Summary

Several studies suggest that traditional models based on stress-strain constitutive laws are not able to thoroughly predict the behaviour of reinforced concrete (RC) and prestressed concrete (PC) structures and the ductile-to-brittle transitions that might arise for large size-scale beams as well as high-performance concrete matrices. On the other hand, modern design approaches require that RC structures present a sufficient deformation capacity for warning before failure, the possibility of moment redistribution in the case of statically indeterminate structures, the ability to react to accidental loadings (robustness) and, the energy dissipation in case of earthquake.

In this context, Fracture Mechanics has been demonstrated to be capable of describing in a unified approach the mechanical instability phenomena occurring for RC and PC beams in bending, such as concrete cracking in tension, reinforcement slippage and/or yielding as well as concrete crushing in compression, together with size-scale effects and ductile-to-brittle transitions.

In the first part of this Thesis, the Cohesive/Overlapping Crack Model (COCM) is adopted in the investigation of the nonlinear behaviour of RC, PC as well as fibre reinforced polymer bar - reinforced concrete (FRP-RC) beams. These investigations suggest a clear flexural to crushing failure transition by increasing the beam depth, h, and/or the reinforcement percentage, ρ. More precisely, by means of the Buckingham's Theorem, it is demonstrated that this transition is governed by five nondimensional numbers: the Tension Matrix Brittleness Number, s_{t}; the Compression Matrix Brittleness Number, s_{c}; the Lower Limit Reinforcement Brittleness Number, $N_{\mathrm{P}}^{\mathrm{L}}$; the Upper Limit Reinforcement Brittleness Number, $N_{\mathrm{P}}^{\mathrm{U}}$ and the Prestressing Brittleness Number, $N_{\mathrm{P}}^{\mathrm{p}}$. These Brittleness Numbers are used to define upper and lower size-scale dependent reinforcement limits in which RC and PC beams exhibit a stable and ductile behaviour. Thus, a systematic reference to provisions currently included in Standards is provided in order to demonstrate how these regulations are not able to ensure the same safety factor for beams having different size-scale leading, in some cases, to completely brittle unsafe behaviours.

In the second part of the Thesis, an extension of the COCM to multi-cracked structures is presented, and advanced data structures for crack localization and propagation in a finite element mesh are discussed. Moreover, a generalized arc-length method based on the Crack Length Control Scheme is provided for competing

crack growth as well as to follow unstable snap-back branches in a stable manner.

In the third part of the Thesis, the shear failure of RC beams without stirrups is addressed: the mechanical and geometrical parameters influencing the shear strength of RC beams as well as the calculation models currently included in Standards are presented. Thus, crucial results obtained in the past by means of Linear Elastic Fracture Mechanics together with the outcomes within this Thesis are used to investigate the failure-mode scale-transitions in RC structures in a unified approach.