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Reply on RC1

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Author comment on "Seismic soil–structure interaction analysis of wind turbine support structures using augmented complex mode superposition response spectrum method" by Masaru Kitahara and Takeshi Ishihara, Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2021-81-AC1, 2022

We would like to thank the reviewer for his/her comments and the time dedicated reviewing the manuscript. We have taken into account all the queries and requests from the reviewer. The individual responses to each comment are as follows.

Reply on C1:

As the reviewer mentioned, the present work is rooted on an existing technique for RSM (i.e., complex mode superposition RSM), however a novel method termed the augmented complex mode superposition RSM is developed by the authors to extend the applicability of the technique to wind turbine support structures. The novel contributions are mainly three folds:

(i) The already published study, in which the complex mode superposition RSM was proposed, was aimed at estimating peak values of story drifts of building type shear structures, and only the maximum displacement profile of multi-DOF system was analytically derived. On the other hand, the seismic design of wind turbine support structures requires the peak values of shear forces and bending moments acting on the towers and footings. Thus, the maximum shear force and bending moment profiles of multi-DOF system are analytically derived in the present study based on the framework of the complex mode superposition RSM.

(ii) While the modal damping rations are calculated by solving a complex eigenvalue problem in the complex mode superposition RSM, an empirical formula (Eq. 15) is proposed in the novel augmented complex mode superposition RSM to substitute 10 % for the excessive values of the modal damping ratios derived from the complex eigenvalue problem. This formula is not an existing one but is rather derived by the authors based on a parametric study in the present work, in which different modal damping ratios from < 1 % to > 50 % are considered for the footing sway motion modes, by changing tower geometries as well as soil conditions. (While the cases with different soil conditions are not in the current manuscript, the authors are ready to put it on the revised manuscript.) This parametric study demonstrates that the complex mode superposition RSM works well if the damping ratio is less than 10 %, whereas it underestimates the shear forces acting on the footings if the damping ratio is larger than 10 %. As a consequence, 10 % is proposed as a threshold and, it is validated through Figs. 6 and 8, where the augmented complex mode superposition RSM with the proposed formula accurately estimates the shear forces on the footings for all cases.

(iii) To consider the mass moment inertial of the rotor and nacelle assembly and the p-Δ effect, Eqs. (17-19) are derived by the authors based on the framework of the complex mode superposition RSM.

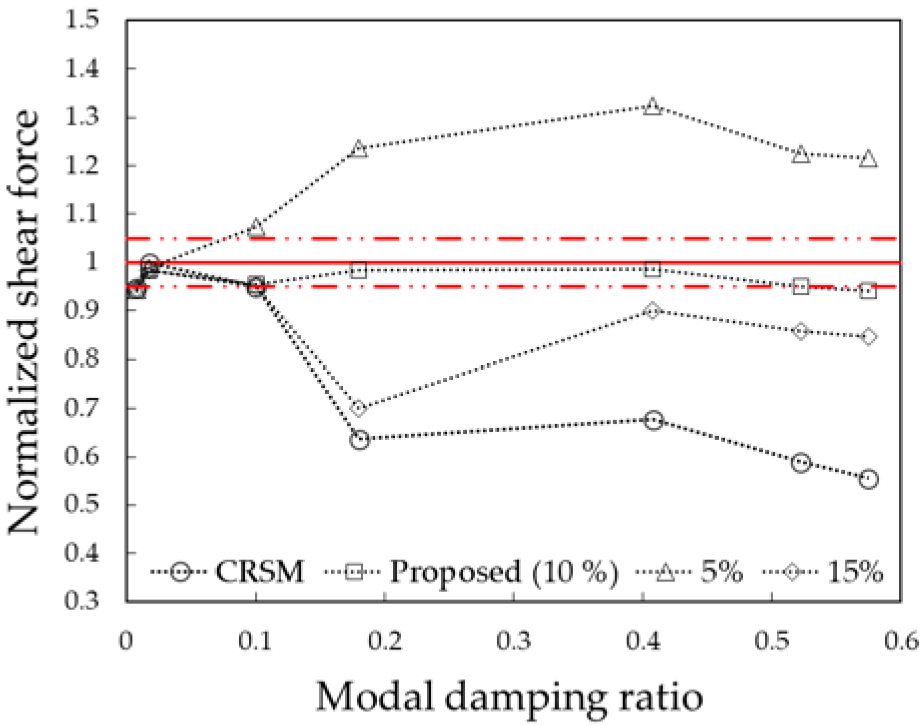
These three contributions are necessary to analytically estimate seismic loadings on the wind turbine support structures, and could result in an accurate and efficient seismic design framework. The authors will clearly state these contributions in the introduction part of the revised manuscript to emphasize the novelty of the present work.

Reply on C2:

As described above, the empirical formula, especially for the 0.1 value in it, is derived from the parametric study in the present work considering the damping ratios < 1 % to > 50 %.

Reply on C3:

Taking the reviewer's comment into account, the authors add an additional cases with different soil conditions to consider the modal damping ratios of 0.8 ,1.8, 10, and 18.5 %. The parametric study including these additional cases demonstrates that 10 % is a reasonable choice for the limit of the damping ratio over which the substitution should be take place. The following figure shows the normalized shear forces on the footings for the cases with the modal damping ratios as 0.8, 1.8, 10, 18.5, 40.8, 52.2, and 57.5 %. The last three cases are used in the case study with different rated powers. It is demonstrated that the original complex mode superposition RSM (termed as CRSM) severely underestimates the shear forces on the footings. Three candidate values for threshold, i.e., 5, 10, and 15 %, are considered, and it can be seen that taking 5 and 15 % as threshold over/underestimate the shear forces, while taking 10 % provides the results with satisfactory accuracy of the relative errors less than 5 %. The authors will also add this figure in the revised manuscript to show the resutls of the parametric study.



Reply on C4:

In the entire manuscript, the authors used artificially generated ground motions obtained from the design spectra. In Fig. 3, not the response spectra of recorded strong ground motions but the artificially generated ground motions having the phase properties of these recorded strong ground motions are illustrated. In the revised manuscript, the authors will modify the captions in Fig. 3 such as “El Centro phase” to avoid confusion.

Reply on C5:

Figs. 5-7 show the results of the 2 MW wind turbines with two foundation solutions, i.e., gravity and piles, while Fig. 8 illustrates the results of the case study varying the rated power. The authors will carefully refer these figures in the revised manuscript so that the readers can understand to which of the cases do these figures correspond.