Reply to Reviewers' and Editor's Comments

(Manuscript number: wes-2023-149)

Fatigue life evaluation of offshore wind turbines considering scour and passive structural control

By Yu Cao, Ningyu Wu, Jigang Yang, Chao Chen, Ronghua Zhu, Xugang Hua

Overall Response:

We are very grateful to the Editor and Reviewers for their constructive comments on this manuscript. We have revised and improved the manuscript based on the comments and clarified the issues brought up in the paper. In the following sections, point-by-point responses to the comments were provided. The original comments are in italics. The authors' responses are highlighted in blue. The corresponding changes are highlighted in red in the revised manuscript.

Other comments:

Reviewer #1

Comment 1: *In Section 2.1, the combined soil and structural damping is presented as 1% without elaboration. This figure seems quite low for soil. Also, how is this implemented in Rayleigh damping?*

Response: In this study, both soil damping and structural damping are combined together and set as Rayleigh damping. The Rayleigh mass coefficients and Rayleigh stiffness coefficients are calculated by the follow equation.

$$\alpha_1 = \alpha_2 = \frac{\zeta_C}{\frac{1}{2\omega} + \frac{\omega}{2}}$$

where α_1 and α_2 are the Rayleigh mass and stiffness coefficients, respectively ω is the natural frequency of the 1st fore-aft mode, and ζ_C is the combined damping ratio.

According to the authors' previous studies on damping in monopile-supported OWTs (Chen and Duffour, 2018) , the structural damping is in the range of 0.2%-1.5%, and the soil damping is between 0.17% -1.3%, so a total damping ratio of 1% for the first mode is a little small but still a rational quantify to define the damping.

Revised manuscript:

L110-L115: The damping matrix is applied by means of Rayleigh damping, and the combined damping ratio of soil damping and structural damping is assumed to be 1% (Chen and Duffour, 2018) . The Rayleigh mass and stiffness coefficients α_1 and α_2 are defined by $\alpha_1 = \alpha_2 = \frac{\zeta_C}{\frac{1}{2\omega}+\frac{\omega}{2}}$. ω is the natural frequency of the first fore-aft mode, and ζ_C is the combined damping ratio. The RNA is represented by a lumped mass at the tower top.

Comment 2: *In Equations 1 and 2, there is ambiguity regarding dimensions. How are "C_T" and "K_T" defined, and how do they differ from "c_T" and "k_T"? Since the TMD should have one DOF, how is the "u_T" vector defined?*

Response: In Equations 1 and 2, there is indeed an ambiguity about the matrix dimension problem. Equations 1 and 2 have been modified to clarify the matrix notations as follows:

$$\mathbf{M}_\mathrm{S}\ddot{\mathbf{U}}_\mathrm{S} + \mathbf{C}_\mathrm{S}\dot{\mathbf{U}}_\mathrm{S} + \mathbf{K}_\mathrm{S}\mathbf{U}_\mathrm{S} + \mathbf{C}_\mathrm{T}(\dot{\mathbf{U}}_\mathrm{S} - \dot{\mathbf{U}}_\mathrm{T}) + \mathbf{K}_\mathrm{T}(\mathbf{U}_\mathrm{S} - \mathbf{U}_\mathrm{T}) = \mathbf{F}_\mathrm{wind} + \mathbf{F}_\mathrm{wave}, \quad (1)$$

$$\mathrm{m}_\mathrm{T}\ddot{\mathrm{u}}_\mathrm{T} + \mathrm{c}_\mathrm{T}(\dot{\mathrm{u}}_\mathrm{T} - \dot{\mathrm{u}}_{s-top}) + \mathrm{k}_\mathrm{T}(\mathrm{u}_\mathrm{T} - \mathrm{u}_{s-top}) = 0, \quad (2)$$

In Equation 1, the equation is constructed based on all the nodes of the wind turbine structure plus the tunned mass damper. $\mathbf{M}_\mathrm{S}, \mathbf{C}_\mathrm{S}, \mathbf{K}_\mathrm{S}, \mathbf{C}_\mathrm{T}, \mathbf{K}_\mathrm{T}$ have the same dimensions, and $\mathbf{U}_\mathrm{S}, \mathbf{U}_\mathrm{T}$ have the same dimensions. In Equation 2, the equation is constructed for the TMD node at the top of the tower, $\mathrm{m}_\mathrm{T}, \mathrm{c}_\mathrm{T}, \mathrm{k}_\mathrm{T}$ are the mass, damping and stiffness of the TMD, and $\mathrm{u_T}, \mathrm{u}_{\mathrm{s}-top}$ are the displacement of the TMD and the displacement of the top node respectively.

The definitions of $\mathbf{C_T}, \mathbf{K_T}, \mathrm{c_T}, \mathrm{k_T}$ are explained as follows: $\mathbf{C_T}$ is a matrix containing $\mathrm{c_T}$, $\mathbf{K_T}$ is a matrix containing $\mathrm{k_T}$, and their relations are as follows:

$$\mathbf{C_T} = \begin{bmatrix} 0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \mathrm{c_T} \end{bmatrix}, \mathbf{K_T} = \begin{bmatrix} 0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & k_\mathrm{T} \end{bmatrix}, \mathbf{U_T} = \begin{bmatrix} 0 \\ \vdots \\ \mathrm{u_T} \end{bmatrix}, \mathbf{U_s} = \begin{bmatrix} \mathrm{u_{s-1}} \\ \vdots \\ \mathrm{u}_{\mathrm{s}-top} \end{bmatrix}$$

$\mathrm{u_T}$ is the absolute displacement of TMD at the top of the tower. In this paper, TMD moves in the FA direction and does not move in the SS direction, so $\mathrm{u_T}$ is the displacement vector of TMD in the FA direction with respect to time.

Revised manuscript:

L118-L130: The TMD is mounted on the top of the tower, and the effect of the TMD is considered by adding its mass, damping, and stiffness terms at relevant positions in the local mass, damping, and stiffness matrices of the beam element representing the tower top. The equation of motion of the OWT main structure is:

$$\mathbf{M_s}\ddot{\mathbf{U}}_\mathbf{s} + \mathbf{C_s}\dot{\mathbf{U}}_\mathbf{s} + \mathbf{K_s}\mathbf{U_s} + \mathbf{C_T}(\dot{\mathbf{U}}_\mathbf{s} - \dot{\mathbf{U}}_\mathbf{T}) + \mathbf{K_T}(\mathbf{U_s} - \mathbf{U_T}) = \mathbf{F_{wind}} + \mathbf{F_{wave}}, \quad (1)$$

where $\mathbf{M_s}$, $\mathbf{C_s}$, $\mathbf{K_s}$ are the mass, damping and stiffness matrices of the main structure. $\mathbf{C_T}, \mathbf{K_T}$ are matrices with same dimensions containing $\mathrm{c_T}, \mathrm{k_T}$. $\mathbf{U_s}$ is the displacement vector of the main structure, and $\mathbf{U_T}$ is the displacement vector containing $\mathrm{u_T}$. $\mathbf{F_{wind}}$, $\mathbf{F_{wave}}$ are the aerodynamic and wave load vectors. The equation of motion for the TMD can be represented by

$$\mathrm{m_T}\ddot{\mathrm{u}}_\mathrm{T} + \mathrm{c_T}(\dot{\mathrm{u}}_\mathrm{T} - \dot{\mathrm{u}}_{\mathrm{s}-top}) + \mathrm{k_T}(\mathrm{u_T} - \mathrm{u}_{\mathrm{s}-top}) = 0, \quad (2)$$

where $\mathrm{m_T}, \mathrm{c_T}, \mathrm{k_T}$ are the mass, damping and stiffness of the TMD, $\mathrm{u_T}, \mathrm{u}_{\mathrm{s}-top}$ are the displacement of the TMD and the displacement of the top node. The modelling of SSI is realized by an equivalent stiffness matrix, which will be introduced in detail subsequently in Section 2.3.

Comment 3**：** *In Section 2.4, the forces on the right side of Equation 6 are nonlinear, and their truncation essentially linearizes them. Please elaborate on this and clarify this step in the manuscript.*

Response: Sorry for the confusion. In Equation 6, before the modal reduction to a 4-DOF model, it indeed requires linearizing the aerodynamic forces from the rotor on the tower top and the hydrodynamic forces, which are not mentioned in the manuscript. We have added explanations for the force linearization.

Revised manuscript:

L244-L249: The total aerodynamic forces from the rotor applied on the tower top node are linearized to the sum of a term corresponding to the forces for an assumed rigid tower, plus a term proportional to the tower top linear and angular velocities. The hydrodynamic forces are linearized by ignoring the relatively small monopile vibrations. The details for force linearization can be found in the authors' previous studies (Chen, Duffour, Fromme, et al., 2021).

Reference:

Chen, C., Duffour, P., Fromme, P. and Hua, X. (2021). Numerically efficient fatigue life prediction of offshore wind turbines using aerodynamic decoupling. Renew. Energy, 178, 1421–1434. https://doi.org/10.1016/j.renene.2021.06.115

Comment 4**：** *According to Section 3, the studied TMD operates in the FA direction, and the SS direction is uncontrolled. This should be mentioned in the Abstract, Introduction, and Conclusion sections.*

Response: The authors have revised the abstract, introduction and conclusion, adding the explanation that TMD operates in the FA direction, and the SS direction is uncontrolled.

Revised manuscript:

L24-L28: Abstract: This optimization technique aims at finding optimal parameters of the TMD which maximizes the fatigue life of a hotspot at the mudline, and effect of time-varying scour can be considered. This study assumes the TMD operates in the FA direction, and the vibration in the SS direction is uncontrolled.

L85-L86: Introduction: The TMD operates in the FA direction and does not work in the SS direction.

L551-L552: Conclusions: This study establishes a rapid numerical model which can consider the effect of scour and installation of a TMD, and the TMD operates only in the FA direction.

Comment 5：*The mass ratio of the TMD, chosen as 1% in the study, is quite low and could result in unfeasible TMD displacement. This effect should be discussed.*

Response: Thank you for your suggestion. The authors find that there is indeed a lack of discussion about whether the feasible displacement of TMD is sufficient. According to many engineering practices, TMDs with a mass ratio of 1%-2% can effectively suppress the wind-induced vibration of high-rise building structures. Moreover, previous studies have found that the TLCD with a mass ratio of 1% and the TMD with a mass ratio of 2% can effectively suppress vibration (Colwell and Basu, 2009; Lackner and Rotea, 2011b; R. Zhang et al., 2019). In the study, the authors considered that excessive mass would lead to increased construction cost and difficulty, as well as the excessive change of the inherent characteristics of the original structure, so the mass ratio of TMD was chosen to be 1%. And according to your comments, the authors studied feasible displacements with a mass ratio of 1%. The authors have calculated the displacements of the top of the wind turbine tower and TMD under the wind speed of 22m/s. It is found that the relative displacement between TMD and tower top is smaller than the inner diameter of tower top, indicating that there is no unfeasible displacement.

Revised manuscript:

L325-L330: Considering that excessive mass will lead to increased construction costs and difficulties and changes in the inherent characteristics of the original structure, the mass ratio of the TMD system to the main structure is first selected to be 1%. Moreover, previous studies have found that TLCD with a mass ratio of 1% and TMD with a mass ratio of 2% can effectively suppress vibration (Colwell and Basu, 2009; Lackner and Rotea, 2011b; R. Zhang et al., 2019).

L426-L433: In the TMD design process, the feasible displacement should be considered. The smaller the mass ratio of TMD is, the larger the feasible displacement is required. The 22nd environmental state corresponds to the greatest vibration responses of the wind turbine tower top due to large wind speed variations and lower aerodynamic damping, and the stroke of the TMD could be the largest. As shown in the Fig. , the relative displacement between the TMD and the tower top is much less than the inner diameter of the wind turbine tower top in the 22nd environmental state. It shows that the stroke of the TMD is sufficient when the mass ratio of TMD is 1%.

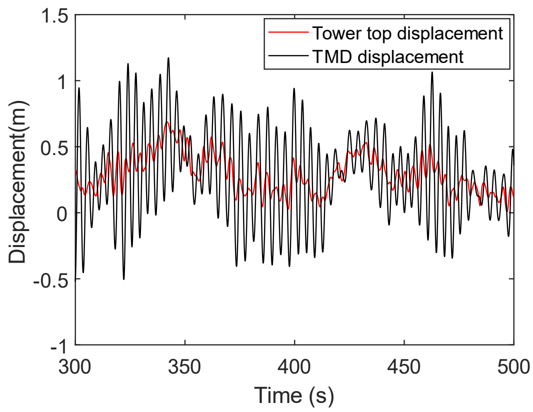


Fig. 9 Displacement of tower top and TMD under the 22nd environmental state

Reference

Colwell, S. and Basu, B. (2009). Tuned liquid column dampers in offshore wind turbines for structural control. Engineering Structures, 31(2), 358–368. https://doi.org/10.1016/j.engstruct.2008.09.001

Lackner, M. A. and Rotea, M. A. (2011b). Structural control of floating wind turbines.

Mechatronics, 21(4), 704–719. https://doi.org/10.1016/j.mechatronics.2010.11.007

Zhang, R., Zhao, Z. and Dai, K. (2019). Seismic response mitigation of a wind turbine tower using a tuned parallel inerter mass system. Engineering Structures, 180, 29–39. https://doi.org/10.1016/j.engstruct.2018.11.020

Comment 6： *Section 4.5 presents additional results with the TMD (FOT), optimized considering overall fatigue performance. These results should be integrated into Section 4.4 and presented alongside the TMD optimized for the initial state of the structure. This would allow, for example, the inclusion of a third and fourth curve in Figure 9, showing results incorporating TMDs optimized by FOT."*

Response: The author divided the contents of 4.4 and 4.5 into two sections, mainly due to the different main contents of the two sections. In section 4.4, the influence of scour depth changes on the fatigue life of wind turbines with or without coupling TMD is mainly studied. In section 4.5, the TMD parameter optimization based on the overall fatigue life of the wind turbine is mainly studied when the wind turbine is at a given mass ratio or a given mass ratio interval considering time-varying scour depth.

It is not reasonable to add the optimization results of TMD to Figure 9. In section 4.5, the TMD parameter optimization based on the overall fatigue life of the wind turbine is performed according to the time-varying scour depth. The fatigue life calculation for the parameters of the initial TMD of the structure is shown in Table 6. In this section, the scour depth is constantly changing, and the relation curve between scour depth and time refers to the scour curve of N7 single pile in the North Sea in Figure 5. The results show a fatigue life at different scour depths, so they cannot be added to Figure 9.

Comment 7： *Title: Consider the alternative, "Effect of Scour on the Fatigue Life of Offshore Wind Turbines and Its Prevention Through Passive Structural Control."*

Response: Thank you for your suggestion. The alternative topic you provided not only shows the influence of scour on fatigue life of wind turbines, but also further highlights the prevention of fatigue damage caused by scour of wind turbines through passive control. We think your proposed alternative title really better fits to the research content of this article. So, we decide to change the article title according to your suggestion.

Revised manuscript:

L1-L2: Title: Effect of scour on the fatigue life of offshore wind turbines and its prevention through passive structural control

Comment 8: *Abstract: The text requires editing. Some sentences are difficult to understand and contain grammatical errors. For example, ""... either by a traditional method or a newly developed ..."" should be ""... both a traditional method and a newly developed ... are presented.". Additionally, the sentence "... scour can decrease the fatigue life by about 26%, and the TMD can ... increase the fatigue life," lacks complete information about the effect of TMD. Also, the tenses change inconsistently throughout the text.*

Response: There are indeed grammatical errors and difficulties in understanding the sentences in the abstract. According to your valuable comments, the authors have modified the grammar and sentence to make the expression of the content more understandable and convenient for readers to read.

Revised manuscript:

L17-L34: Abstract: Offshore wind turbine (OWT) support structures are exposed to the risk of fatigue damages and scour, and this risk can be effectively mitigated by installing structural control devices such as tuned mass dampers (TMDs). However, time-varying scour altering OWTs' dynamic characteristics has an impact on the TMD design and fatigue life, which was rarely studied before. In this paper, a simplified modal model is used to investigate the influence of scour and a TMD on the fatigue life evaluation of a 5 MW OWT's support structure, and a traditional method and a newly developed optimization technique are both presented to obtain TMD parameters. This optimization technique aims at finding optimal parameters of the TMD which maximizes the fatigue life of a hotspot at the mudline, and effect of time-varying scour can be considered. This study assumes the TMD operates in the FA direction, and the vibration in the SS direction is uncontrolled. Results show that scour can decrease the fatigue life by about 24.1%, and the TMD can effectively suppress vibration and increase the fatigue life. When the scour depth reaches 1.3 times the pile diameter, the TMD with a mass ratio of 1% can increase the fatigue life of OWT's support structure by about 64.6%. Further, it is found that the fatigue life can be extended by 25% with the TMD optimized by the proposed optimization technique, compared to that with the traditionally optimized TMD which does not take the change of dynamic characteristics into account.

Comment 9: *In the Introduction, the literature review includes vibration control systems only up to 2021. Recent years have seen accelerated developments, including floating and monopile OWTs. Presenting these up-to-date examples would more clearly define the research gap.*

Response: The author fully agrees with you about the lack of the latest research status in recent years in the introduction and has revised and improved the introduction according to your suggestions.

Revised manuscript:

L38-L70: Introduction: With the continuous development of large-size fixed-bottom OWTs, local scour and scour protection of pile foundation have become a common issue (L. Wang et al., 2020; X. Wang et al., 2019; F. Zhang et al., 2022). Scour have a significant impact on dynamic characteristics, vibration magnitudes, and thus fatigue life of OWTs under wind and wave loads. On the one hand, the action of currents and waves causes local scour pits around pile foundations, which reduces the burial depth of pile foundations. This phenomenon usually causes a reduction in natural frequencies of OWTs and changes in other dynamic characteristics, possibly leading to resonance, large amplitude stress cycles and fatigue damage when one of natural frequencies is close to the rotational frequency of the blades (Sørensen and Ibsen, 2013). On the other hand, current scour protection measures cannot completely avoid scour and have their own shortcomings. For example, armouring protection has the disadvantages that the projectile cannot be accurately cast in complex sea conditions and is easy to be washed away (G. Wang et al., 2023; F. Zhang et al., 2023). Flow-altering protection has the disadvantages of high cost and changing the dynamic characteristics of the foundation (Tang et al., 2023). As offshore structures, wind turbines are vulnerable to corrosion from seawater, which makes the fatigue problem worse (Amirafshari et al., 2021). Thus, the scour-induced changes in dynamic characteristics and risk in resonance inevitably induce a further increase in fatigue damage and deserve in-depth research (Mayall et al., 2018).

Many researchers have studied the effect of scour on fatigue damage accumulation in OWTs. For instance, Tempel et al. (2006) investigated the frequency and fatigue of piles under different scour depths and concluded that scour has a little effect on the natural frequencies but a great effect on fatigue damage. Zhang et al. (2021) found that scour depth has a significant influence on monopile impedance. Rezaei et al. (2018) showed that scour leads to an increase in the maximum bending moment of the monopile and a shortening of the fatigue life. To mitigate the fatigue damage in OWTs, installing structural control devices is an effective way. It was demonstrated that TMDs have a positive effect on reducing vibration amplitudes of wind turbine systems (Lackner and Rotea, 2011a; Dinh and Basu, 2015; Lu et al., 2023; Aydin et al., 2023). Dai et al. (2021) conducted a shaker experiment using a scaled wind turbine model and showed that the installed TMD can suppress the vibration of the structure more effectively considering soil-structure interaction (SSI).

Comment 10： *Again in the Introduction, the paper's contribution should be stated in the present tense: "In this study, ABAQUS is used ..." Furthermore, it is unclear what the FE model in MATLAB includes. The text mentions considering the scour effect, but the previous sentence stated ABAQUS was used for SSI.*

Response: According to your comments, the authors have modified the tenses. There is ambiguity about the description of the MATLAB model and the presentation of this part is modified in the original manuscript. In the wind load module, turbulent wind and constant wind can be generated according to demand, and in the hydrodynamic module, regular and irregular wave loads can be generated. The TMD module can set different parameters, and the beam element method is used to build wind turbine models of different sizes in the structure module. Regarding the scour effect mentioned in MATLAB, it is achieved by means of an equivalent stiffness matrix derived from the ABAQUS model.

Revised manuscript:

L77-L86: The purpose of this study is to explore the effect of scour on the fatigue life of wind turbine structures and the control effect of TMD on the fatigue life of wind turbine structures under scour conditions. The authors use a 5 MW single-pile wind turbine as a case study to carry out related research. In this study, ABAQUS is used to establish a detailed SSI model with different scour depths. A finite element model considering wind loads and TMD was established in MATLAB, and the scour effect is considered by establishing a relationship with the ABAQUS model by means of the equivalent stiffness matrix. And the finite element model is simplified to a modal model for fast prediction of fatigue life. The TMD operates in the FA direction and does not work in the SS direction.

Comment 11： *The paragraph mentioned above should first introduce the objectives of the study. Currently, it summarizes only the methodology. The overall purpose should be clarified as: "The aim of the present study is to ... (investigate the effect of scour ...*

introduce an optimization method for TMDs ... through a case study involving a monopile 5 MW wind turbine.)"

Response: The author agrees with you and has adjusted the content of the introduction. The author first introduces the purpose of the study, and then introduces the method of the study.

Revised manuscript:

L77-L92: The purpose of this study is to explore the effect of scour on the fatigue life of wind turbine structures and the control effect of TMD on the fatigue life of wind turbine structures under scour conditions. The authors use a 5 MW single-pile wind turbine as a case study to carry out related research. In this study, ABAQUS is used to establish a detailed SSI model with different scour depths. A finite element model considering wind load and TMD was established in MATLAB, and the scour effect is considered by establishing a relationship with the ABAQUS model by means of the equivalent stiffness matrix. And the finite element model is simplified to a modal model for fast prediction of fatigue life. The TMD operates in the FA direction and does not work in the SS direction. This study investigates the effect of different scour depths on the performance of the TMD and the fatigue life of a 5 MW OWT's support structure including a tower and a monopile foundation, and the optimization of the TMD's parameters considering time-varying scour depths to maximum fatigue life is also presented. This study provides some knowledge of the effects of the time varying scour and the TMD on the fatigue life of wind turbines, as well as a new TMD design method targeting at enhancing fatigue resistance.

Comment 12: *At the end of the Introduction, the structure of the paper should be outlined: "The remainder of the paper is organized as follows: Section 2 describes ..."*

Response: The author highly appreciates your comments. According to your comments, the author added an overview of the structure of the paper at the end of the introduction, providing a systematic overview of the content of each chapter.

Revised manuscript:

L92-L96: The rest of the paper is organized as follows: Section 2 introduces the numerical models used in the research. Section 3 introduces the traditional TMD design method and the newly developed parameter optimization method. Section 4 describes the load cases for the fatigue analysis, the analysis results of this study and the TMD parameter optimization results. Section 5 concludes the study.

Comment 13： *In Figures 9 and 10, adding a grid or labeling significant values on both curves would be helpful.*

Response: Thank you for your suggestion. The author highly appreciates your comments. According to your comments, the author modified Figure 9 and Figure 10 by adding grid lines to the graph to make the results better presented and easier for readers to read.

Revised manuscript:

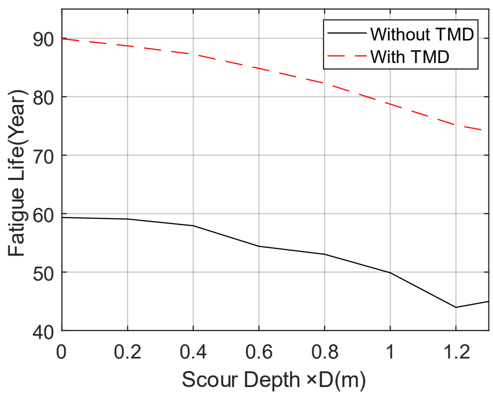


Fig. 13. Fatigue life of wind turbine with different scour depths

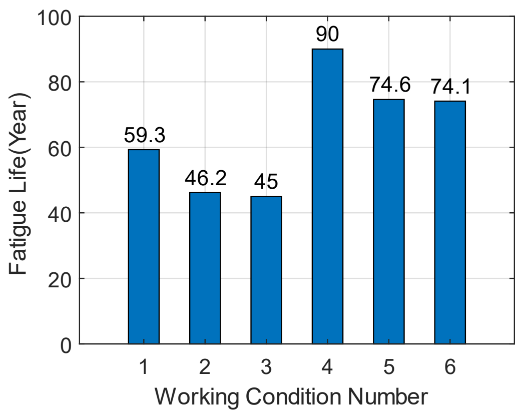


Fig. 14. Fatigue life of the wind turbine under six operating conditions

Comment 14： *In Figures, try to use for better resolution.*

Response: Thank you for your suggestion. The author highly appreciates your comments. According to your comments, the authors have altered all the pictures.

Revised manuscript:

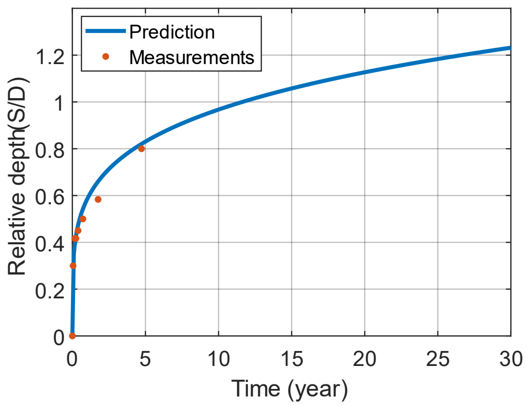


Fig. 7. Time-varying scour depth curve for pile N7 in the North Sea

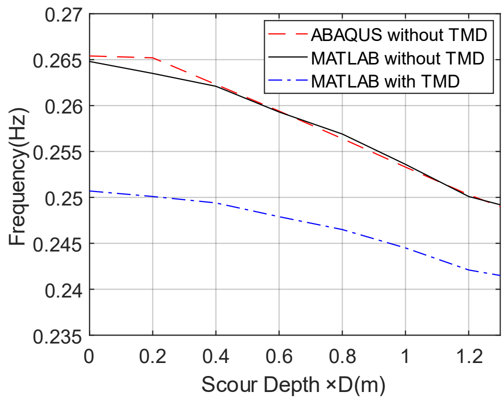


Fig. 8. Relationship between wind turbine natural frequency and scour depth

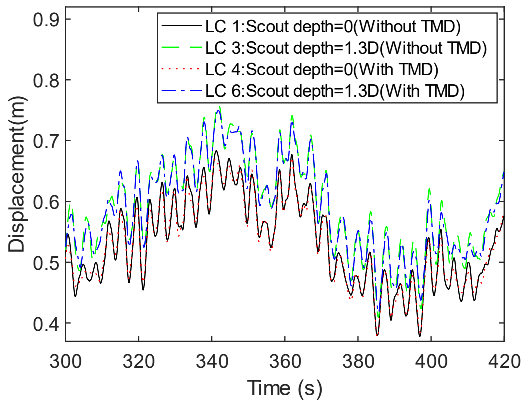
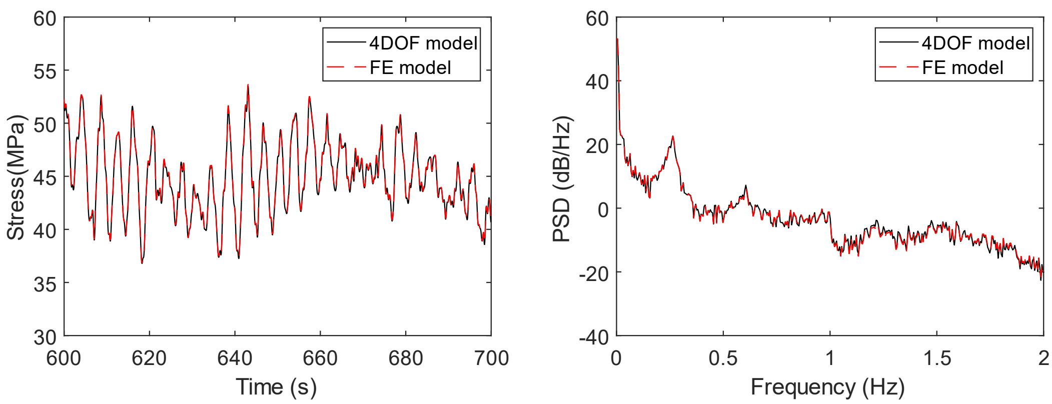


Fig. 10. Dynamic response of wind turbine under wind-wave coupled loads for four operating conditions



(a) (b)

Fig. 12. Comparison of stresses at the mudline from the FE model and the 4-DOF model in time domain (a) and frequency domain (b)

Comment 15： *There are quite a few self-citations (e.g., Chen 2018- Chen 2021: 6 times). Please, check the necessity of these references.*

Response: The author highly appreciates your comments. According to your comments, the authors have further checked the self-citations, and found that the fourth and the fifth of the six self-citations are repeated citations, and the repeated citation has been removed. The self-citations are explained as follows:

The paper "Modelling wind turbine tower-rotor interaction through an aerodynamic damping matrix" is cited mainly because the wind load calculation method and aerodynamic linearization technology adopted in this study follows the method in this reference.

The authors adopt the values of damping ratio is based on previous research achievements, so [Modelling damping sources in monopile-supported offshore wind turbines] is necessary. The details for force linearization can be found in [Identification of aerodynamic damping matrix for operating wind turbines]. The calculation method of wind load and the establishment method of simplified modal model refer to the previous paper: [Numerically efficient fatigue life prediction of offshore wind turbines using aerodynamic decoupling].

Revised manuscript:

References

Chen, C. and Duffour, P. (2018). Modelling damping sources in monopile-supported offshore wind turbines. Wind Energy, 21(11), 1121–1140. https://doi.org/10.1002/we.2218

Chen, C., Duffour, P., Dai, K., Wang, Y. and Fromme, P. (2021). Identification of aerodynamic damping matrix for operating wind turbines. Mech. Syst. Signal Process., 154, 107568. https://doi.org/10.1016/j.ymssp.2020.107568

Chen, C., Duffour, P. and Fromme, P. (2020). Modelling wind turbine tower-rotor interaction through an aerodynamic damping matrix. J. Sound Vib., 489, 115667. https://doi.org/10.1016/j.jsv.2020.115667

Chen, C., Duffour, P., Fromme, P. and Hua, X. (2021). Numerically efficient fatigue life prediction of offshore wind turbines using aerodynamic decoupling. Renew. Energy, 178, 1421–1434. https://doi.org/10.1016/j.renene.2021.06.115