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IMPLEMENTATION OF THE GENERALIZED BRAZIER EFFECT IN ANALYSIS OF WIND TURBINE BLADES

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Summary. As wind turbine blades are getting longer and more slender, new failure modes occur and these may be related to the non-linear geometric Brazier effect[1,2,3], where the bending moments ovalize the thin-walled cross-sections. For general cross-sections the torsional moments have a similar effect. The combined effect is denoted the general Brazier effect, and it is described in an accompanying paper. The stresses caused by the generalized Brazier effect are directed perpendicular to the beam axis, and this may have a large influence on the fatigue life of composite structure. The generalized Brazier effect can be calculated in an approximate way which enables to add the additional non-linear geometric effects to the results from the wind simulation. This has been described in the accompanying paper, and in this paper focus will be on the practical implementation in a Finite Element program. The accuracy of the proposed method has been illustrated on a wind turbine blade from SSP Technology A/S.

1 INTRODUCTION

Simulations of wind load on wind turbines are made by beam-type finite element models in order to have realistic simulation times. The beam-type finite element calculations can handle the non-linear geometric effects related to large displacements and rotation of the blade. However, the more localized non-linear geometric effect from the generalized Brazier effect cannot be calculated by the simplified beam-type elements. A full 3D solid/shell finite element model can account for all non-linearities, but with long and unrealistic computation times.

Reference[3] demonstrated a general method to account for the Brazier in an approximate way. The torsional moment has a similar effect, and this has been described in an accompanying paper. The idea in the approximate method is to add the contribution from the generalized Brazier effect in an approximate i.e. linearized way only using stresses from a full nonlinear geometric beam-type solution.

The aim of this paper is to implement the general Brazier effect based on the method from reference[3] in an ANSYS environment using APDL (Ansys Parametric Definition Language).

The generalized Brazier effect is explained in two steps. In section 2 the influence of the bending moments is illustrated and in section 3 the contribution from the torsional moment is illustrated.

2 BRAZIER EFFECT FROM BENDING MOMENTS

The first step is to establish the stress state in a full solid/shell model. This can be established from a nonlinear geometric analysis on a beam-type element model. However, for convenience we have in this context used a linear model solid/shell model. The specific load case is taken from an experiment where the wind turbine blade was subjected to a three-point combined test load[4,5].

In the following the longitudinal direction of the blade is the z-axis. The Brazier forces in each element depend on the derivative of the rotations of the xy-plane with respect to z and the nodal forces in the z-direction. Determination of the Brazier force for a single element is shown in equation (1).

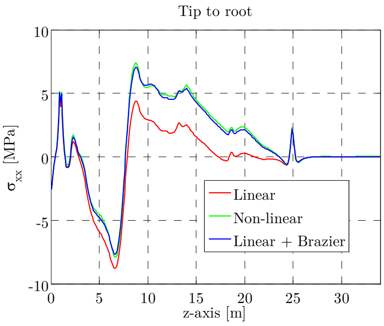
$$F_{B,x} = \int \sigma_{zz}\ dA_z\, \Delta\theta_y, \qquad F_{B,y} = \int \sigma_{zz}\ dA_z\, \Delta\theta_x \tag{1}$$

The Brazier forces are added to the linear analysis and Figure 1.a. show how the Brazier forces are distributed to the nodes in the cross section at 10 m from the root. Forces with high magnitude are located in the top and bottom flange in the load carrying structure due to high bending stresses. At the trailing edge in the top flange and in the bottom flange the Brazier forces point towards the leading edge. The forces lead to in-plane deformations denoted shear distortion[4] and are shown in Figure 1.b.

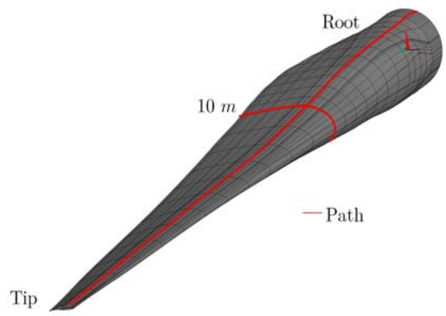
(a) (b)

Figure 1: Cross section at 10 m from the root (xy-plane). (a) Non-linear Brazier forces applied cross section. (b) Cross-sectional deformation caused by non-linear Brazier forces.

In-plane stresses along a path on the outer top surface from tip to root are compared between three types of analysis: linear, linear plus the Brazier correction and a nonlinear. The path is illustrated in Figure 2.b. Stresses are compared in Figure 2.a. and the approximate method gives very accurate results.



(a)



(b)

Figure 2: (a) Shows the in-plane stresses σ_{xx} along a path placed on the wind turbine blade from the tip towards the root. (b) Shows the locations of paths.

3 GENERALIZED BRAZIER EFFECT FOR TORSION

Wind turbine blades are tapered giving rise to a complicated stress state which can be hard to comprehend. In order to illustrate the effect of torsion a simplified model of a wind turbine blade has been made without tapering. The profile is loaded with opposite torsional moments at each end.

The generalized Brazier effect is equivalent with local in-plane moments (M_z). Based on the initial stresses, M_z is calculated for each element as shown in equation (2). The value depend on the element area (A_z), shear stresses (τ_{zx}, τ_{zy}) and shear center offset $(\Delta x, \Delta y)$[6].

$$M_z = \int \tau_{zx}\ dA_z\, \Delta y + \int \tau_{zy}\ dA_z\, \Delta x \tag{2}$$

The local in-plane moments are subsequently converted to equivalent structural nodal forces (F_x, F_y). The structural nodal forces are applied to the Finite element model and solved in a linear analysis. The global deformations are shown in Figure 3.

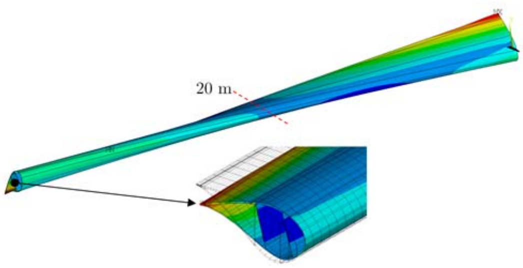
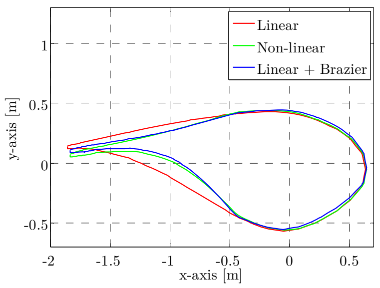
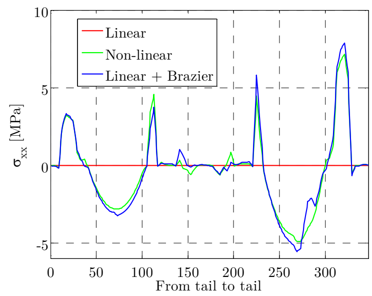


Figure 3: Illustrates the global deformations of the uniform wind turbine blade caused by opposite directional torsional moments.

Cross-sectional deformations are shown in Figure 4.a. The results from the linear analysis show no in-plane deformations, and have the same shape as the undeformed. However the correlation between the non-linear geometric analysis and the linear with the additional nonlinear correction is quite good. The cross section has significant inward deformations between the load carrying structure and the trailing edge. These deformations lead to in-plane stresses and this is shown in Figure 4.b. where the in-plane stresses from the non-linear analysis and the linear with the additional nonlinear correction are very similar.



(a)



(b)

Figure 4: (a) Comparison of cross-sectional deformation. (b) Comparison of σ_{xx} on a circumferential path outside the airfoil.

4 CONCLUSION

The paper demonstrates that the effects of the generalized Brazier effect can be calculated based on a simplified linearized contribution. The method is quite accurate and if implemented in the current beam-type wind turbine blade simulations could lead to a far more realistic stress determination. This could lead to a better estimate of the fatigue life and could also lead to more optimal designs.

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