EFFICIENT MODELING OF CONTINUUM BLADES USING ANCF CURVED SHELL ELEMENT

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Large-size wind turbine blade is divided into two regions classified by structural and aerodynamic characteristics. The structural region (blade-root section), carries the highest load with low aerodynamics efficiency. The aerodynamical region (blade-span), is aerodynamically significant and therefore thinnest finite element can be utilized. The ANCF is used for constructing continuum models of blade-span with uniform structure [1]. Furthermore, a non-uniform and twisted structure model is carried out in [2]. Both models utilized the ANCF thin plate element due to its aerodynamical nature. The complete blade model with its two regions as well as methods of modeling slope discontinuities are carried out in [3] successfully. However, it is concluded that the use of thin plate element, specifically in the structural region, is not the optimum choice due to the ignorance of the strain along the element thickness. Furthermore, it is found in that the use of thick plate element within the ANCF leads to high numerical stiffness because of the oscillation of gradient along the element thickness. In this investigation, the modified displacement field [4], is used such that a material point is defined by the midsurface and the rotation of the element fiber along the material line, that is orthogonal to the midsurface in the undeformed configuration. Such material line remains straight and unstretched during the deformations, see Fig. (1-a,b) which can be expressed as Eq. (1). It is considered that the material line in the direction of normal vector \( \mathbf{n} \) at the curvilinear coordinate system \((g_1, g_2)\). The displacement \( \mathbf{r_m} \) represents the global displacement of the an arbitrary point along the mid-surface. The displacement \( z \mathbf{n} \) is due to the rotation of the line. The gradient vectors of the deformed shape can be represented as: \( g_1 = \frac{\partial r_m}{\partial x} + z \frac{\partial \mathbf{n}}{\partial x} \), \( g_2 = \frac{\partial r_m}{\partial x} + z \frac{\partial \mathbf{n}}{\partial x} \), \( g_3 = \mathbf{n} = g_1 \times g_2 / \| g_1 \times g_2 \|. \) The local curved surface frame for the undeformed configuration can be represented by \((g_{01}, g_{02}, g_0)\). The Cartesian coordinate frame \((a_{01}, a_{02}, a_{03})\) is defined; the transformation between these two frames can be found as Eq. (2). Therefore, the strain of initially curved shell element can be represented as the difference between the current and initial values as presented in Eq.(3). The strain vector is formalized, taking into consideration, the membrane as well as curvature strain. Numerical methods are carried out to estimate the elastic forces and the generalized force Jacobian. The static solution of 40[m] long is carried out using NR method successfully,
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Figure 1: Initially curved shell element: (a) Displacement filed and configurations, (b) Strain measures and transformation, (c) Blade-root using shell element and (d) Static deformation of different loads see Fig.(1-c,d). It is concluded that the use of shell element can be enhance the dynamic model for design process of such blades.

\[ \mathbf{r} = \mathbf{Se} + z \mathbf{n} = \mathbf{r}_m + z \mathbf{n} \]  
\[ \frac{d\xi}{dn} = \begin{bmatrix} a \left( \mathbf{g}_{m01} \cdot \mathbf{a}_{m01} \right) & a \left( \mathbf{g}_{m01} \cdot \mathbf{a}_{m02} \right) \\ b \left( \mathbf{g}_{m02} \cdot \mathbf{a}_{m01} \right) & b \left( \mathbf{g}_{m02} \cdot \mathbf{a}_{m02} \right) \end{bmatrix}^T \begin{bmatrix} dx \\ dy \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} \\ 0 & J_{22} \end{bmatrix} \begin{bmatrix} dx \\ dy \end{bmatrix} \]  
\[ \epsilon = \frac{1}{2} \mathbf{J}^T \begin{bmatrix} \epsilon_{11} \epsilon_{01} \epsilon_{12} \epsilon_{02} \epsilon_{22} \epsilon_{02} \end{bmatrix} \mathbf{J} = \begin{bmatrix} J_{11}^2 \epsilon_{11} & J_{11} \epsilon_{12} + J_{11} \epsilon_{22} & J_{12} \epsilon_{11} + 2J_{12} \epsilon_{12} + J_{22} \epsilon_{22} \\ J_{11} \epsilon_{12} + J_{11} \epsilon_{22} & J_{12}^2 \epsilon_{11} + J_{12} \epsilon_{12} + J_{22}^2 \epsilon_{22} & J_{12} \epsilon_{12} + 2J_{12} \epsilon_{12} + J_{22} \epsilon_{22} \end{bmatrix} \]  

REFERENCES


