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Behaviour of RC columns strengthened by steel caging under combined bending and axial loads

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ABSTRACT

The steel caging technique is used to strengthen RC columns all over the world, as it has been shown to be effective, economical and easy to apply. Most studies carried out to date on this strengthening technique have focussed on isolated sections of columns subjected to axial loads. This paper deals with an experimental study on the behaviour of RC columns strengthened by steel caging under combined bending and axial loads. Full-size specimens were laboratory tested and the beam–column joint was also simulated. Two different types of element were used to solve the strengthening in the zone nearest to the joint. These were: (1) capitals welded to the steel cage in contact with the beam and (2) steel tubes joining the cage on both sides of the joint. The results obtained show that the technique described considerably increases the resistance and ductility of columns strengthened in this way. The results are compared with those that could be obtained with the proposal of Eurocode No. 4 and also with the results of two other similar studies.

1. Introduction

Steel caging is at the present time the variant of steel jacketing most often used to strengthen RC columns [1]. It is normally used on square or rectangular section columns and involves the use of longitudinal angle sections fixed to the corners of the column, to which transverse steel strips are welded. The space between cage and column is filled with cement or epoxy mortar.

As has been shown by Adam et al. [1], when a column is strengthened with a steel cage there are three ways of dealing with the areas close to the ends of the column:

(a) Adding capitals welded to the steel cage so that they are in contact with the beam.
(b) Welding tubes to the strengthening angles that pass through the beam–column joint.
(c) Leaving the area without any additional elements.

The steel caging technique is used to strengthen RC columns all over the world [1–7], as it has been shown to be effective, economical and easy to apply [1–3]. Although the use of steel cages is widespread and highly effective, there has been little research into RC columns strengthened by this technique [1,8].

Most of the studies that have been carried out on RC columns strengthened by steel caging have focussed on isolated sections of columns subjected to axial loads, e.g. Giménez et al. [9,10], Cirtek [5] and Ramírez [11], as well as the numerical studies in Adam et al. [1,12,13] and Cirtek [14]. Adam et al. [15,16] also studied the influence of the beam–column joint on the behaviour of axially loaded RC columns strengthened by steel caging.

Even though the combination of an axial load and bending moment has already been studied for the case of strengthening RC columns with FRP [17,18] and steel plates [19], only Montuori and Piluso [7] investigated the effects of eccentric compression loads on RC columns strengthened by steel cages.

2. Objectives and novelty of the study

The present study is a continuation of previous work carried out at the Institute of Concrete Science and Technology (ICITECH) of the Technical University of Valencia that focussed on the behaviour of axially loaded RC columns strengthened by steel caging [1,8–10,12,13,15,16]. The new study aims to investigate the behaviour of strengthened columns under combined bending and axial loads.

As a novel element, the present study considered the influence of the beam–column joint and also two possible ways of solving the strengthening the zone nearest to the joint, as compared to that of Montuori and Piluso [7], in which the specimens were eccentrically loaded.

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The results of the experimental study given in this paper include analyses of:

(a) Behaviour and failure mode of the specimens.
(b) Increase in the resistance and ductility of the strengthened column.
(c) Comparison of two possible ways of solving the strengthening of the column ends (capitals or tubes).
(d) Comparison of the results obtained with the proposals of Eurocode No. 4 [20] and the results obtained by Montuori and Piluso [7] and by Li et al. [6].

3. Specimen characteristics

3.1. General

The test specimens consisted of two lengths of RC column with a central transverse element representing a beam, so that the beam–column joint was situated at the centre of the specimen. The specimen geometry was very similar to that used by Adam et al. [15,16], Watson and Park [21] and Yazzar [22].

Column cross sections were slightly larger than the minimums recommended by most international codes [23,24]. UPN-260 pieces (channel section type, outside depth 260 mm, outside flange width 90 mm, flange thickness 14 mm and web thickness 10 mm) with welded steel plates were attached to the ends of the column lengths to form a type of "steel box" whose objective was to dissipate the energy transmitted by the hydraulic jack in addition to acting as the connecting element with the steel test frame.

Reinforcement of the column lengths was similar to the minimum permitted by most international codes [23,24]. Beam reinforcement was determined by the normal residential-building slab design requirements. It should be emphasised that the transverse reinforcement of both column lengths was strongest at the ends of the specimens, with the aim of avoiding possible failure due to the loads applied at these points. The longitudinal reinforcement of both column lengths was welded to the "steel box" at the ends of the specimens. Specimen geometry and reinforcement details are shown in Fig. 1.

A total of ten specimens were tested, including two with no strengthening (identified as Ref), to be used as control references. There were two different types of strengthened test specimen with different types of beam–column joint solution. Specimens Type C (see Fig. 2) solved the beam–column joint by means of capitals (made of steel angles) welded to the steel cage and in contact with the beam. In type T specimens (see Fig. 2) the steel cages that strengthened the two column lengths were connected by steel tubes, as recommended by Fernandez-Cánovas [25]. A total of four specimens of each type (C and T) were tested under bending and axial loads.

3.2. Material properties

The concrete mix used was designed to simulate a column with low compressive strength in need of strengthening. The compressive strength of the concrete was determined by tests on cylindrical specimens 150 mm in diameter and 300 mm long. A total or 18 cylindrical specimens were tested which gave a mean compressive strength value of 11.6 MPa (standard deviation 0.74) at 28 days. The cylindrical specimens gave a mean compressive strength value of 12 MPa (standard deviation 0.98) at the moment of testing the simulated columns specimen.

The yield stress in reinforcement steel and steel cage was f_{ys} = 500 MPa and f_{yL} = 275 MPa, respectively. The cement mortar between cage and column had a cement/sand weight ratio of 1:2.

3.3. Instrumentation

Each of the control specimens (Ref) was fitted with a total of seven linear variable displacement transducers (LVDTs).

Type C specimens were fitted with 26 strain gauges (8 on the strips and 18 on the angles) and 7 LVDTs (see Fig. 3a). Type T

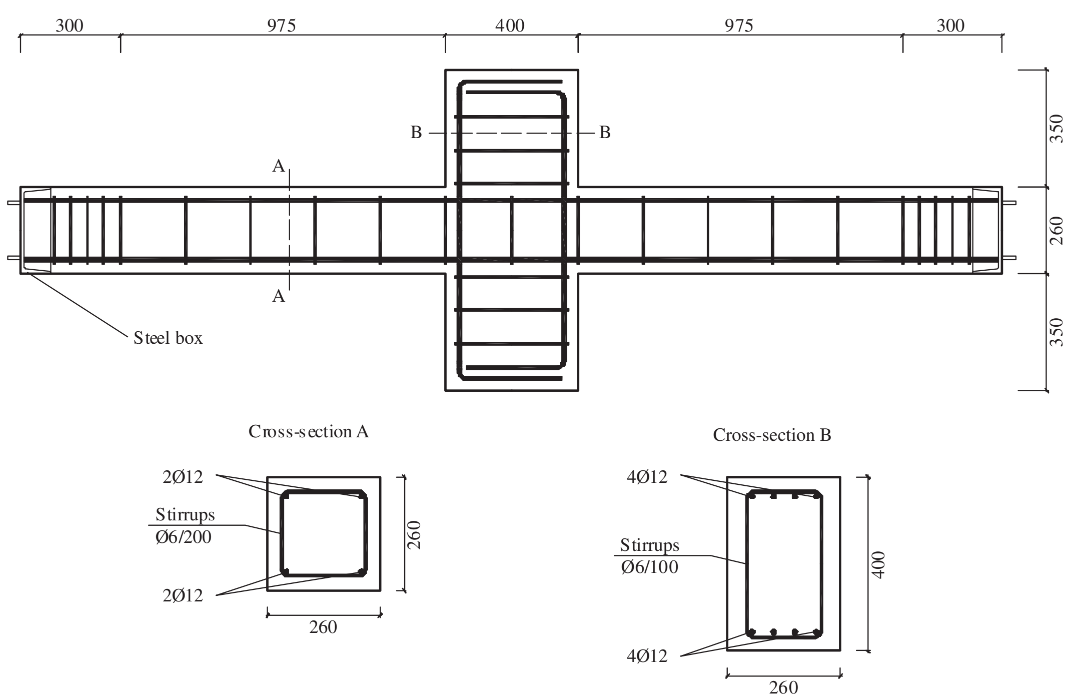

Fig. 1. Specimen geometry and reinforcement.