Wind Energ. Sci. Discuss.,
doi:10.5194/wes-2016-37-RC2, 2017

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Interactive comment on "Effect of the Foundation Modelling on the Fatigue Lifetime of a Monopile-based Offshore Wind Turbine" *by* S. Aasen et al.

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Received and published: 24 January 2017

General comments

The paper is a case study that compares four different foundation models in the context of load analysis for offshore wind turbines. One model is the classical p-y approach, two models are strong simplifications using springs at mudline, and one model implements a nonlinear stiffness characteristic with hysteresis. The models are compared with respect to fatigue damage in time domain simulations using a typical set of operational load cases, including idling.

The topic is highly relevant for offshore wind energy, and it is interesting to see a new

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Discussion paper

foundation model evaluated. The paper is quite readable, and the topic suits Wind Energy Science journal well.

I would like to recommend publication, but I am not convinced of the value of the paper in its present form. My main issue with the paper is that the comparison of the different foundation models is not based on any common principles or a well thought of methodology. To put it differently, the comparison is not "fair", and therefore little knowledge can be gained from the study. Apart from that, I found a number of issues with the presentation that should be fixed. All of this is explained in my detailed comments below.

Specific comments

1. Section 4.4.3 describes the calibration of Model 3. This was performed using finite element simulations of soil behavior. However, important details about these simulations are missing - the number of elements, for example, and how the convergence of the solution was assessed. Why should we consider the results of these analyses as representative of reality? What gives us this confidence? Moreover, why were the loads applied with an arm of 40 m, whereas the real turbine has the thrust load acting at 107.6 m height? What loads were used? Were the properties of the soil model determined for each load case separately?

2. Section 4.4.3: to continue from the previous item, why were the other foundation models not also fitted to the results of the finite element simulations? This would allow for a much more interesting comparison. As it is, the different models lead to different natural frequencies and damping values of the wind turbine system, and therefore of course to differences in fatigue damage. It is unclear how results can be compared at all, and how the new Model 3 should be assessed relative to the existing models. A clear methodology is missing here.

3. Conclusions: "The results clearly show that choosing an appropriate conceptual

foundation model can have significant positive effects" - The word "positive" implies that we are interested in lower damage in the results of simulations, which is not necessarily the same as being interested in more realistic and more accurate models of the underlying physical processes. I would strongly recommend to remove the word "positive". Similarly, Model 3 seems to result in higher damping at high load levels, which is again judged to be "positive". The first question is, is it realistic? If you can demonstrate sufficiently that the Model is more accurate than the other models (even when these are fit and used optimally), then it is possible to mention that it is a positive thing that the damage is also less than previously thought.

4. Conclusions: I am missing a real conclusion of the study. What are the recommendations with respect to the discussed foundation models? Which one should we use?

5. Section 2.3 discusses previous work on numerical modelling of foundation effects in offshore wind turbines. While a number of recent references are given, I miss a mention of Zaaijer et al ("Foundation modelling to assess dynamic behaviour of offshore wind turbines", Applied Ocean Research 2006) where similar simplified spring models were studied, albeit for smaller wind turbines. Also the work of Achmus et al (e.g. "Behaviour of monopile foundations under cyclic lateral load", Computers & Geotechnics 2009) is relevant in this context.

6. Figures 2-5: The illustrations of the different foundation models are more confusing than useful and should be revised. For example, Figure 2 shows a point representing a stiffness matrix, whereas Figure 3 shows an additional rotational spring with a damper. However, the model in Figure 2 also has a rotational spring (if I understood it correctly), so why is there no spring in Figure 2 also? Figure 5 visualizing the model with a nonlinear characteristic and hysteresis contains an illustration of a number of elastic-perfectly plastic springs combined in parallel.

However, the spring used in the model is a rotational spring and not a translational spring as the illustration suggests.

7. There is some confusion with respect to the pile length below mudline. Figure 4 tells the reader that it is 10 m, whereas on the next page a value of 9.5 m is mentioned. It is also unclear to the reader why this particular value was chosen and if the results are sensitive to this aspect of the model.

8. Section 3.2.3: "Masing's rule" should be explained to readers not familiar with it.

9. Section 3.2.4: It is unclear which degrees of freedom are affected by this model. In particular, is it a 1D or 2D model? It is also unclear how the bottom of the pile is treated. Typically this is modelled as being clamped to the ground, to guarantee suitable boundary conditions for finite element analyses, but this seems not to be the case here?

10. The order of the models is somewhat unnatural. The classical p-y approach comes last, whereas it should probably be the first model. The new nonlinear model occurs in between, whereas it should probably be the last model.

11. Environmental data were taken from a 25 m site, but the study assumes 20 m of water depth. Why?

12. Section 4.4.1: "coupling effects between the two horizontal axes are neglected ... since mainly in plane loads are consider, the simplification is considered to be acceptable" - Does this reasoning also apply to the (important) idling load cases?

13. Figure 10: What are the scales? What are the units?

14. Figures 12-13: There seems to a mistake with the scales and units. The x-axes are similar, but with an order of magnitude difference? The y-axis in Figure 13 should read "Horizontal displacement ..."? The figure is also not displaying a moment-displacement curve as reported in the caption, is it?

15. Section 4.5: "Parameter values used in this thesis ..."? If the results in the paper are based on a master thesis, this needs to be mentioned (e.g. in a footnote) and the thesis should be cited.

16. Section 4.5: "absolute values should be evaluated accordingly" - I assume that you want to say that "the reported values should be evaluated accordingly?" It is not true that "This will not influence relative values ...", the results will be skewed to a certain degree - you should explain your reasoning here in more detail.

17. Figure 14: What are the eigenfrequencies of the different wind turbine models? The results of the decay test shown suggest that there are differences between the different models? Then the difference in accumulated damage reported in Figure 16 can probably be explained by these frequency differences already. It is unclear what further effects the differences in foundation modelling have. In particular, it is not true then that "it can be seen how the nonlinear foundation stiffness influence fatigue damage".

18. Figure 17: Comparing the damage for the idling load cases, it is unclear which of the wind turbine models can move in the side-to-side direction and which cannot - it seems that some foundation models restrict the relevant degrees of freedom, for example, whereas others do not. This could already explain a large amount of the differences and should be discussed in more detail. Especially since "this gives a significant contribution to the total fatigue damage" - please report quantitatively how large this contribution is, instead of just saying that it is "significant", which has no objective meaning here.

19. Figure 15 and Section 5.2: What are Models 2a and 2b? These should be introduced in Section 3.2, where the methods are described, not in the results section.

20. Section 5.2: "On these locations rotor dynamics dominate the loading, which are

not considerably influenced by the soil-foundation response." - This is somewhat surprising, as I would expect differences in damping (from the soil) and the eigen-frequencies of the structure to influence these results. Why is this not the case?

Technical corrections (p=page, l=line)

- p2, l15: "This foundation results in"?
- p4, l16: "depending on load level"?
- p4, l21: "and are a function"?
- p6, l11: "Airy wave components"?
- p6, l16: Reference to a webpage should preferably be a footnote
- p6, l16: Remove "crude", as this method has been the state of the art for a long time - and with reasons.
- p6, l20: "Model 4 refers"?
- p7, l7: "moments typically dominate ... for OWT monopiles"?
- p7, l11: I assume that omega is an "angular velocity"?
- p10, l13: "unit weight"
- p10, l10: One should focus on describing the model used to describe the wind, not on the particular implementation in specific software.
- p10, l13: "Airy wave"
- Table 1: Seems to contain a typo. The first probability of occurrence should be "0.00671"

- p12, l8: "are considered"?
- p13, l4: "the foundation stiffness for Model 1 is independent of load level" - this is presumably also the case for Model 2?
- Figure 10: "Rotational stiffness as a function ..."?
- p13, l16: Use decimal points for numbers, not decimal commas.
- p15, l2: "are included as reference" - It should be stressed here that these were not used to calibrate Model 3, to avoid confusion.
- Figure 12: Is this the same data as in Figure 10?
- Figure 15: The symbols in the graphs are not explained in the legend
- p20, l21: "Calculations were also done for the tower top and blade root".

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