POLITECNICO DI TORINO

Thesis Abstract

Multi-scale Modelling and Design of Composite Structures

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This dissertation proposes a new paradigm for Carrera's Unified Formulation (CUF) based multi-scale structural modelling by bridging micromechanics, and the advanced one-dimensional/beam structural theory. The achievements in the exploration process can be summarised in the following two aspects: a geometrically nonlinear macro-scale CUF-based beam model and a geometrically nonlinear multi-scale CUF-based beam model.

The exploration started from a study of nonlinear structural modelling established by coupling the nonlinear CUF and Asymptotic Numerical Method (ANM). This geometrically nonlinear CUF-based beam model has been accomplished in collaboration with G. De Pietro. It is one of the first studies that extends one-dimensional equivalent single layer CUF models coupled with ANM to account for geometrical non-linearities using a total Lagrangian formulation (large deformation and rotation but small strains). Static nonlinear, post-buckling and snap-through analyses of beam structures have been presented, and the corresponding load-displacement and load-stress curves have been assessed. Results have been compared with two-dimensional FEM solutions. It has been shown that, for the considered cases, a quadratic through-the-thickness description ensures accurate displacements and normal axial stress component. A higher expansion order is required to predict the shear stress component accurately, especially for very high load levels. In the considered post-buckling analysis, both high-order and low-order one-dimensional CUF models have detected the bifurcation point accurately. However, accurate results for the shear stress call for a higher-order model. In the snap-through analysis, a refined beam theory is required to accurately track the equilibrium path.

To address geometrically nonlinear problems in beam structures from different scales, a geometrically nonlinear CUF-based multi-scale beam model has been derived by coupling the proposed macroscopic model and the Multilevel Finite Element (also known as FE^2) framework, which is also the main novelty of this thesis. The solution procedure consists of a macroscopic/structural analysis and a microscopic/material analysis. At the macroscopic scale, the unknown constitutive law is derived from a numerical homogenisation of a Representative Volume Element (RVE) at the microscopic level. Vice versa, the microscopic deformation gradient is calculated from the macroscopic model. As far as the geometrically nonlinear problem is concerned, the resulting non-linear mathematical system is solved by ANM, which is more reliable and less time to consume compared to

classical iterative methods. The proposed framework is used in investigating the effect of microscale imperfections (not straight carbon fibres) on the macroscale response (instability). Results are analysed in terms of accuracy and computational costs towards full FEM solutions. Three factors have been identified for an imperfection sensitivity parametric analysis: the wavelength, the amplitude and the size of RVE.