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Investigating Orthogonal Wavelets in the Damage Detection of the Wind Turbine Tower with Soil-Structure Interaction

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1. Introduction

Wind energy is one of the most hopeful renewable energy sources that is also growing. The wind turbine tower supports the complete wind turbine system, and its damage may cause catastrophic failure of the wind turbine. In this study, the extensive analysis of the multilevel 2D wavelet decomposition approach, using orthogonal wavelets and soil-structure interaction, is performed numerically. The established finite element model is calibrated and verified with the NREL 5-MW reference onshore wind turbine. Then, defining several damage scenarios, the 3-dimensional modes of the finite element model of the damaged structure are investigated using the proposed method. The findings imply that the quality of the damage detection in the soil-structure interaction models has generally increased.

2. Review of the Suggested Method

The finite element model based on the NREL 5-MW wind turbine is developed in the commercial finite element program Abaqus/CAE 6.14-2 x64. A correlation is made between the predicted modal frequencies from the developed model and FAST for the fixed base wind turbine model. Eighteen damage scenarios have been imagined on the wind turbine tower. The foundation is examined on two different soils, a normally consolidated clay and dense sand. The multilevel 2D wavelet decomposition approach using orthogonal wavelets was used to detect damage in a wind turbine tower. Table 1 displays the names of all available orthogonal wavelet families and their wavelets for MATLAB R2016b.

The first three fundamental mode shapes of the tower were used for input signals of the wavelet algorithm. MATLAB DWT is applied to the spatial mode shape of the FEM model and thereby identifies damage-induced irregularities in the mode shape according to wavelet diagonal detail coefficients.

Table 1. All available orthogonal wavelet families and their wavelets for MATLAB

Family	Wavelets
Haar	Haar
Daubechies	db1, db2, db3, db4, db5, db6, db7, db8, db9, db10, db**
Symlets	sym2, sym3, sym4, sym5, sym6, sym7, sym8, sym**
Coiflets	coif1, coif2, coif3, coif4, coif5
DMeyer	Dmey
Fejer-Korovkin	fk4, fk6, fk8, fk14, fk18, fk22

3. Modeling the Wind Turbine

The 3D FEA model was used for modeling the wind turbine, and a Cartesian coordinate system was chosen. Figure 1 shows 3D finite element model of the full turbine-foundation-soil. The wind tower has a circular hollow-section with the diameter and wall thickness decreasing linearly along its height.

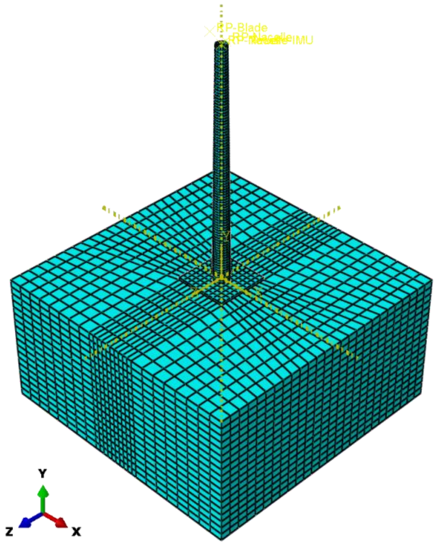

Figure 1. 3D finite element model of the full turbine-foundation-soil

The considered foundation is a square concrete 20 m × 20 m and 1 m in depth and is modeled by a linear isotropic plate of thickness 1 m. The soil was modeled to a depth of over 50 meters and a horizontal distance of over 100 meters.

4. Damage Detection of the Wind Turbine Tower

A maximum of three decomposition levels is done for the discrete wavelet transform of the first three fundamental mode shapes of the wind tower. The results shows that the mode shapes for an undamaged and damaged tower have no meaningful difference from each other.

Figure 2 shows the results of DWT analyses for the second longitudinal mode shape without SSI of damage scenario 5 with Fejer-Korovkin8 (FK8) wavelet transform decomposition at level 3. As can be seen in this figure, the damage elevation position has been accurately detected on it.

The quantitative number of wavelets that were allowed in the acceptable range is summarized in Table. Conditions 1, 2, and 3 refer to the fully fixed model, SSI (soil 1) and SSI (soil 2), respectively. According to this table, except for the first and second lateral mode shapes, the remainders of the mode shapes have an increasing number of permissible answers. Furthermore, the effect of soil-structure interaction is significant. The results show a 36% and 19% increase in the number of

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permissible soil-structure interaction responses compared to the fully fixed model for scenarios 1 to 9 and 10 to 18, respectively.

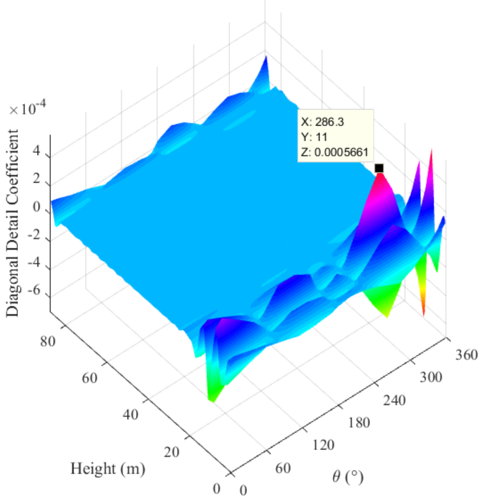

Figure 2. DWT of 2nd fore-aft mode shape without SSI of damage scenario 5 with FK8 wavelet transform decomposition at level 3

Table 2. The quantitative number of wavelets that were allowed in the acceptable range

Scenario	Condition	fore-aft mode shape			side-to-side mode shape			Total
		1st	2nd	3rd	1st	2nd	3rd	
1 to 9	1	22	13	13	17	1	126	192
	2	49	34	20	13	0	145	261
	3	49	34	20	13	0	145	261
10 to 18	1	35	61	113	76	116	143	544
	2	68	64	112	73	182	149	648
	3	68	64	99	73	182	128	614

5. Conclusion

The main results of this research are reviewed as follows:

1. The level 2 wavelet decomposition had the best performance for different damage scenarios and two soil types;
2. Where the severity of the damage is not as high, the accurate detection of damage is harder;
3. The best orthogonal wavelets with the best quality response in scenarios 1 to 9 with/without SSI are as follows: Daubechies 5, Daubechies 9, and Symlets 7 at the level 2 decomposition of the first fore-aft mode shape with qualitative accuracy of 0.5 to 1.0 m;
4. The best orthogonal wavelets that have the best quality response in scenario 10 to 18 with/without SSI are as follows: Daubechies 3 and Symlets 3 at the level 2 and Fejer-Korovkin 8 at the level 1 decomposition of the first side-to-side mode shape and Daubechies 2 and Symlets 2 at the level 2 decomposition of the third side-to-side with qualitative accuracy of 0 to 0.5 m.