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Modal analysis of small turbine blade made from glass fibres composites

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Abstract. The paper presents the modal analysis of a wind turbine type WTB type GE 1.5sle, scale 1:5, obtained by numerical modeling. 3D virtual model of blade was designed in CatiaV5 and imported in Abaqus software. The structure was built up as GFRP laminated composite with 5 layers and the materials properties were obtained from tensile test. In the first stage, the modes and natural frequencies of the blade were modelled as a composite structure reinforced with glass fibre fabric. In the second step the modal response of the blade having delaminated areas was analyzed. The results emphasized that the values of the natural frequencies change both in the analysis of the free structure and the fixed structure.

1. Introduction

The wind blades represent the most important parts of wind turbine both from expensive price point of view and efficient and reliable system too. These structures are characterized by complex geometry and materials which must resist to various loading over long period. Because of components exposure to highly aggressive environmental conditions, the blades material suffers cracks, debonding, delamination or even ruptures. The blade structural performance depends on measurement and analysis techniques and the equipment used. The structural behaviour of wind turbine blades can be predict using finite element analysis (FEA). The literature presents numerous studies about modal analysis of wind turbine blades with different profile or length. [1] identified the natural frequencies and natural vibration modes of the Al 2024 wind turbine bladewind which was supported by the hubat the one end and another end is free. Generally, [1] noticed that the maximum deflection occurs at the tip of the blade because of torsional and vertical forces. [2] shows that some of the modes of the composite blade (Naca airfoil) are significantly affected by a crack and that the modal parameters change more significantly with a more severe crack. They performed two types of modal tests in according with type of induced cracks: edge cracks and surface cracks. Experiments shows that the frequencies decrease with increasing of crack severity because of stiffness changes of blade. [3] modelled a fibre reinforced plastic (FRP) turbine blade with NACA AIRFOIL 4412 profile (45 m length) and extracted the natural frequencies for 10 modes.

[4] analysed the vibration of wind blade due to complex loads. They noticed that the first six modes are flap wise dominant, but structural optimization design proposed by [4] does not exhibit resonant

behaviour. [5] studied with FEA the effect of the layer orientation modal and static analyses, finding that applying all layers in the 0-degree direction is stiffer variant.

The literature is very scarce on modal analysis of delaminated wind blades with FEA, in contrast with dynamic behaviour of structure. The aim of this article is to analyze the influence of the influence of the degree of delamination on the modal response of the blade.

2. Materials and method

2.1. Preprocessing

In Catia was designed the geometry of a GE1.5sle wind turbine type, 1:20 scale (figure 1, a). Wind blade is provided with a stiffening profile made of composite material as well as the blade shell. The blade was modeled as a 5-layer composite of glass fiber fabric and epoxy resin whose characteristics are shown in Table 1. Subsequently, three cases of delamination of the blade were simulated in zones 1 and 2 (figure 1, b): single layer delamination, delamination of two layers and delamination of 3 layers (figure 1, c). The delaminated surfaces were established taking into account the risk areas presented by the blades during operation according to the literature [6,7,8]. Modeling was performed in Abaqus, using hexahedral linear elements C3D8I and quadratic tetrahedral elements type C3D10M. The modal analysis was performed both for the free blade and for the blade fixed at one end and free at the other end.

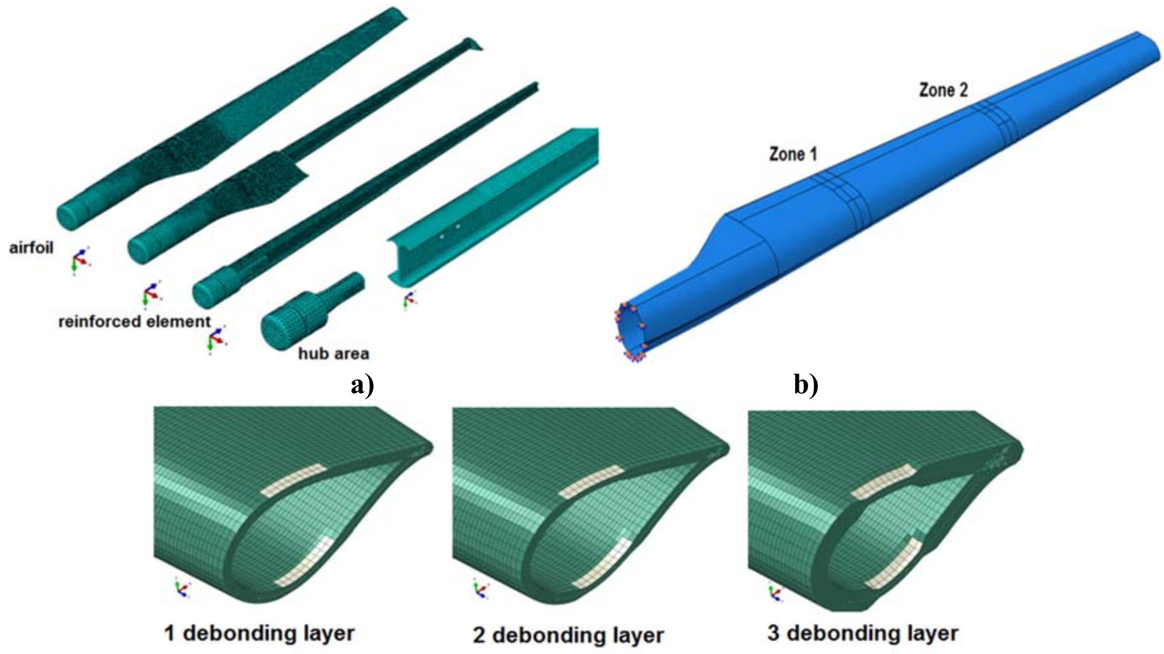


Figure 1. Meshed model of wind turbine blade type GE1.5sle, length of 1.5 *m:* a) structural elements of blade; b) delamination area; c) type of delamination.

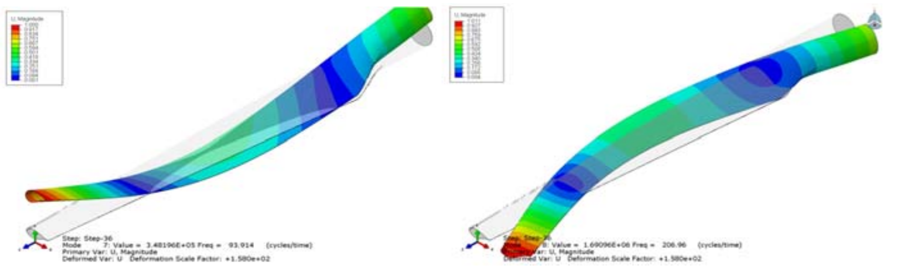
Table 1. Elastic properties of composite layers.

Composite RT500 fiber glass fabric Matrix: epoxy resin	Density ρ [kg/m3]	Thickness of layer h [mm]	Number of layers	Young Modulus [MPa] E_1	Young Modulus [MPa] E_2	Shear Modulus G_{12} [MPa]	Poisson coefficient ν
0/45/90/45/0	2400	1.6	5	36000	8800	3050	0,1615

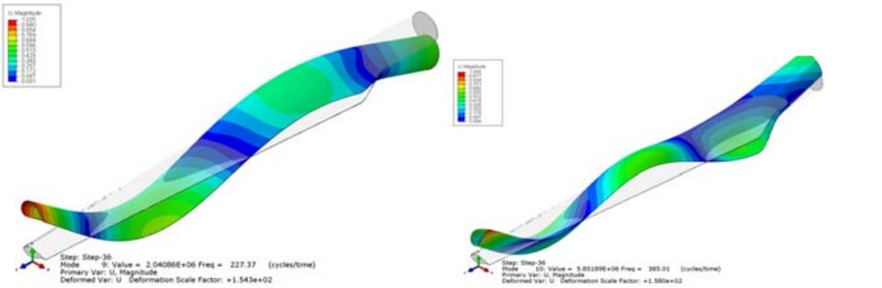
3. Results and discussion

3.1. Modal analysis of free wind blade

In the modal analysis of the free blade, the first ten modal shapes and natural frequencies were extracted. The first six modes are not relevant in terms of their own frequencies, the structure behaving as a mechanism. Only the seventh mode has been able to extract the values of its natural frequencies and vibration modes. In figure 2, the blade vibration modes are presented in the first case – wind blade without degradation of the structure. In the other cases (case 2 - blade with one delaminated layer, case 3 - blade with two delaminated layers, case 4 - blade with 3 delaminated layers), the modal shapes are similar, varying only the natural frequencies (figure 2). The FEA aim was to determine whether or not significant changes in the dynamic behaviour of the wind blade due to the presence of a delaminated layers in composite structure.



a) 1st flap wise Bending Mode shape b) Edgewise Bending Mode shape



c) Combined Bending Mode shape d) 2nd flapwise Bending Mode shape

Figure 2. Mode shape obtained with Abaqus, in case of free vibration of wind blade structure.

Analyzing the influence of the degree of damage of the structure on the modes and frequencies of the free structure, it is observed that the lamination of the blade does not influence the modal shapes (figure 2 and 3). In table 2 are presented the values of eigen frequencies for free structure.

Table 2. Natural frequencies for all cases of wind blade structure.

Vibration Mode	Eigen frequencies *f* [Hz]			
	Case 1	Case 2	Case 3	Case 4
7	93.914	93.749	93.545	93.205
8	206.960	207.080	207.130	207.050
9	227.370	227.360	227.020	226.550
10	385.010	384.930	383.910	381.510

The predominant types of vibration modes are: first flap wise bending mode shape, edge wise bending mode shape, combined bending mode shape and second flapwise bending mode shape.

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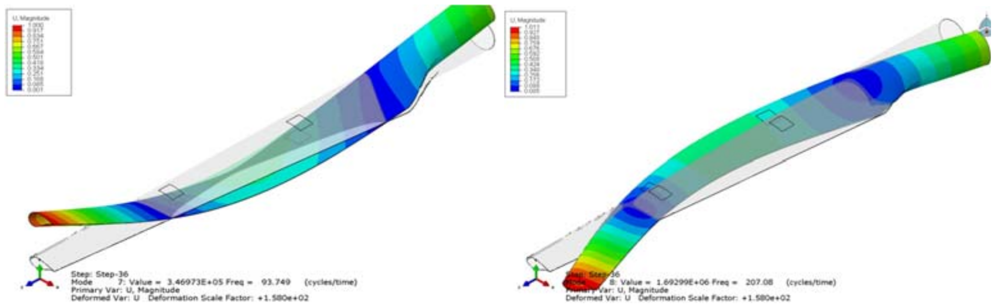
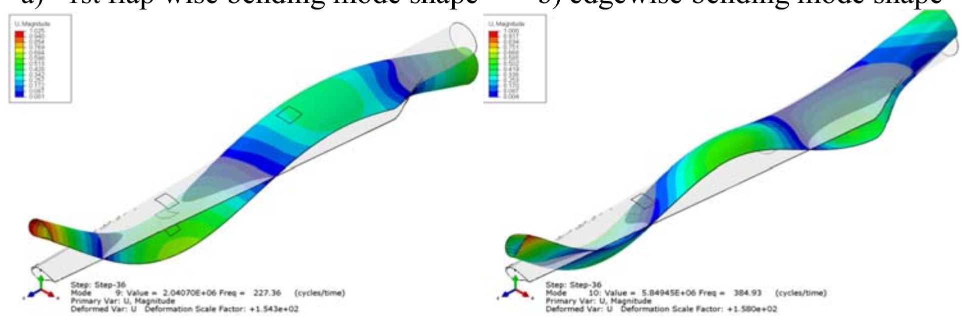
Relatively small differences are recorded in the values of their natural frequencies, which have a tendency to decrease with the increase in the degree of damage of the layers. It is also noted that as the blade stiffness decreases by increasing the degree of delamination, its natural frequencies decrease. Differences increase with increasing of vibration mode (Table 2).



a) 1st flap wise bending mode shape b) edgewise bending mode shape



c) combined bending mode shape d) 2nd flapwise bending mode shape

Figure 3. Mode shapes obtained with Abaqus, in case of free vibration of delaminated wind blade.

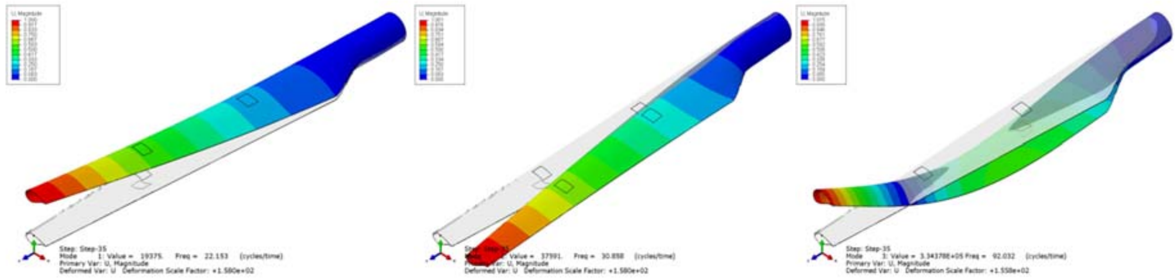
3.2. Modal analysis of fixed wind blade

The modal analysis of the blade fixed at one end (hub) - situation which simulating reality has led to the obtaining of modal shapes and eigen frequencies presented in table 3.

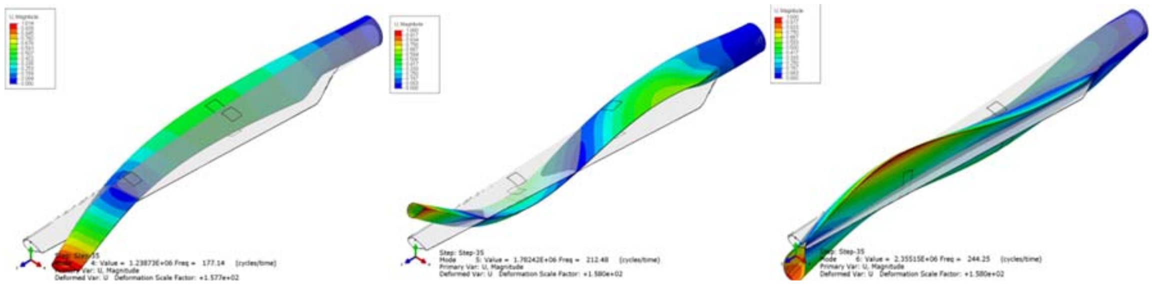
Table 3. Natural frequencies for all cases of fixed wind blade structure

Vibration Mode	Natural frequencies *f* [Hz]			
	Case 1	Case 2	Case 3	Case 4
1	22,139	22,146	22,153	22,159
2	30,752	30,806	30,858	30,908
3	92,169	92,137	92,032	91,903
4	176,800	177,000	177,140	177,190
5	212,650	212,680	212,480	212,220
6	244,810	244,890	244,250	242,600
7	380,090	380,110	379,630	378,550
8	408,820	408,840	408,800	408,750
9	475,850	475,670	475,480	475,750
10	494,760	495,150	495,660	496,210

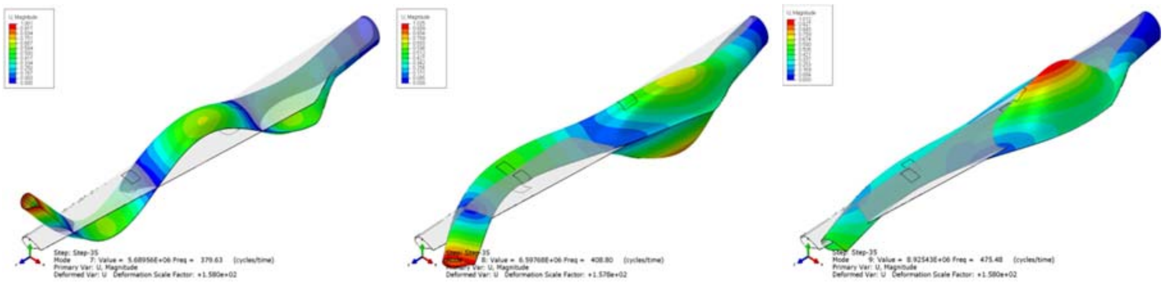
Figure 4 shows that predominant modal shapes are the flapwise, edgewise, torsion and combined bends of order I, II and III and IV (for the first 10 extracted modes). The flapwise modes is the most dangerous for integrity structure of blades because of occurring out of the plane of rotation of the blades could lead to the turbine blades colliding with the tower resulting in catastrophic failure of the structure (figure 4, a, c, e, g).



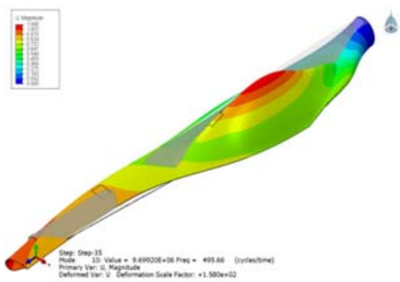
a) First flapwise bending mode b) First edgewise bending mode c) Second flapwise bending mode



d) Second edgewise bending mode e)Third flapwise bending mode f) Torsional mode



g) Forth flapwise bending mode h) Third edgewise bending mode i) Combined mode



j) Combined edgewise bending and torsional mode

Figure 4. Mode shapes obtained with Abaqus, in case of fixed wind blade.

The edgewise vibrations occur in the plane of rotation and the torsion vibration of the wind blade are generated by the gyroscopic effect. The variation of frequency response of the blades with different severity of structure delamination is very small in present study due to small demage areas assumed (Table 2). However, a sensible change in its eigen frequencies can be observed with increased delamination. Generally, the frequencies values are decreases with the size of crack as it was noticed by [9, 10].

4. Conclusion

The study aims to emphasized the changes in natural frequnecies and eigenmodes in case of delamination occurence in composite blade structure. Even if geometric stiffness is unchanged in case of a small delamination area, during functioning, the cracks propagates increasing the demage. To avoid entire demage and accidents, is important to known the senzitive modification of modal response.

5. References

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Acknowledgments

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