Spar Design Optimization with Concrete Substructure

Lars-Petter Solvang Johnsen

Department of Marine Technology, NTNU

Objective

The aim of this project was to update an existing design optimization model for floating wind turbines with concrete substructures. The project involved a literature review of wave and wind loads, FWT dynamics, concrete platform design, and fatigue and extreme strength assessment for concrete structures. Two numerical models of 10 MW concrete spars were built, and post-processing tools for fatigue and extreme load estimation were developed. The SIMA and SPAROpt results were compared, and an integrated multidisciplinary optimization tool in SPAROpt was used for design optimization with a limited number of design variables.

Method

The study involved a comparative analysis of two simple flexible spar designs with different diameters and thicknesses based on modes from Oh et al. [1]. The analysis used time domain (SIMA) and frequency domain (SPAROpt) methods. The frequency domain approach used a linearized model with few degrees of freedom to quickly obtain results. However, this approach is limited in its ability to capture nonlinearities. On the other hand, the time domain analysis allowed for a more accurate representation of the system's behavior, but it required more computational time. Overall, the combination of these two methods provided a comprehensive understanding of the spar's performance under different loading conditions.

Results

Figure 1 illustrates the flexible model and spectral analysis for under-, around-, and over-rated wind speeds. The presented verification demonstrates agreement in the shape and magnitude of the response spectra. However, SPAROpt appears to underpredict the response at the peak wave-frequency and overpredict the resonant response for certain load conditions. Whether this is a persistent problem with the analysis model or a singular issue with the reference design under consideration is uncertain.

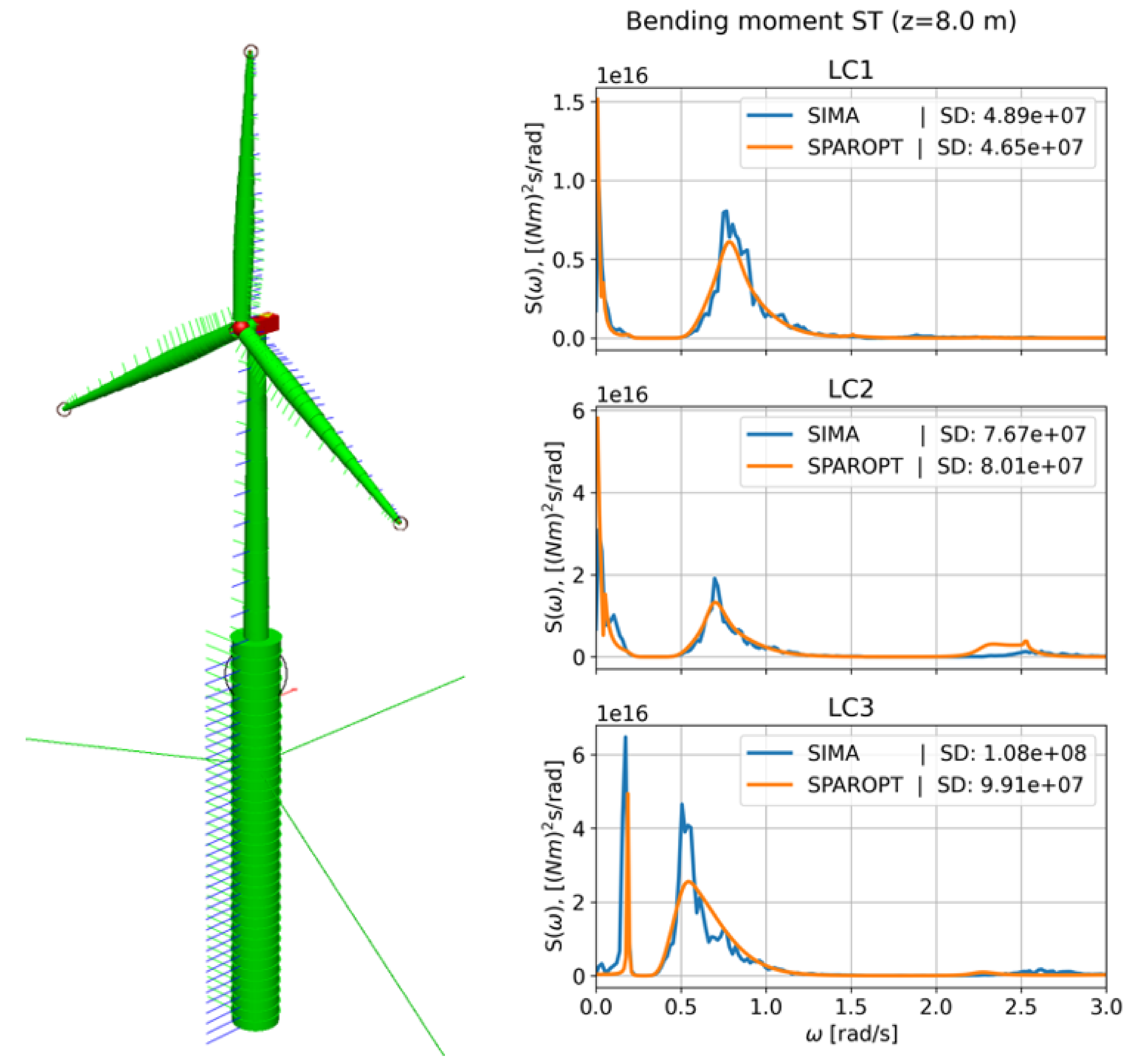

Figure 1:Left: Flexible model, Right: Spectral comparison analysis

The DLC 1.6 for operational conditions in severe sea state are used in the estimation for concrete capacity and fatigue as seen in Table 1.

Table 1:Environmental conditions for spectral analysis

	$V_{hub}[m/s]$	T_p [s]	H_s [m]
	11.1		11.1
DLC1.6		11.71	12.7
	15.00		14.3

Figure 2 shows a comparison among the capacity of pretension wires, the tensile strength of concrete, and short- and long-term axial compressive capacity of the concrete modeled in SIMA and SPAROpt.

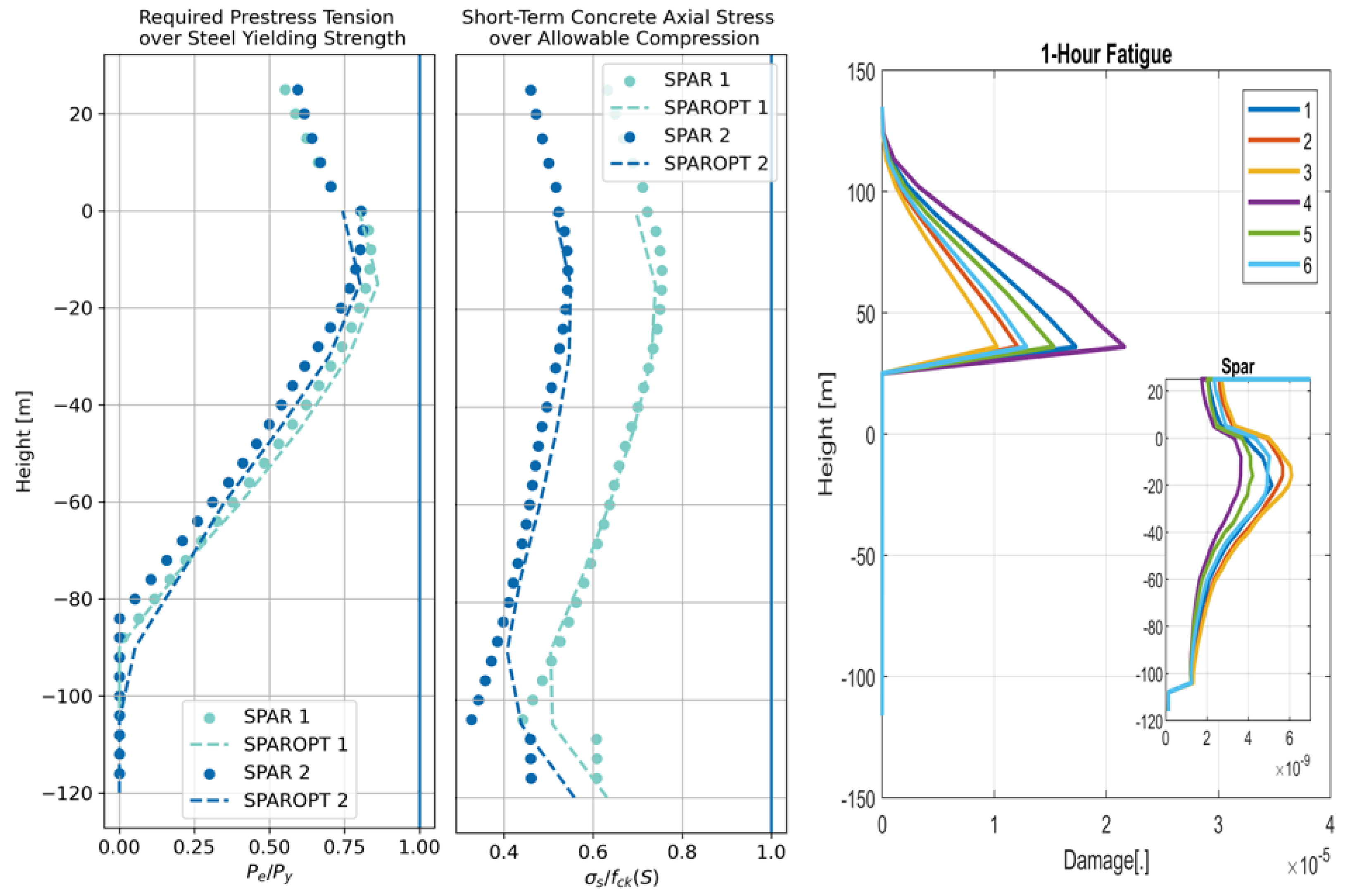

Figure 2:Structural capacity estimation from loads form SIMA and SPAROpt.

A one-hour fatigue calculation was conducted to evaluate the fatigue damage of the steel tower and concrete hull. The method considers stress amplitude, the number of stress cycles, and the concrete material properties to calculate the fatigue life of the structure. DNV provides two approaches for calculating the fatigue life, namely, stress-based and strain-based approaches, which are used depending on the complexity of the structure. The results revealed that the concrete hull suffered significantly less fatigue damage compared to the steel tower. This finding indicates that the concrete hull is better suited to withstand long-term fatigue loading conditions. Utilizing Multi-Disciplinary Analysis and Optimization (MDAO) techniques, led to a successful reduction of the mass of the hull by optimizing its draft and diameter while maintaining comparable performance. However, our findings revealed an unexpected impact of structural thickness, emphasizing its crucial role in design optimization.

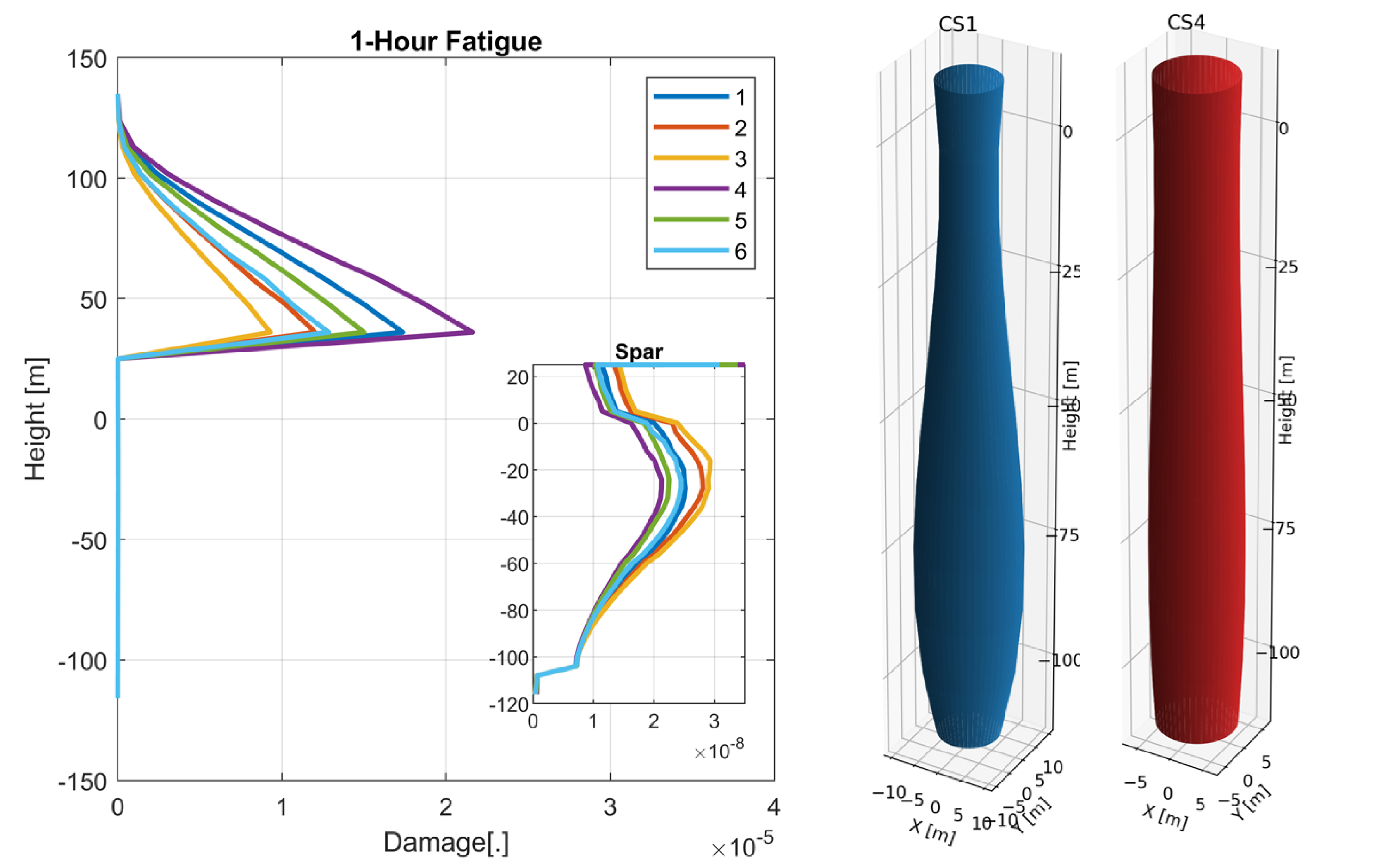

Figure 3:Left: 1-hour fatigue of concrete hull and steel tower.Right: Optimized structure hull

Conclusion

Both SIMA and SPAROpt exhibited similar trends in spectral analysis, but the latter method tended to overestimate excitations at rated wind speeds and underestimate them for under and above-rated. Additionally, there was a significant deviation in areas near the connection between the steel and concrete. The study found that the fatigue life of the concrete structure was exceptionally long and highly dependent on pretension. Although larger structures with the same pretension had 7.5 times lower fatigue life, the concrete substructures still exceeded the expected lifetime of a wind turbine. The study concluded that concrete substructures could be a promising option due to their longer fatigue life compared to steel structures. However, the connection point between the concrete hull and the steel tower may present challenges that need to be addressed during the design phases, including fatigue of reinforcement and buckling of the Tower. The optimization demonstrates the effectiveness of MDAO in achieving lighter structures with similar performance while highlighting the significance of considering structural thickness in future design optimizations.

Contact Information

- larspettersj@hotmail.com

References

[1] H. I. Sho Oh and Y. Takahashi. Structural design of a prestressed-concrete spar-type floater for 10 mw wind turbines, 2020. URL https://dx.doi.org/10.1088/1742-6596/1669/1/012012.