Numerical analysis of linear buckling of wind turbine blade with different trailing bonding models

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Abstract. The work focus on the linear buckling analysis of wind turbine blade with different trailing bonding models. Based on finite element model, it has been demonstrated that there are some differences for buckling load factor between different models. Several different models are valid for buckling analysis.

1. Introduction

The rotor blade length has been continuously increased for improvement the capacity and efficiency of the turbine. Sandwich structure is chosen for part of the structure of the wind turbine blade because sandwich structure has many excellent characteristics, such as high stiffness to weight ratio, high strength to weight ratio, excellent fatigue properties etc. because of the thin composites shell cross section, stability analysis is vital criterion for wind turbine blade design. Some researchers (1) believe that the ultimate strength of the blade is governed by instability phenomena in the form of delamination and buckling. Many works (2, 3, 4) have discussed the buckling calculation, but the FE models of the blades are different. Less research pays attention to the trailing edge models. In this work, comparison of the models with different trailing bonding models has been conducted to evaluate the linear buckling results.

2. Panel buckling theory

ESDU standard 94007 has given the panel buckling theory, which is based on the elastic, thin plate, small deflection, and classical laminate theory. Many details also can be referred from the paper (2). Based on the classical laminate theory, the load-deformation relationships can be obtained:

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\text{(1)}
\]

\[
\text{(2)}
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Figure 1. Panel buckling

where $N$ is the forces, $M$ is the moment, $\varepsilon$ is the strain, $\kappa$ is the curvatures. Boundary condition can be assumed as buckling modes with sinusoidal displacement of form, seen Figure 1. where $u$ and $v$ are in-the-plane displacements, and $w$ is the out-of-plane displacements. $\lambda$ and $\eta$ are parameters associated with the number of buckled half-waves along x and y directions respectively. The critical buckling load in the longitudinal direction per unit width of plate ($N$) can be obtained from (3).

3. Modelling

The investigated blade consists of two spar caps and two spar webs (see Figure 2, 3). Based on the aero-dynamic considerations, the cross sections of the blade are different aerofoils. From the root to the tip, there is a taped shape. A brief summary of information of the blade is shown in Table 1. The static test and fatigue test have been finished on this blade according to the GL 2003.
Table 1. General specifications of investigated blade.

| Rate power  | 1.5MW |
|-------------|-------|
| Maximum chord | 3.1m  |
| Length       | 40.3  |
| Twist        | 15°   |

3.1. Different trailing models

In this paper, different FE model of the blade based on ABAQUS was presented for linear buckling analysis (see figure 4). In model A, there is only one share node between pressure side and suction side. Model B has some shell elements to connection both sides. In Model C, there are some solid elements bonding the both sides by sharing the node. Model D has the shell-solid coupling to bonding the both sides. These models have the same mesh density and shell elements definition of the composites except the trailing edge. In Model A, on both trailing side, there are some the adhesive plies. In Model B, the shell elements between both sides are confined to the adhesive plies. In Model C and D, solid elements are confined as the adhesive. On the outboard face of the solid elements of the Model D, there are some skin laminas.

Figure 3. Cross section of the blade.

Figure 4. Cross section of the blade.
3.2. Load cases
In numerical analysis, two type load case are applied on the FE model. one is minimum edge-wise direction bending moments, another is minimum flap-wise bending moment. Both are the envelope of the entire extreme load case.

3.3. Boundary condition
The end nodes of the root are fixed all 6 degrees of freedom. the forces are applied on the main spar cap (see figure 5).

4. Result
Based on the FEM, numerical analyses have been conducted to evaluate the effect of the trailing model on the linear buckling. From Table 3, Model B and C have little deviations. Under the min edge-wise moments, load factor of the Model D is 2.9, while the Model A is 1.63. Generally speaking, in order to define the shell-solid coupling, the constraint require more fine mesh of the solid part, Model D maybe need to improve the mesh density. More work need to be done continuously.

| Type | Min flap-wise load factor | Min edge-wise load factor |
|------|--------------------------|--------------------------|
| A    | 2.42                     | 1.63                     |
| B    | 2.23                     | 2.31                     |
| C    | 2.25                     | 2.38                     |
| D    | 2.19                     | 2.9                      |

Table 3. Linear buckling load factor of first model.

Figure 5. FEM of blade showing the loads and boundary conditions.

5. Conclusion
There are some differences among the four models. Although more works need to be done extensively and continually, the result maybe alerts the designer pay attention to the different FE models. The
conclusion is that the model B and C maybe are good choice for linear buckling analysis. When the trailing edge under compression, it is not advisable for numerical calculation based on Model A.

References
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