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STATIC MULTI-CRACKING MODELING OF LRC BEAMS

Rena C. Yu* **and Gonzalo Ruiz**

ETSI de Caminos, C. y P.
Universidad de Castilla-La Mancha
Avda. Camilo José Cela, s/n, 13071 Ciudad Real, Spain
Web page: http://www.uclm.es/cr/caminos
* e-mail: rena@uclm.es

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Summary. *We propose a methodology to model complex fracture processes in lightly reinforced concrete (LRC) beams. The discrete cohesive approach accompanied with an insertion algorithm is adopted, a modified dynamic relaxation method is chosen as an alternative solver. The concrete matrix and steel rebars are modelled explicitly; the connection in between is represented by means of interface elements. Such elements allow for slip of re-bars and transmit forces to the matrix that may generate secondary cracking around the reinforcement. The methodology is validated against three-point bending tests on LRC beams.*

1 INTRODUCTION

In this paper we investigate the evolution of complex fracture processes in lightly reinforced concrete (LRC) specimens subjected to static loading. We have already modelled the static multi-crack propagation for plain concrete [1]. Based in this previous work, we face here the case of reinforced concrete. The barrier effect created by the steel rebars for the propagation of discrete cracks has been overcome in simplified ways. Briefly, they consist of substituting the rebars by the forces they produce on the mesh representing the concrete [2, 3]. Here we endeavor to deal explicitly with the problem of fracture propagation through the re-bars.

We simulate the concrete matrix, the steel rebars and the interface between the two materials. The cracks in the concrete matrix are described by using cohesive theories of fracture combined with the direct simulation of fracture and fragmentation. Individual cracks are tracked as they nucleate, propagate and brach, being incumbent upon the mesh to provide a rich enough set of possible fracture paths. The crack propagation through the concrete matrix is hindered by the presence of reinforcing bars. Indeed, the propagation of the cracks is arrested when the process zone reaches a re-bar, since the steel tensile strength is higher than that of concrete. The developement of the cracking process from then on implies the deterioration of the interface, which is modeled by inserting interface elements endowed with an effective adherent law along the steel-concrete contact. As the external loads increase the cracks in the matrix are finally able to propagate through the steel bar. Thus, the *sewing effect* of the steel bars is modeled explicitly. The difficulty of looking for a stable solution is avoided by means of the dynamic relaxation method, which always succeeds in finding a solution if such a solution exists. The slow convergence of the method is compensated through a modified technique presented in [1].

The feasibility of the proposed methodology is demonstrated through the modelling of a three-point-bending beam reinforced with different steel-concrete ratios. A brief description of the simulations results for each case is described next.

2 SIMULATION OF FRACTURE OF LRC BEAMS

We validate the model by simulating some of the experiments of Ruiz, Elices and Planas [4] on lightly reinforced concrete (LRC) beams. These are bending tests that generate a single main crack that propagates through the reinforcement layer. Besides, the authors provide the whole set of material parameters that are necessary to feed the constitutive models of concrete, concrete cracking, steel and the steel-concrete interface.

Figure 1 scketches the beam dimensions and type of loading. The beams were of several sizes and were reinforced with adherent or smooth bars; for our simulations we choose beams that were 75 mm in depth and 50 mm in width reinforced with a single layer of reinforcement. The ratio between the area of the steel cross-section and the concrete cross-section was 0.26%. The mechanical properties that are used in the simulations were obtained through independent characterization tests. Figure 2 shows the initial discretization of the beam, performed with 10-node cuadratic tetrahedra. The fine discretization required by both the small characteristic length of the concrete and the small steel cross-section leads to a mesh of 5646 elements.

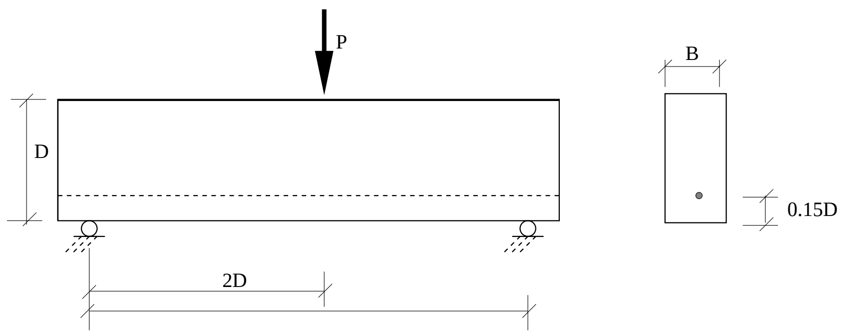

Figure 1: A three-point-bending beam with rectangular section, where $D = 75$ mm and $B = 50$ mm.

Figure 3 shows the resulting crack pattern in one of the numerical tests. A main crack propagates through the reinforcement layer. The rebar protrudes from both crack lips and sews them so as to keep them fastened. Please, note that the concrete around the steel follows the protrusion of the bar before breaking apart. Fig. 3 also represents the damage contour indicating the extent of energy consumed on the crack surface compared to the specific fracture energy of the material. Our validation also comprises a comparison

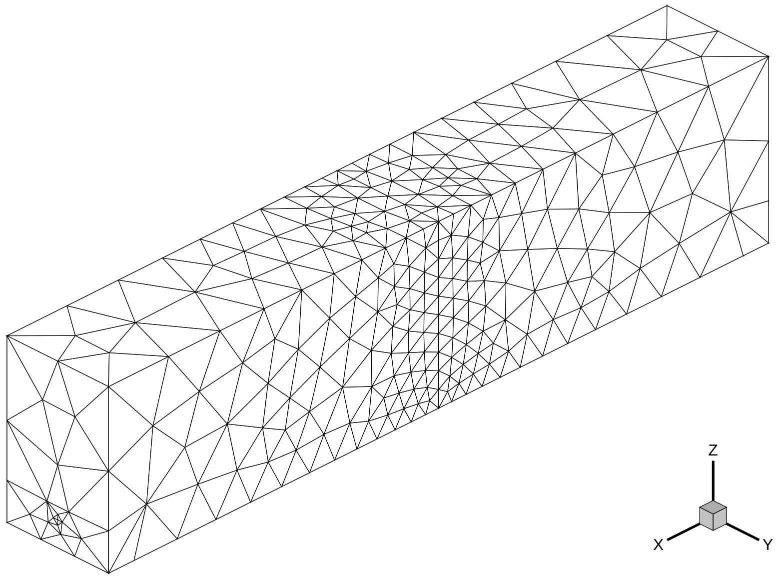

Figure 2: Initial mesh of the beam, 5646 quadratic tetrahedra

of the load-displacement curves obtained in the tests with their numerical counterparts. Figure 4 shows that the simulations get very accurately the mechanical response of the reinforced beam.

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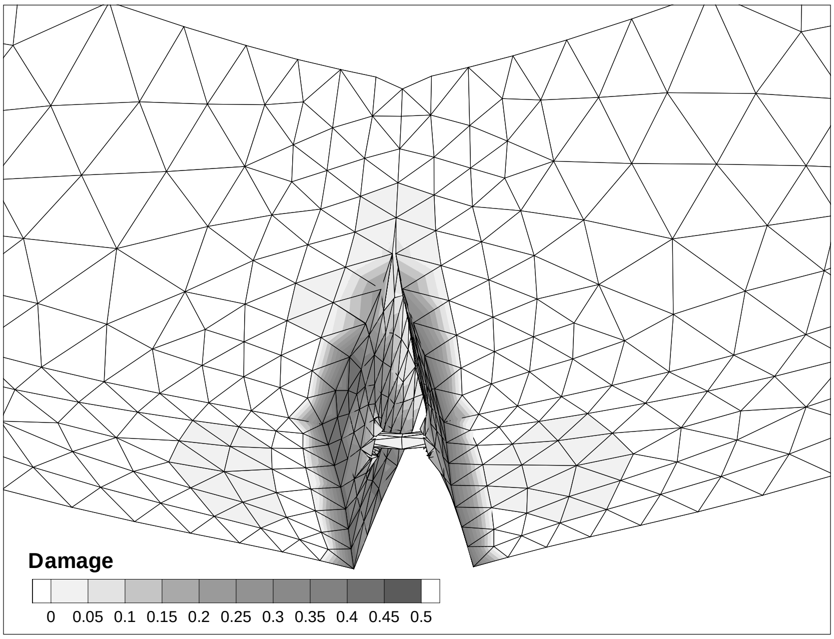

Figure 3: Contour plot of the damage variable close to the middle section for a displacement under the load point of 0.06 mm. The displacements are enlarged to aid visualization of the crack process

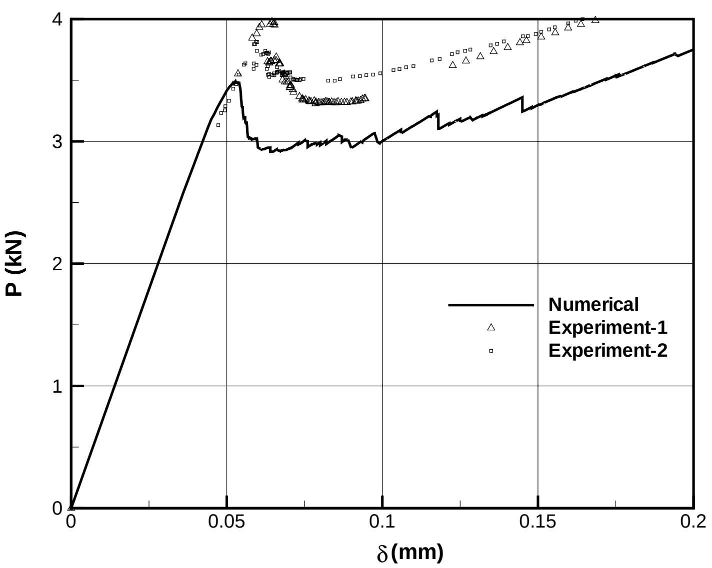

Figure 4: Load-displacement curve for $\rho = 0.26\%$ (smooth reinforcement).