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WIND ENERGY SCIENCE DISCUSSIONS

Interactive comment on “A comparison study on jacket substructures for offshore wind turbines based on optimization” *by* Jan Häfele et al.

Anonymous Referee #1

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General comments:

The authors present a fairly comprehensive framework for cost optimization of jacket designs. This framework includes variables controlling topology (both discrete and continuous ones), more involved cost models than simply the total mass and approaches for assessment of both fatigue damage and extreme loads that are more accurate than the limited number of load cases usually studied in support structure optimization. All this while keeping the computational effort at a tractable level. Seen in isolation, this already represents a certain amount of progress compared to state-of-the-art jacket optimization approaches. While there are certain limitations present (for example the number of design variables), these are generally not limitations of the framework, but simply limitations of the application of that framework in the current study. In general,

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the presented approach seems well founded and seems to be computationally well behaved. Hence, the framework seems like a potentially promising methodology for future jacket optimization endeavors. However, there are some key features that are missing and need to be addressed. Especially related to the justification of the framework (the cost function and the variables affecting design topology) when compared to previous work, based on the specific results of the study rather than more general ideas about the design process. While some examples will be addressed specifically below, in general the paper could also use a bit of revision language-wise.

Specific comments:

Abstract:

- On page 1, lines 12-13, you write: ”The approach shows reasonable and promising results, ...” Even for the abstract, this is a little vague. You should say something about how the method seems to succeed in finding global minima with reasonable computational effort and how the method allows for a systematic way of comparing cost and structural performance for optimal designs with different topologies.

1. Introduction:

- On page 2 you have a fairly comprehensive literature review. You might also want to consider adding a note about Sandal et al (2018, Marine Structures) where the effect of varying leg distance (functionally equivalent to what you call leg radius) was studied to a certain extent.

2. Problem statement:

- On page 4, lines 2-4, you write about the limited effect of changes to eigenfrequencies for the design. This would likely be a larger (if not necessarily critical) issue if the soil and foundation were modeled in more detail than what you have done in this study. Though you correctly note that any design close to resonance would fail the fatigue check, there are practical reasons (related to the numerical behavior of the optimization process) that can make it beneficial to include explicit constraints on the eigenfrequency rather than relying exclusively on the fatigue constraints.

3. Objective and constraints:

- On page 7, line 10, you define c_7. This is constant for all designs and hence has no effect on the optimization process. While it may be instructive to note the existence of such additional costs in practice, for the optimization problem being solved such a term is irrelevant. Hence, you should at the very least state whether this term is part of the implemented computations or if it is merely added at the end of the optimization.

- On page 9, lines 3-4, you describe a "space-filling sampling of the input space." As far as I can see, the details of this sampling is not given either here or in the previous paper about the surrogate modeling. It would be instructive to have some more details here. At the very least, specifically what kind of sampling method are you using?

- On page 9, lines 13-14, you write "A number of 128 turned out to be a good compromise between accuracy and numerical effort." The details of this was given in previous work, but for the sake of the reader of the present work it would be instructive to give a quick summary of what level of accuracy 128 load cases represents.

- On page 9, lines 16-17, you write "The output value h_{FLS} is the most critical fatigue damage among all damage values of the entire jacket..." Considering the results you present later, this does not seem to have been a problem here, but note that using such a constraint (the maximum of a discrete set) could lead to discontinuities that affect your gradients (sensitivities) adversely.

- On page 9, line 27, you write "Extreme load parameters are derived by the block maximum method according to Agarwal and Manuel (2010)." This needs a little more detail. Does this include a statistical extrapolation to a 50-year (or n-year) return value?

- On page 9, lines 28-29, you write "... evaluated with respect to the extreme load of the member, where the highest utilization ratio occurs." Here you have the same potential issue as with the fatigue constraint.

5. Jacket comparison study:

- On page 12, lines 18-21, you summarize the different fixed integer design variable combinations you study. Note that term c_6 in your previously defined cost function is constant for each of these combinations and hence has no (computational) effect on the individual optimization problems (merely adds a constant term to the solution).

- On page 12, lines 27-33 [also on page 16, lines 3-6], you describe the behavior of your optimization routines. It would be instructive to plot an example of the convergence. For example cost (and maybe feasibility) vs number of iterations. How many function evaluations is typically involved per iteration? The number of function evaluations (in terms of both objective and constraints) is a more direct measure of computational speed/effort than the number of iterations (and is more easily generalized to different machines). It also says something about how the algorithm is behaving.

- On pages 13-14, you discuss the properties of the optimal designs. What do the initial designs look like (especially in terms of cost and feasibility with respect to code checks)? How are the optimal designs compared to a "typical" initial design, maybe compared to the OC4? Is the most optimal design topology (N_L, N_X) = (3,3) also the one with the most improvement compared to "initial" designs? How is this for the various other topologies? Obviously, the results here are only meant to illustrate the method, so the specifics of the optimal designs are not so important. However, it would give more insight into the effect of your cost model and your chosen design variables if you explain in more detail what kind of optimal designs your methodology tends to produce, with more clear reference to initial designs. What would you say are the design driving variables?

- On page 14, line 5, you write "Altogether, this is meaningful and not far off from structural designs that are known from practical applications." Do the authors mean that the designs are close to that seen in practical applications or that the costs are?

Please elaborate a bit on this statement.

- On page 16, Figure 3, you show a cost breakdown of the optimal designs. Since C_1 and C_5 both depend on the mass, note that the mass is associated with the largest proportion of the cost, but this is not immediately obvious from the figure. From a practical point of view, these two points indeed represent different aspects of the production and installation process, but since both these terms directly contribute to lighter designs, their effects in an optimization context are the same (and in the figure, these two terms are clearly just scaled versions of each other). While C_6 does not impact the optimization directly, its presence in the cost breakdown is justified by how it clearly shows where a significant portion of the difference in total cost between 3- and 4-legged designs come from. The importance of C_7 is more questionable, as it just shifts the total cost of each design by a constant value. It may make this cost breakdown more "realistic" in a practical sense, but does it impact how the authors' proposed design approach would be utilized? Were these fixed costs larger or equal in size compared to the other terms, one might conclude that differences between the topologies were negligible and therefore not worth (or to a lesser extent worth) pursuing, but this is not the case here. In any case, this term needs more justification by the authors.

- What is the sensitivity of the optimal designs to each term in the cost function? If possible, what would the optimal designs look like if some/certain terms were neglected? If that is too comprehensive, what is the contribution of each term in the cost function to the gradient of the objective function? Especially those elements of the gradient corresponding to the most design driving variables. Evaluate this at, e.g., the initial design, an intermediate design and close to the optimal design. Comparing terms that are more highly dependent on tube dimensions to the ones that depend more strongly on topology, does the inclusion of the latter terms change the direction of the gradient or does it merely reinforce the steps the algorithm would otherwise take?

Given that C_1, C_2 and C_3 (and hence also C_5) all depend in some way on effective tube dimensions (changing mass, weld volume, outer areas), does the different weighting of the design variables induced by the inclusion of all three terms in the cost function have a significant impact on the optimal design? In other words, since several of the cost terms are in a sense ”proportional” (partially or otherwise) to the total mass, how much is changed by the inclusion all of these terms (rather than just the mass)? Clearly, these terms contribute significantly to the actual cost. However, given the correlation with mass, do they have a large effect on the solution of the optimization problem?

Similarly, since many of the design variables controlling topology also enter into the cost terms related to mass, does the inclusion of cost terms entirely related to topology have a significant impact on how these variables are changed by the optimization process? For example, it seems like the costs related to the transition piece is almost completely determined by the number of legs, since the values of R_{foot} and ξ are the same (or almost the same) for all design with the same number of legs. One then wonders if the values of R_{foot} and ξ are actually determined (or at least significantly affected) by the inclusion of the transition piece cost term, or if similar behavior would be seen without this term. If so (and if this was seen to be a more general result also outside the scope of the present study), this would mean that the cost of the transition piece would not need to be included in the continuous optimization problem, but only added in along with the installation cost as an additional cost related to the number of legs.

Shedding some light on these issues would considerably strengthen the proposed cost-model methodology compared to previous studies using just mass optimization.

- On page 16, lines 6-7, you write ”The number of iterates may be decreased, when using finite differences of the objective function to obtain gradients ...” What exactly do the authors mean here? Having precise analytical gradients of the objective function would generally tend to improve the behavior of optimization routines, since this is less prone to numerical error.

6. Benefits and limitations of the approach:

- On page 17, lines 24-26, you write ”... these approaches assume that the structural topology is always optimal, even in case of significant variations in tube dimensions. However, when combined with the approach presented in this work, state-of-the-art tube dimensioning may be much more powerful." If possible, please comment on how the inclusion of variables related to design topology changes how the structure is optimized compared to pure tube size optimization. I.e. to what extent is the reduction (or change overall) of tube size "replaced" by changes to topology?

Technical corrections:

- Abstract, page 1, line 6: "The objective function is replaced by a sum term..." For clarity, replace by "The conventional mass objective function is replaced by a sum of terms..." or equivalent.

- Abstract, page 1, line 8: "... numerical cost ..." Since "cost" was already used with a different meaning, replace by a different word to avoid confusion.

- Section 1, page 2, line 20: "... legs or bays are rather interesting than the exact dimensions". Replace "rather interesting" by "more critical" or similar.

- Section 1, page 3, line 2: "More realistic load sets..." Use "comprehensive" instead of "realistic".

- Section 2, page 3, line 31: "... are not impacted by design variables." Change to "... are not impacted by the selected design variables."

- Section 2, page 4, lines 1-4: I would recommend combining these two list entries into a single entry, since they are closely related.

- Section 3.2, page 7, line 13: Define the subscript index m in the text.

- Section 3.3, page 9, lines 13-14: Replace "A number of 128..." with "128 design load cases ..."

- Section 4, page 10, line 19: "... when the number of constraints and design variables are in the same dimension." Replace "dimension" with "order of magnitude".

- Section 5.2, page 12, line 1: ”... the soil layup of the Offshore Code ...” Replace ”layup” with ”conditions” and/or ”model” depending on what the intended meaning is.

- Section 5.4, page 16, line 6: ”The number of iterates may ...” Replace ”iterates” by ”iterations”.

- Section 5.4, page 16, lines 7-8: ”... but is not vital in this dimension of computational expenses.” Replace ”in this dimension” with ”at this level”.

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