Structural modelling of composite beams with application to wind turbine rotor blades

The ever changing structure and growing size of wind turbine blades put focus on the accuracy and flexibility of design tools. The present thesis is organized in four parts - all concerning the development of efficient computational methods for the structural modelling of composite beams which will support future growth in the rotor size. The first part presents a two-node beam element formulation, based on complementary elastic energy, valid for fully coupled beams with variable cross-section properties. The element stiffness matrix is derived by use of the six equilibrium states of the element corresponding to tension, torsion, bending, and shear. This approach avoids the need for explicit interpolation of kinematic variables and provides a direct locking-free formulation. The formulation includes a consistent representation of distributed loads and enables recovery of the exact internal force distributions. In the second part a formulation developed for analysis of the stiffness properties of general cross-sections with arbitrary geometry and material distribution is presented. The full six by six cross-section stiffness matrix is obtained by imposing simple deformation modes on a single layer of 3D finite elements. The method avoids the development of any special 2D theory for the stress and strain distributions and enables a simple and direct representation of material discontinuities and general anisotropy via their well-established representation in 3D elements. The third part presents an extension of the 3D cross-section analysis by an efficient Finite Element modelling approach for thin and thick-walled sections which substantially reduces the meshing effort. The approach is based on discretizing the walls of the section using a single layer of displacement based elements with the layers represented within the elements. A post processing scheme is also presented to recover inter laminar stresses via equilibrium equations of 3D elasticity derived in the laminate coordinate system. In the final part of the thesis a flexible method for analysing two types of instabilities associated with bending of thin-walled prismatic beams is presented. First, the flattening instability from the Brazier effect is modelled by representing the cross-section by two-dimensional non-linear co-rotating beam elements with imposed in-plane loads proportional to the curvature. Second, the bifurcation instability from longitudinal stresses is modelled with a Finite Strip buckling analysis based on the deformed cross-section. The analysis is well suited for early stages of design as it only requires a simple 2D line mesh of the cross-section.