Abstract

Concrete is a quasi-brittle material that has a weak tensile strength in comparison to its compressive strength. Due to the low tensile strength of concrete, it is common to use concrete with reinforcement to carry the tensile stresses. As a consequence, the presence of reinforcement affects the crack development and crack propagation in reinforced concrete. Developing cracking evaluation methods is important for the safety assessment and renovation of existing infrastructure. An improved understanding of concrete cracking is an implicit requirement to achieve these aims. The main aim of this research was to investigate the nature of fracture in reinforced concrete. The fact that crack propagation in reinforced concrete is complicated by different mechanisms (crack initiation, crack curving, crack propagation, and crack arrest) involved in the failure process makes it difficult to study and model.

An experimental investigation was undertaken to explore the cracking process of reinforced concrete (RC) beams and to observe the details of the localized fracture process zone development and crack branching phenomena which are known to be toughening mechanisms in quasi-brittle materials. Digital image correlation (DIC), a robust, non-contact tool for fracture measurements, was used to provide insight into the fracture process. High resolution digital images were taken at different loading stages and, by comparing the images, it was possible to infer the surface strains and crack opening. It was found that the presence of the reinforcement prevented premature fracture and led to crack branching where a single crack bifurcated in the region of the concrete compression zone. Larger beams were associated with a lower relative height at which branching develops and a greater reinforcement ratio led to a shallower branching angle. These observations were associated

with ductility measures for lightly reinforced concrete and should be taken into consideration when estimating the minimum reinforcement requirements for flexural members.

Based on the experimental observations, an integrated fracture-based model (IFBM) was developed to predict the behaviour of lightly reinforced concrete beams. The proposed model is a closed-form solution that incorporates post-cracking tensile stresses in the concrete, the bond-slip behaviour between the reinforcement and concrete, and compression softening in the concrete compressive zone. The IFBM was formulated in terms of equilibrium, compatibility and constitutive considerations. The stages of the analysis include: the development of a crack, crack propagation with tension softening, concrete compressive softening and rotation. The developed model enabled the study of the ductility of lightly reinforced concrete. The prediction of the cracking process for reinforced concrete beams with a single flexural crack was possible and allowed for a comparison with the experimental results.

The experimental program and the theoretical study provided the basis for the derivation of a ductility number (DN) as a measure of the ductility of lightly RC beams. The ductility number acts as a reflection of how ductile the structure is; the higher the DN, the more ductile the structure. The effect of several material and geometrical properties were reflected in the proposed definition.

A study of the minimum reinforcement requirements in the context of the current research was conducted. It was found that the minimum reinforcement ratio should decrease with increasing beam size. This contradicts the provisions of some prevailing codes and standards which suggest no change in the minimum reinforcement ratio with size. Hence, the current study provides an enhanced framework for the development of minimum reinforcement formulae for the safe design of lightly reinforced concrete beams.