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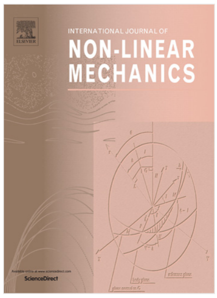

Geometrically nonlinear beam analysis of composite wind turbine blades based on quadrature element method

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Geometrically nonlinear beam analysis of composite wind turbine blades based on quadrature element method

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ABASTRACT: A new nonlinear beam theory is proposed for the analysis of composite wind turbine blades. The beam theory is developed by extending classical Euler-Bernoulli beam theory to a generalized Timoshenko beam. Mechanics-based variables are used to describe finite rotation such that the problems of the sequence dependence or spatially discontinuity of rotational variables can be avoided. Furthermore, nonlinear beam theory is implemented using the weak-form quadrature element method. Numerical examples of both non-rotating and rotating beams are given and the comparison with analytical and finite element results shows high computational accuracy and efficiency of the proposed nonlinear quadrature element. A simple parametric study of a virtual 5-MW wind turbine blade shows that bend-twist coupling due to both material anisotropy and geometrical nonlinearity affects the dynamic performance of the blade significantly.
Key words: nonlinear; composite beam; quadrature element method; wind turbine blade.

1. Introduction

Wind energy is a rapidly growing green and renewable energy. Currently, 8-MW wind turbines with a rotor diameter of 160 m have been installed for commercial use. 10-MW to 20-MW wind turbines are projected to be designed and tested [1]. A longer and slenderer composite blade undergoes larger bending deflections under normal operation conditions. This results in strong geometric nonlinear coupling effects between bending and torsion. How the structural geometrical nonlinearity affects the aeroelastic stability of wind turbine blades is becoming an increasingly important issue [2-4]. The finite element method using beam elements is widely applied to study nonlinear aeroelasticity of a rotating blade because of its accuracy and efficiency. Developing a geometrically nonlinear beam model for the pre-twisted and curved composite blade is a relatively new focus of the wind turbine community. Additionally, composite blades are subject to non-classical effects such as transverse shear deformation, in-plane and out-of-plane cross-sectional warping, and elastic coupling due to anisotropy [5]. Hence, modeling a realistically large composite blade using beam theory should consider all the effects mentioned above.

Wind turbine blades are usually assumed to be able to undergo large deflections while the strain remains small. The main challenge in developing nonlinear beam theory thus comes from modeling finite rotation during large deflections. This usually introduces great complexity to the finite element formulation. The application of geometrically exact beam theories is a powerful way of addressing this problem. Most beam theories use mathematical Euler parameters for description of finite

Abbreviations: DOF, degree of freedom; SVBT, Saint Venant Beam Theory; VABS, Variational Asymptotic Beams Section analysis; BECAS, Beam Cross section Analysis Software; GLL, Gauss-Lobatto-Legendre; FEM, finite element method; NQEM, nonlinear weak form quadrature element method.

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