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Early-stage integrated fatigue & fabrication design methodology to reduce and secure Floating Wind CAPEX Application to the STAR1 technology

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Abstract

Offshore wind floating foundations cost is mainly driven by steel quantities and grades, and ease of fabrication.

In typical oceanic conditions, structural design is generally fatigue driven. **As a main driver, the fatigue validation of the design needs to be dealt with during all project phases, starting as early as possible to secure a robust and reliable design that, in turns, guarantees the bankability of commercial farms projects.**

Ease of fabrication for steel structures is a key CAPEX driver, defined by 1) the use of standard sub elements readily available on the market (for example plates or profiles dimensions and thicknesses), 2) the minimization of weld quantities and weld complexity, and 3) the compatibility of the design with a wide range of worldwide available fabrication lines, allowing for maximizing mechanized fabrication.

At early stages, most floating foundation designs are based only on the hydrodynamic performance and structural behavior in extreme conditions. Fatigue analysis is put off to a later stage. It is recognized that a fully coupled time domain fatigue evaluation can be an extremely intensive computational exercise when performed with standard methodologies and tools. Furthermore, the evaluation of fabrication methodology is also largely excluded on the basis that it will be addressed during project execution in coordination with the fabrication contractor, and not at initial design stages.

The exclusion of fatigue analysis and fabrication considerations exposes the project to four significant risks in the subsequent project execution phases: 1) redesign and structural reinforcements due to fatigue loads, 2) additional engineering design and delays in order to optimize fabrication methods, 3) increased fabrication cost and 4) fabrication schedule disruption with its associated knock-on effects on the overall project schedule.

The present poster will present the method that was used to optimize the STAR1 floater design to avoid these concerns, and the associated results.

Objectives

The objective of this study is to challenge the design of the STAR1 product to identify the optimum CAPEX integrating both steel quantities confirmed by fatigue evaluation and fabricability of proposed designs, ensuring a robust, cost-effective, and fit for EPCI projects design.

Methods

SAIPEM has developed methodologies and tools [1] that enable to efficiently perform parametric design optimization and evaluate fatigue in direct time domain at early design stages. This allows the evaluation of numerous structural configurations while having a high degree of confidence on the steel quantities.

The design steps are as follows:

1) Perform quick parametric configuration research to reduce structural weight while respecting key requirements (stability, tilt under nominal thrust, ..). Typically, thousands of configurations are evaluated.

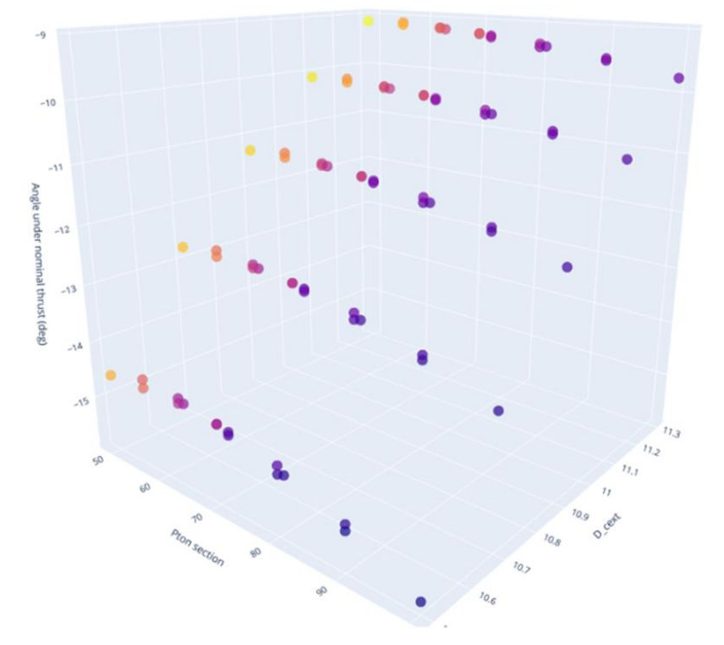


Fig. 1. Parametric configuration research

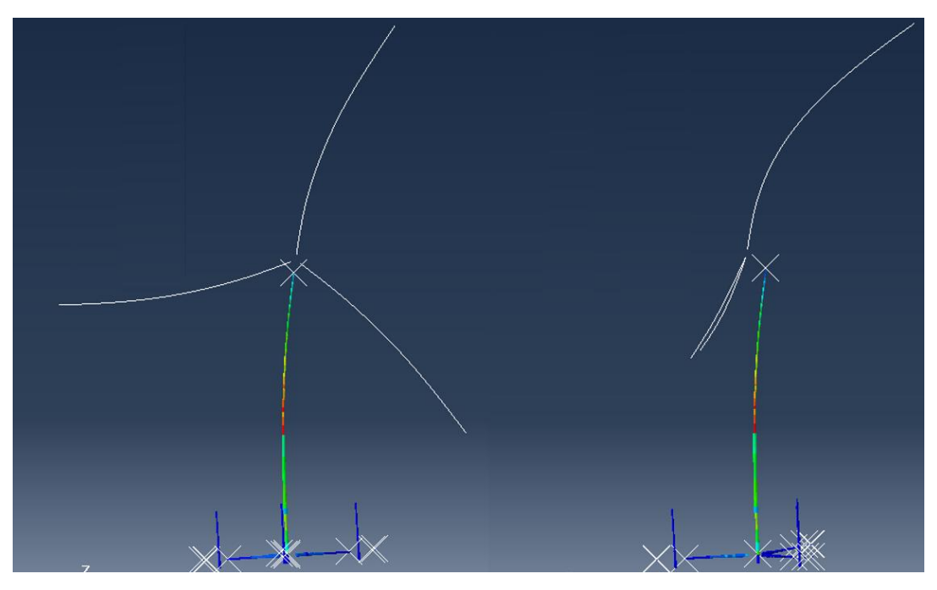


Fig. 2. Bending frequencies evaluation

2) Perform dynamic flexible modal analysis on selected Design Load Cases (DLCs) to generate as output eigen frequencies, RAOs, Tower base moment Damage Equivalent Load (DEL), confirming global behavior and consolidating structural mass. Typically, tens of configurations are evaluated.

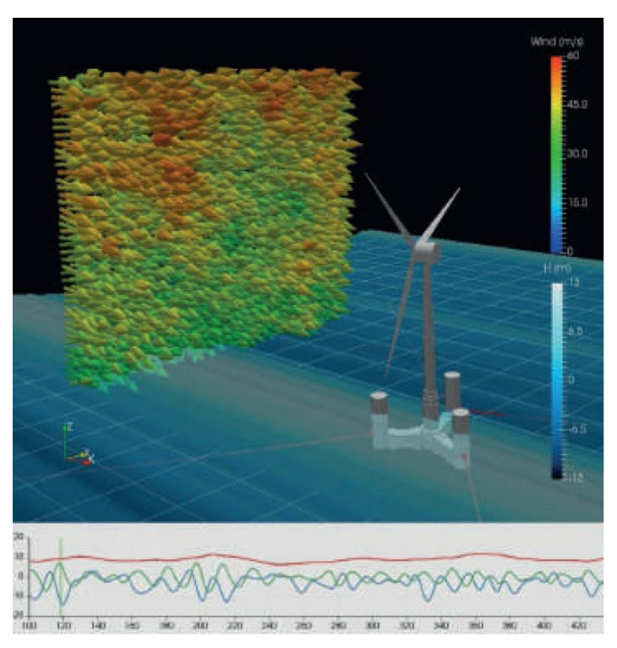


Fig. 3. FOW Coupled simulations

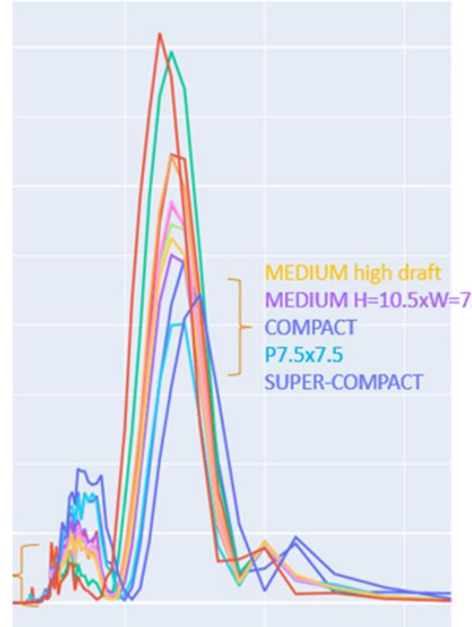
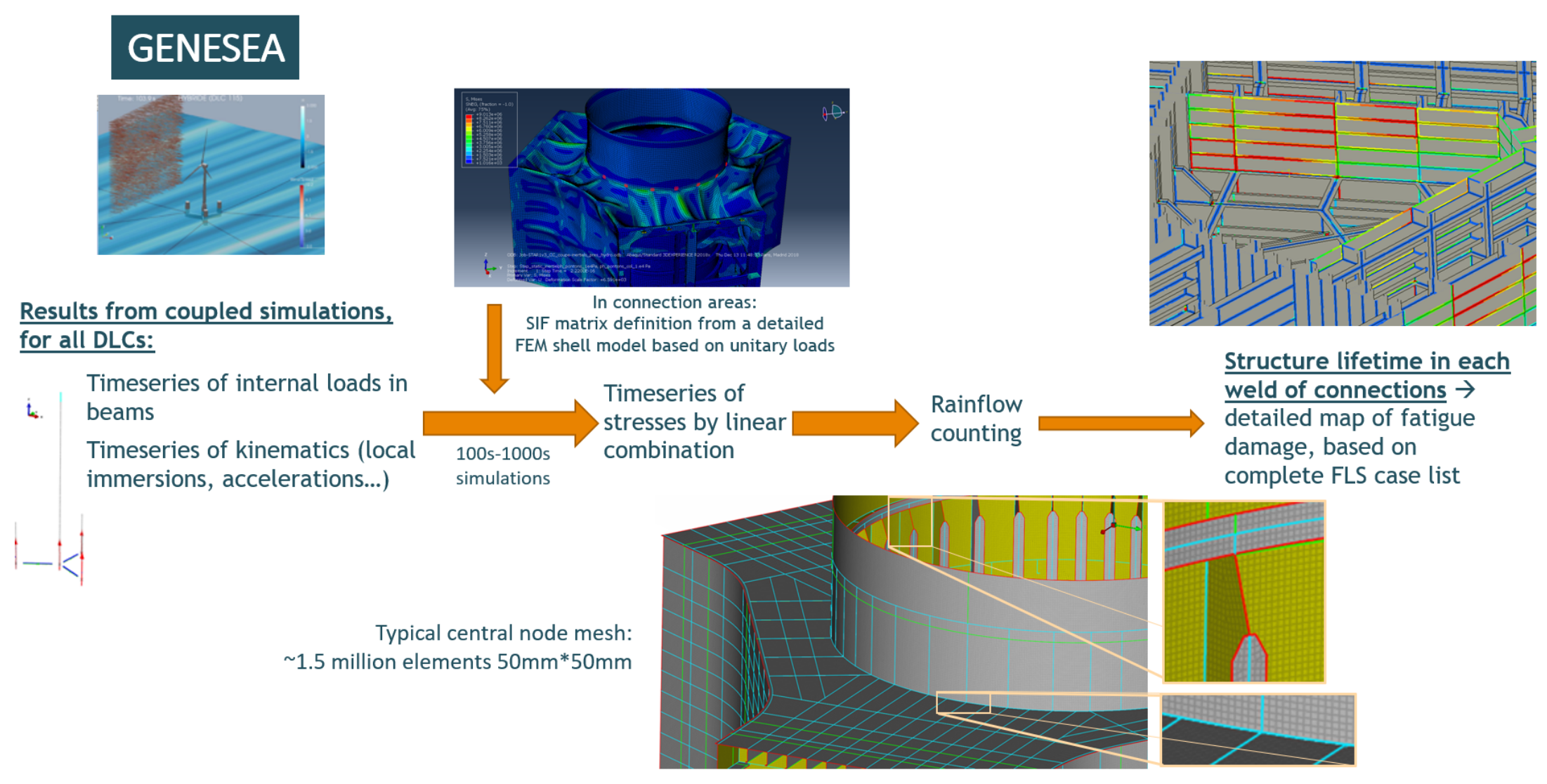


Fig. 4. Tower Base moment RAO

3) Perform at early-stage FEED level ILA: ~500 DLC (~1000 runs) Ultimate Limit State (ULS) and Fatigue Limit State (FLS) in the time domain with structural analysis performed with direct time series of all DLCs. Typically, tens of full ILA loops (each with thousands of runs) are performed for controller, floater and tower optimization, and several structural postprocessing are performed to confirm with minimal uncertainty structural steel quantities.



GENESEA

Results from coupled simulations, for all DLCs:

- Timeseries of internal loads in beams
- Timeseries of kinematics (local immersions, accelerations…)

100s-1000s simulations

In connection areas:
SIF matrix definition from a detailed FEM shell model based on unitary loads

Timeseries of stresses by linear combination

Rainflow counting

Structure lifetime in each weld of connections → detailed map of fatigue damage, based on complete FLS case list

Typical central node mesh:
~1.5 million elements 50mm*50mm

Fig. 5. SAIPEM GENESEA suite for fatigue evaluation

4) Ease of fabrication of each design option is evaluated by quantifying critical elements that define the fabrication complexity and therefore dictate fabrication cost. Such elements are:

- Floater structure members dimensions
- Plate thicknesses and profiles types
- Weld quantity and quality
- Weld processes and potential for mechanization

Figures 6 to 8 illustrate an example of comparison of different structural arrangements allowing different fabrication methodologies.

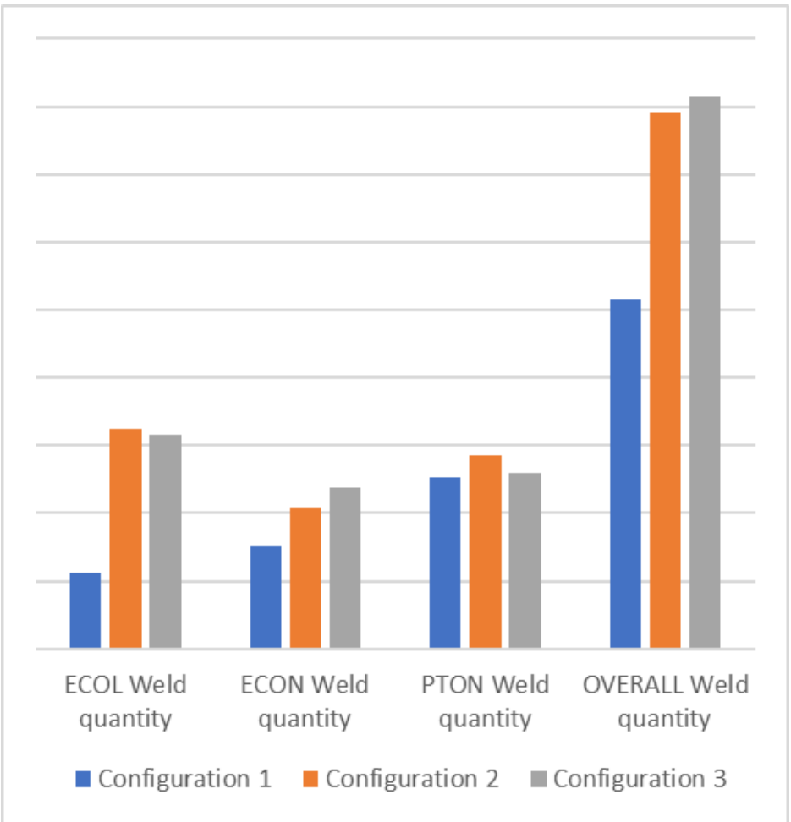


Fig. 6. Weld quantities comparison

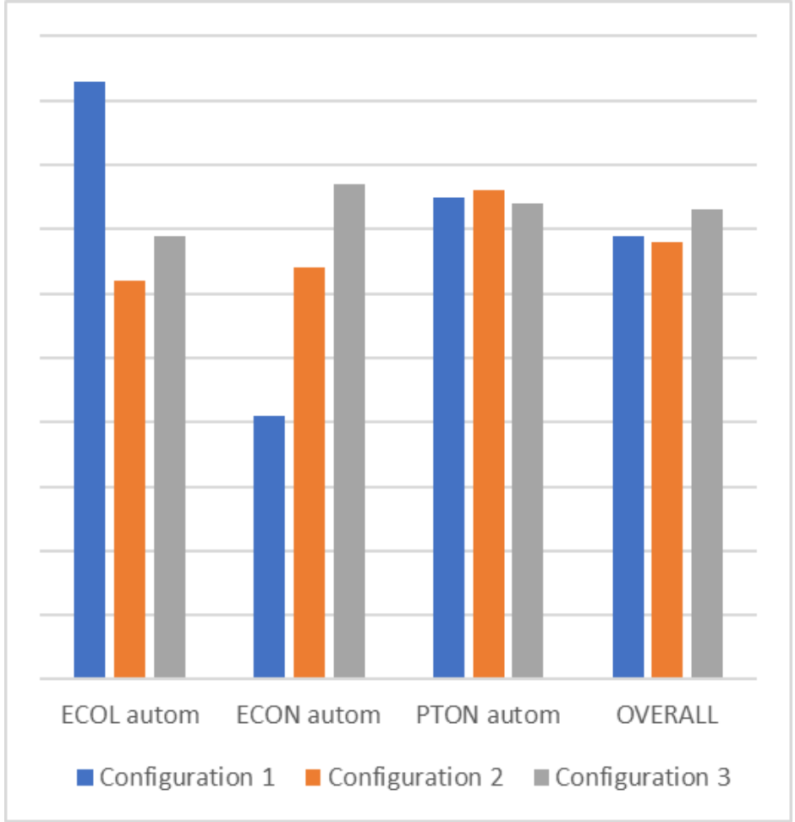


Fig. 7. Weld automatization comparison

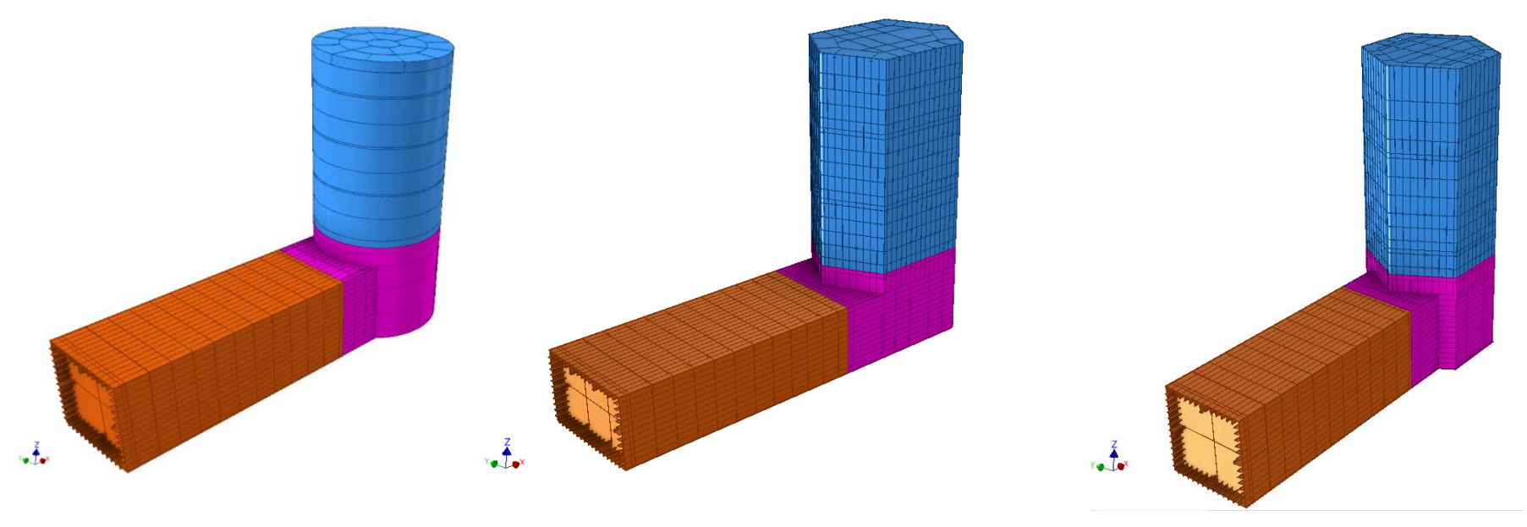


Fig. 8. Example of structural configurations

The two generated outputs of the evaluation (1- steel quantities, 2- fabrication complexity) are exploited to select optimal solution, respecting fatigue design life while minimizing overall project cost.

These results are confronted with worldwide supply chain capabilities to confirm the best design and associated execution scheme for each specific project location.

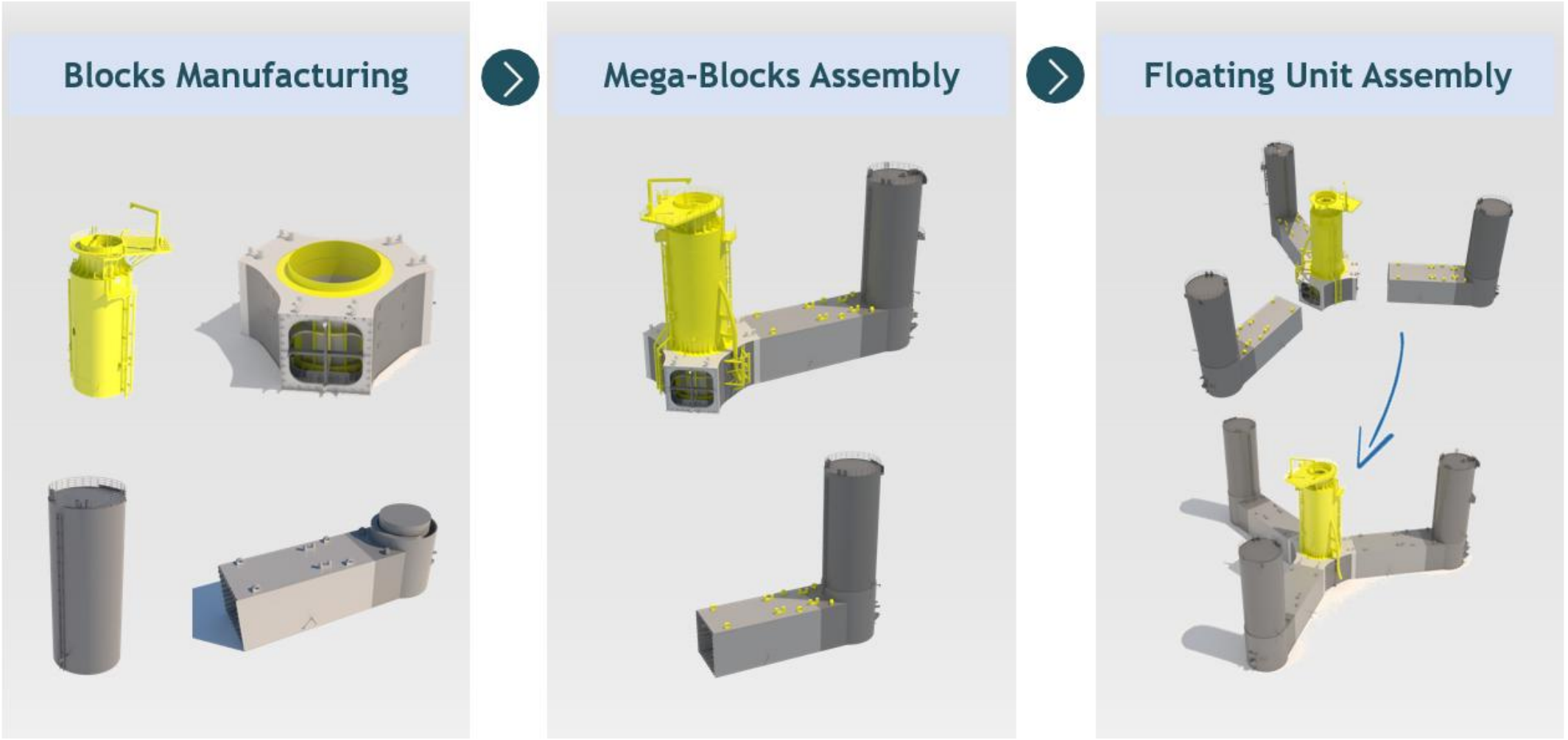


Fig. 9. Example of block split configuration

Fig. 10. Typical final assembly yard arrangement

Results

The parametric configuration research coupled with flexible modal analysis and ILA loops in time-domain with aeroelastic turbine model and controller have allowed to reduce Tower base moment DEL by 30% compared to initial configuration.

This leads to a substantial structural weight reduction.

Structural optimization at early stage, following FEED Level ILA confirms the weight range with minimal uncertainty while fulfilling ULS and FLS requirements of DNV standards. **As a result, primary structure weight has been reduced by 30%, while achieving a high level of maturity**.

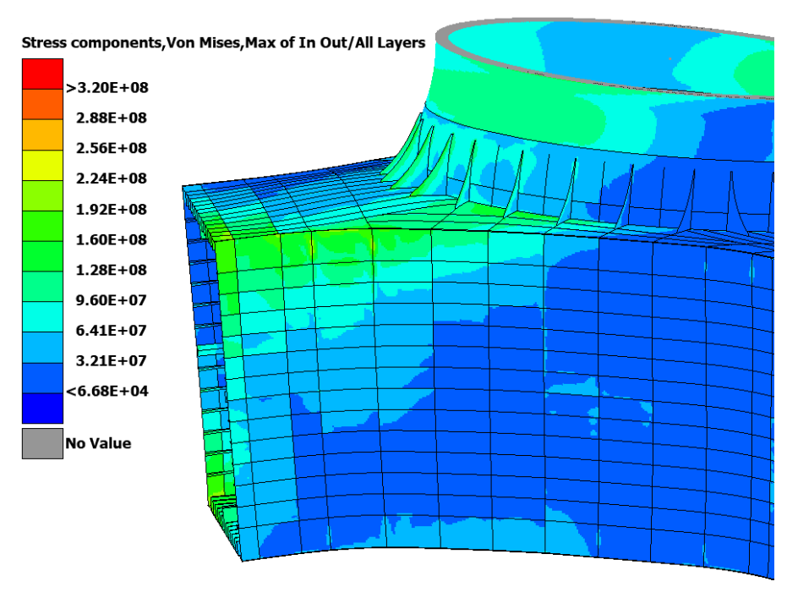


Fig. 11. Example of ULS results on central node

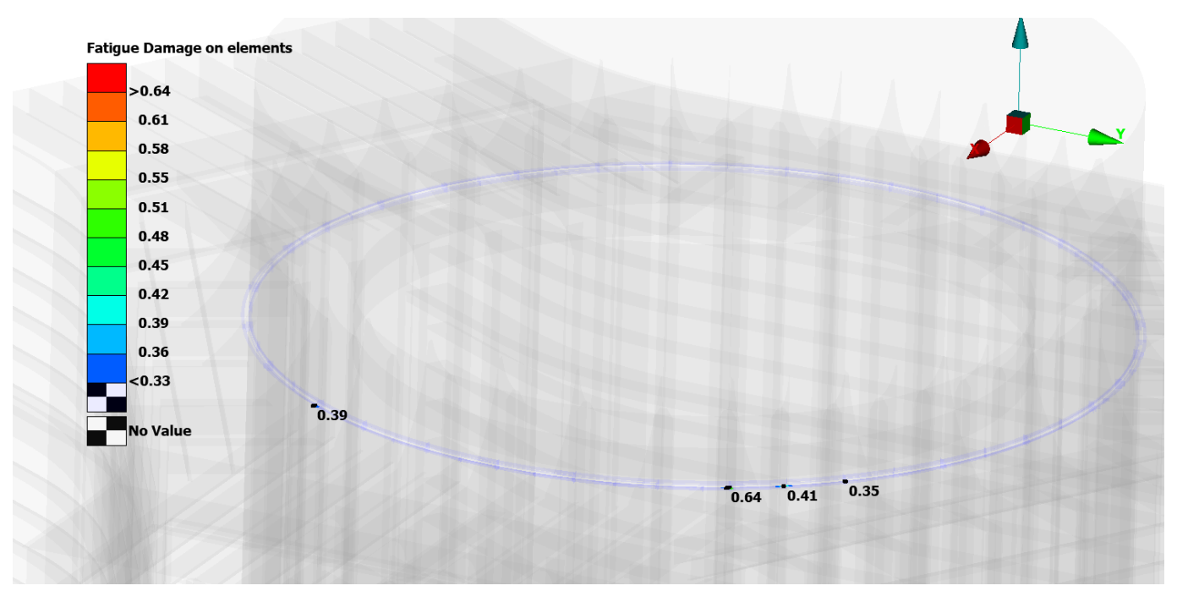


Fig. 12. Example of FLS results on central node

Evaluation of worldwide fabrication capacities and capabilities show that optimal CAPEX can be achieved with cylindrical cans or with ship-building type flat panel construction, depending on local constraints.

Hence, STAR1 can be tailored to meet local supply chain capabilities.

Study results also show that optimal CAPEX is achieved by a balance between structural weight and fabrication complexity and is therefore not always achieved by minimizing structural weight.

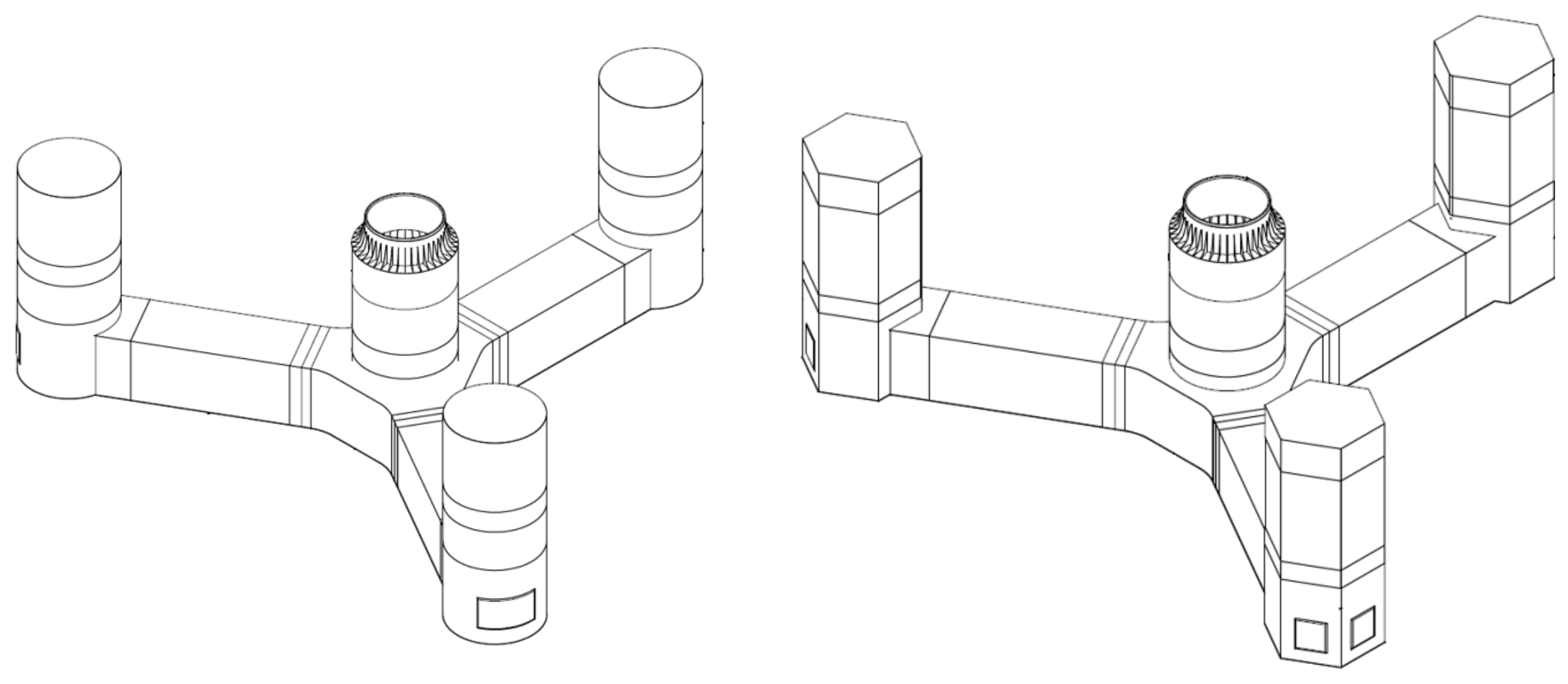


Fig. 13. STAR1 product optimal configurations

Conclusions

This study perfectly illustrates how design tools and methodologies can deliver high value to floating foundation designers and clients, by providing the right design choices at project start and ensuring that only minor design modifications are made during detailed design and project execution phases.

This results both in significant savings and design risks mitigation at the scale of commercial EPCI projects which is a true enabler for the floating wind industry.

References

1. Accurate FOWT fatigue assessment at all design stages, *WindEurope 2022*, Raffaello Antonutti, Alexis Martin

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