Development and Validation of Structural Models for Wind Turbine Composite Blades

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1. Introduction

Wind turbine blades are generally made of composite materials due to their good fatigue performance and high strength-to-weight ratio. Due to the inherent complexity of composite materials and the complicated blade structural layout, accurate and efficient structural modelling of wind turbine composite blades is quite challenging.

Structural models used for wind turbine composite blades can be roughly classified into two groups, i.e. 3D FEA (finite element analysis) model and 1D beam model. Input data of 3D FEA model are the blade geometry information and the blade structural layout information. Constructing 1D beam model requires cross-sectional properties of the composite blades, such as sectional stiffness, which can be obtained by using specialised cross-sectional analysis models, such as PreComp [1], CBCSA [2] and VABS [3]. Due to its efficiency, 1D beam model has been widely used for aeroelasticity analysis of wind turbine blades [4, 5].

In order to facilitate the structural design optimisation of wind turbine composite blades, it is crucial to develop validated structural models for the blades. This paper aims to develop both 3D FEA model and 1D beam model for wind turbine composite blades and to validate both models against each other and against available experimental data.

2. Approach

2.1. Development of 3D parametric FEA model

Due to the complicated aerodynamic shape and structural layout of a wind turbine composite blade, generating a 3D FEA model of the blade using general-purpose commercial finite element packages, such as ANSYS [6] and Abaqus [7], is tedious and time-consuming. In order to facilitate the generation of 3D FEA models of wind turbine composite blades, a Matlab code called ParaFemBlades (**Para**metric **F**inite **e**lement **m**odelling of wind turbine composite **Blades**) has been developed. The blade geometry information (such as chord and twist angle distributions) and the blade structural layout information (such

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as shear web locations and composite layups) are stored in text files. The Matlab code ParaFemBlades reads the input files and then outputs a series of APDL (ANSYS Parametric Design Language) commands, which can be recognised by ANSYS to perform parametric finite element modelling of wind turbine composite blades. The schematic of the parametric FEA model is presented in Fig. 1.

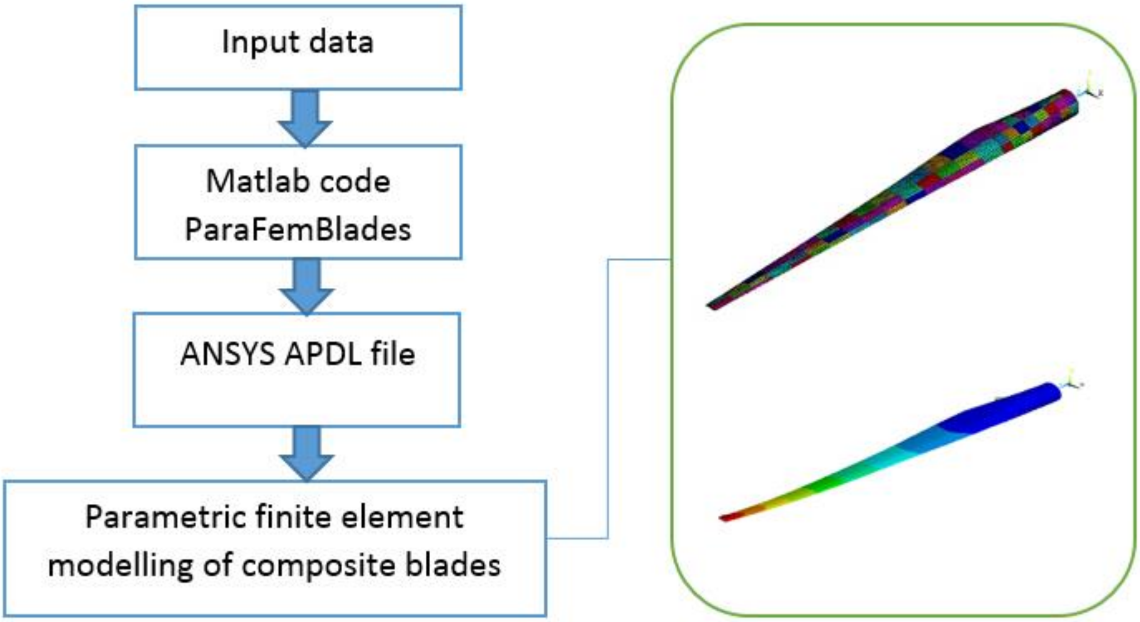


Figure 1. Schematic of parametric FEA model

2.2. Development of 1D beam model

In this work, a beam model for wind turbine blades is developed based on Euler-Bernoulli beam theory [8].

3. Results and discussions

In order to validate the structural models presented in Section 2, three case studies are performed. In the first case study, the beam model is validated against modal testing results of a horizontal-axis wind turbine (HAWT) blade. In the second case study, the beam model is further validated against modal testing results of a vertical-axis wind turbine (VAWT). In the final case study, the results of 3D FEA model are compared with the results of 1D beam model.

3.1. Modal analysis of truncated RB70 Blade

This case study aims to validate the beam model against experimental data. The example used here is the truncated RB70 wind turbine blade [9], which has been subjected to the eigenmode validation within the STABTOOL-3 research project [10].

The beam model (see Fig. 2) is used to perform modal analysis of the truncated RB70 blade. In this case, the blade is non-rotating and free-vibration. A fixed boundary condition is applied to the blade root. The calculated values are compared with measured values reported in Ref. [11], as depicted in Fig. 3. As it can be seen from Fig. 3, the flapwise and edgewise blade mode frequencies calculated from the beam model match well with the experimental data, with the maximum percentage difference (13.70%) occurring for the 3rd edgewise mode.

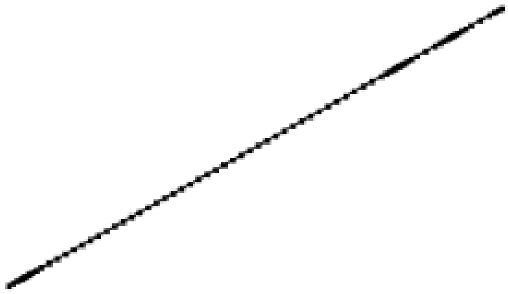


Figure 2. Beam model of truncated RB70 wind turbine blade

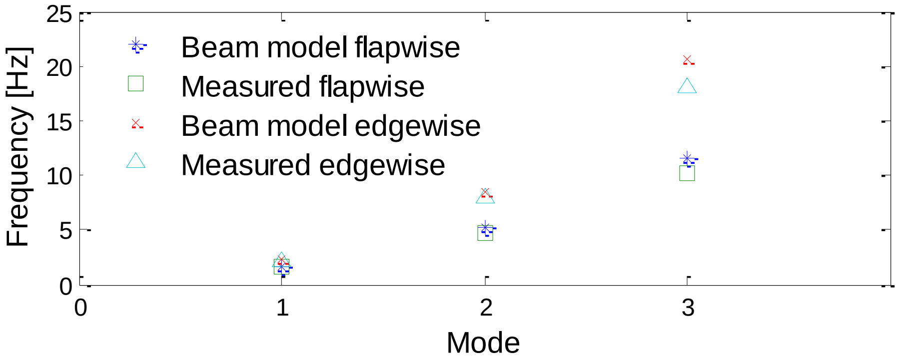


Figure 3. Modal frequencies of truncated RB70 wind turbine blade

3.2. Modal analysis of Sandia 34m VAWT

This case study aims to further validate the beam model against modal testing data. The example considered here is the Sandia 34m wind turbine [12], which is a research-oriented VAWT. A photograph of the turbine is shown in Fig. 4. As it can be seen from Fig. 4, the turbine comprises two blades, and guy cables are used to restrict the movement of the tower top.

Figure 4. Photograph of Sandia 34m VAWT

The beam model (see Fig. 5) is used to perform modal analysis of the Sandia 34m wind turbine. In this case, the rotor is non-rotating and free-vibration. Pined boundary condition is applied to both tower top and tower base. The predicted values are compared with measured values reported in Ref. [12], as shown in Table 1. As can be seen from Table 1, the modal frequencies calculated from the beam model match well with the experimental data, with maximum percentage difference (6.57%) occurring for the 2nd flatwise symmetric model. The associated modal shapes are presented in Fig. 6.

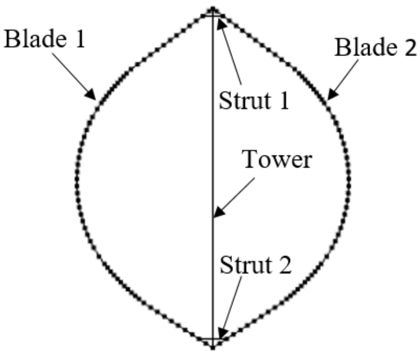


Figure 5. Beam model of Sandia 34m VAWT

Table 1. Mode frequencies of the Sandia 34m VAWT

Mode	Measured values [12]	Euler-Bernoulli Beam Model	Diff. (%)
1st FA (Hz)	1.060	1.007	5.00
1st FS (Hz)	1.060	1.009	4.81
2nd FA (Hz)	2.060	1.997	3.06
2nd FS (Hz)	2.160	2.018	6.57
1st BE (Hz)	1.810	1.819	0.50

(FA=flatwise anti-symmetric; FS=flatwise symmetric; BE=blade edgewise)

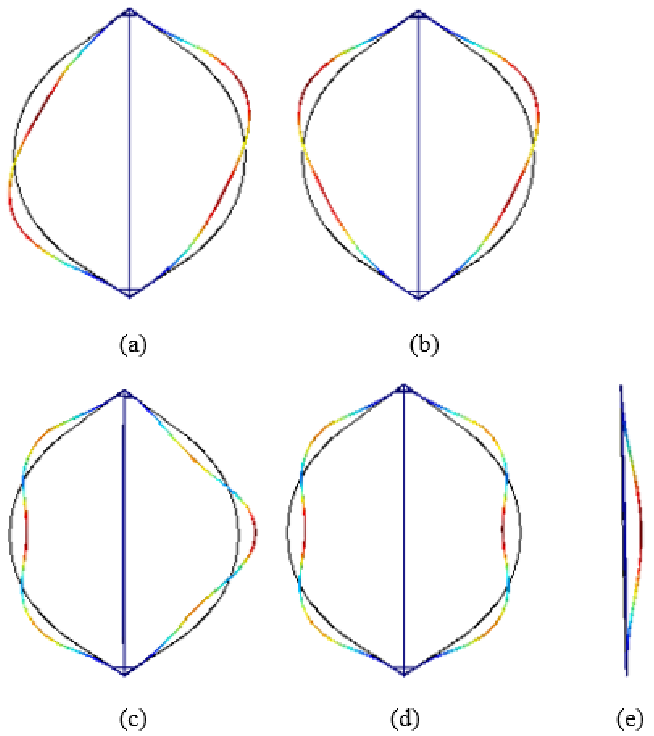
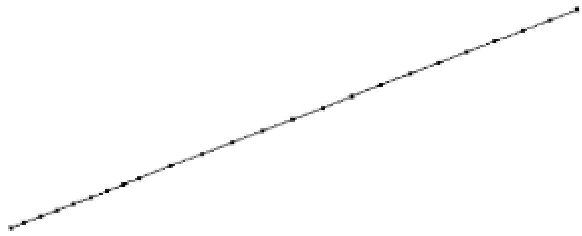


Figure 6. Modal shapes of Sandia 34m VAWT: **a** 1st FA, **b** 1st FS, **c** 2nd FA, **d** 2nd FS, **e** 1st BE

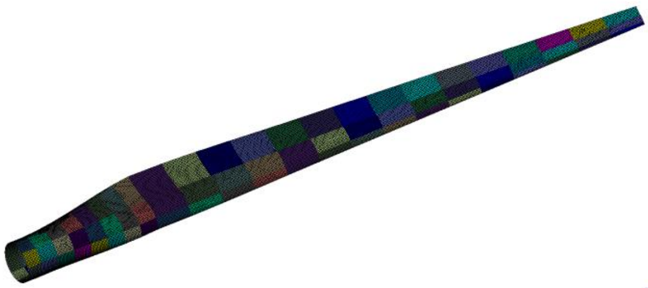
3.3. Modal analysis of WindPACT 1.5MW wind turbine blade

The final case study aims to compare the beam model with 3D FEA model. The example used here is the WindPACT 1.5MW wind turbine [13], which is a reference wind turbine designed by NREL (National Renewable Energy Laboratory).

Both beam model (see Fig. 7a) and 3D FEA model (see Fig. 7b) are used to perform modal analysis of the WindPACT 1.5MW wind turbine blade. In this case, again the blade is non-rotating and free-vibration. A fixed boundary condition is applied to the blade root. The results of beam model are compared with the results of 3D FEA model, as shown in Fig. 8. As can be seen from Fig. 8, the flapwise and edgewise blade mode frequencies calculated from the beam model show reasonable agreement with the results of 3D FEA model, with the maximum percentage difference (16.41%) occurring for the 3rd edgewise mode. The associated modal shapes are depicted in Fig. 9.



(a)



(b)

Figure 7. WindPACT 1.5MW wind turbine blade: **a** beam model, **b** FEA model

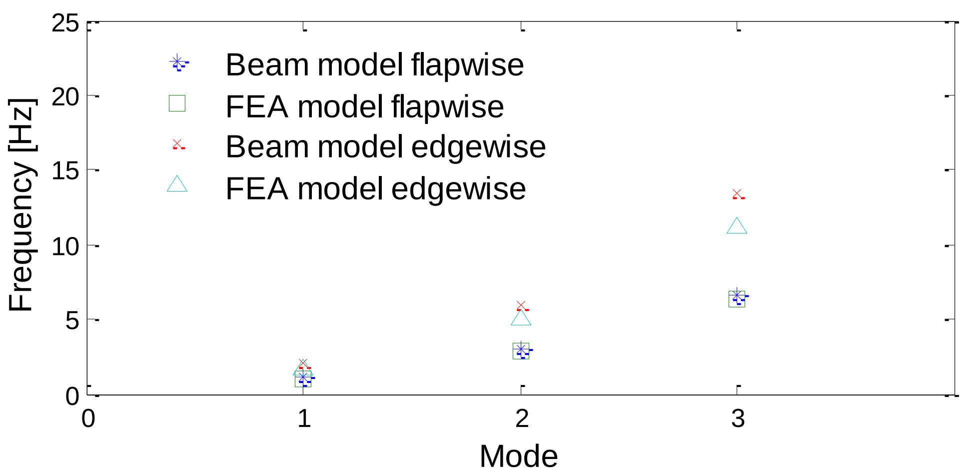


Figure 8. Modal frequencies of WindPACT 1.5MW wind turbine blade

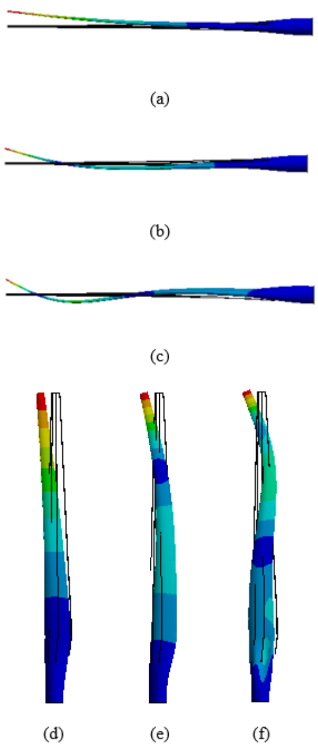


Figure 9. Modal shapes of WindPACT 1.5MW wind turbine blade: **a** 1st flapwise, **b** 2nd flapwise, **c** 3rd flapwise, **d** 1st edgewise, **e** 2nd edgewise, **f** 3rd edgewise

4. Conclusion

In this work, both 3D parametric FEA (finite element analysis) model and 1D beam model for wind turbine composite blades are developed. A Matlab code called ParaFemBlades is developed to read input data and then to output a series of APDL (ANSYS Parametric Design Language) commands, which can be used to automatically generate the 3D FEA model of wind turbine composite blades in ANSYS. The 1D beam model for wind turbine composite blades is developed based on Euler-Bernoulli beam theory. A series of benchmark computational tests are performed in order to validate the developed 3D FEA model and 1D beam model. The following conclusions can be drawn from the present study:

1) Mode frequencies calculated from the beam model match well with the modal testing data of RB70 blade, with the maximum percentage difference (13.70%) occurring for the 3rd edgewise mode, which confirms the validity of the beam model.

2) Mode frequencies calculated from the beam model match well with the modal testing data of Sandia 34m wind turbine, with maximum percentage difference (6.57%) occurring for the 2nd flatwise symmetric model, which further confirms the validity of the beam model.

3) Mode frequencies calculated from the beam model show reasonable agreement with the results of 3D FEA model for the WindPACT 1.5MW wind turbine, with the maximum percentage difference (16.41%) occurring for the 3rd edgewise mode, which confirm the validity of both models.

4) Compared to 3D FEA model, 1D beam model saves much computational time and is able to provide reasonable accuracy. For this reason, the 1D beam model is recommended to be used at the preliminary design stage. 3D FEA model is valuable at a later design stage to verify the preliminary design and to examine detailed stress distributions within the blade structure.

5. Learning objectives

In this work, the following learning objectives have been achieved:

- To develop a parametric FEA model of wind turbine composite blades
- To develop a beam model of wind turbine composite blades
- To validate the FEA model and beam model against each other and against available experimental data

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