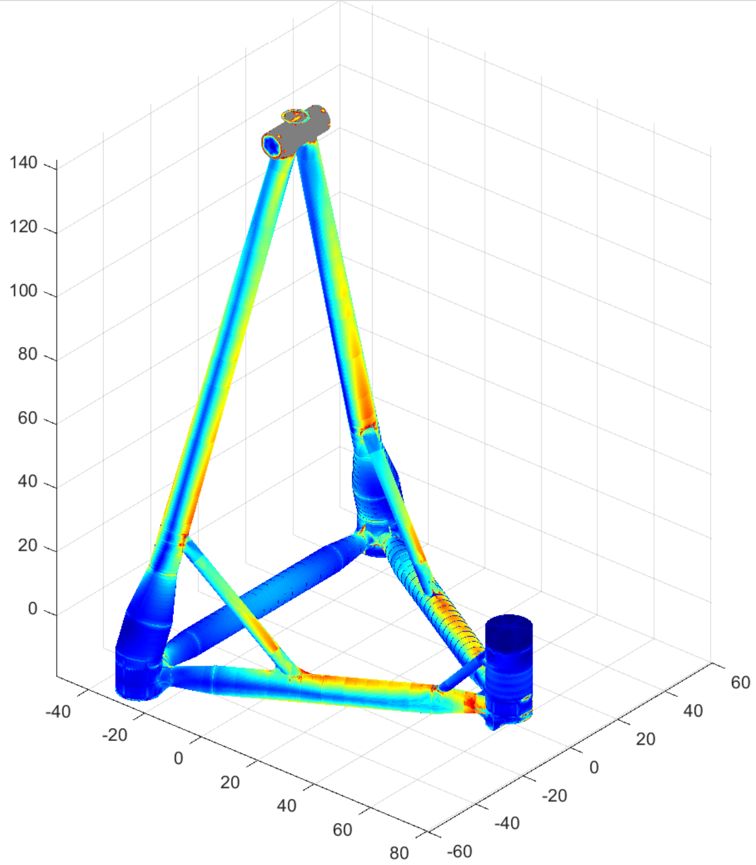
Internal structure (versatile local mesh resolution. Representation of complex geometries)

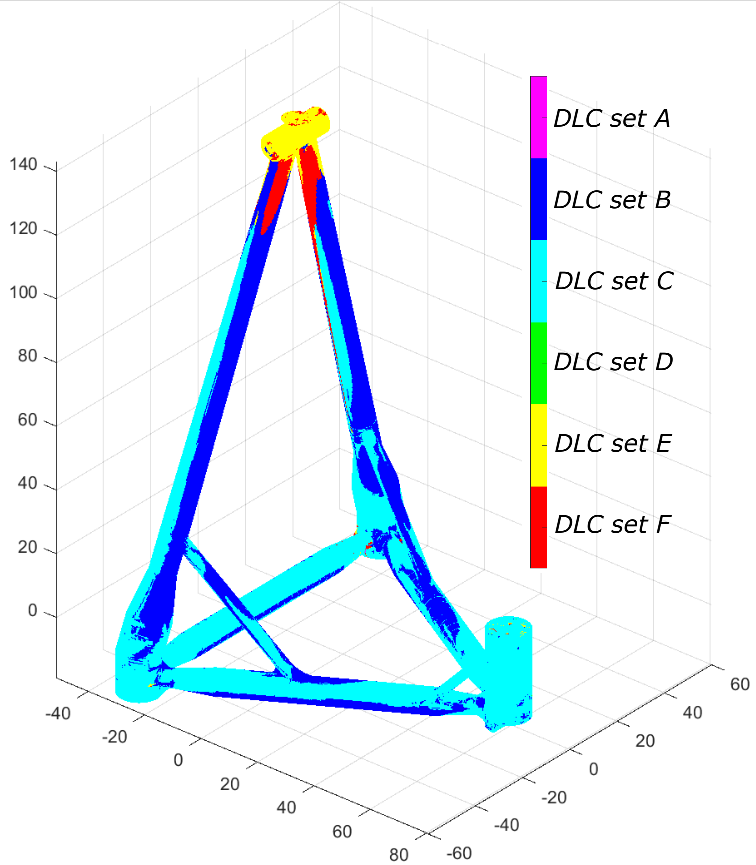


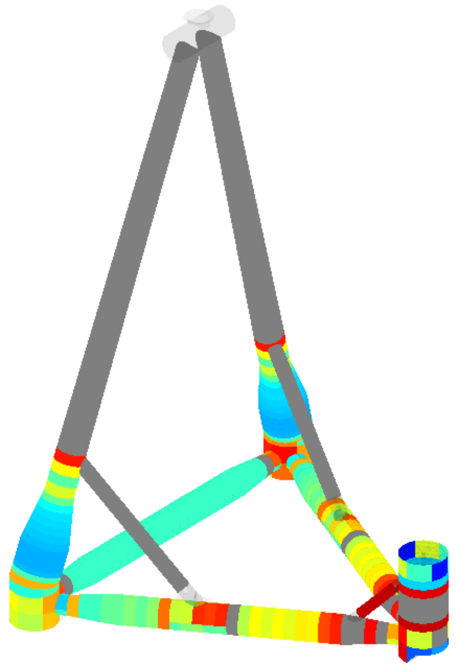
Example Illustrations, not necessarily representing the final Brunel FEED structure.

Example Brunel: Post-processing

<u>Envelope</u> von Mises Stresses incl. load factors and seed averaging	**Governing DLCs**	**Shell buckling utilizations**







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

Conclusions

- Methods from bottom-fixed and O&G are not directly applicable to Floating Wind, respectively do not fully comply with requirements
- Key challenges of approaches generally relate to:
  - Efficient & holistic handling of coupled analysis, load mapping and structural detailed FE checks according to standards, particularly for fatigue (handling of millions of timesteps).
  - Limited to specific substructure concepts, applying simplifications only acceptable for a given specific design.
  - Applying different methodologies for ULS and FLS, not being a comprehensive process based on the full coupled ILA analyses.
- The presented IM-based approach applied by Ramboll is able to address many of the challenges in an efficient manner. Based on principles applied in Ramboll's bottom-fixed design process. It has been successfully demonstrated and is currently in the process of Basic Design Certification.
- The structural design process for floating wind substructures is an ongoing R&D area, (e.g. OC7)

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