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Finite element modelling of steel-caged RC columns subjected to axial force and bending moment

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A B S T R A C T

Steel caging is an effective, economical, easily applied and widely used method of strengthening RC columns. Based on the results of two experimental studies, this paper proposes the finite element modelling of RC columns strengthened by a steel cage under axial loads and bending moments. The FE models were used to obtain the N-M diagrams of experimental cases in which a study was made of the improved resistance of RC columns strengthened with this type of strengthening technique. The paper also includes a comparison of different methods of connecting the cage around the beam–column joint and a parametric study to observe the influence of diverse parameters on the behaviour of the strengthened column, including: angle dimensions, number of strips, the yield stress of the steel used in the strengthening, the dimensions of the capitals at both ends of the column, concrete strength and the characteristics of the reinforcement used in the columns. Finally, the results of the various tests (experimental and numerical) described in the paper are used to be compared with three design proposals and the goodness of fit of each one is analysed.

1. Introduction

Steel caging is one of the methods presently available for strengthening RC columns. This technique is a variant of steel jacketing, which has been shown to be effective, economical and easy to apply [1–3] and is widely used all over the world [1,2–7]. Steel caging 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. Capitals can be welded to the ends of the cage in contact with the beam in order to allow the direct transmission of loads to the strengthening.

A comparison of the number of studies carried out on steel caging with those on other strengthening techniques shows that the former has to date received little attention from the scientific community [1,8]. Several authors have studied the behaviour of an isolated column strengthened by steel caging and subjected to axial load, both experimentally [5,9–11] and numerically [1,12–14]. A detailed study of the beam–column joint was carried out by Adam et al. [15,16] which showed the importance the beam–column joint can have in an axially loaded RC column strengthened by steel caging. Montuori and Piluso [7] made experimental studies on the effects of eccentric compression loads on isolated columns and proposed a calculation procedure. Garzón-Roca et al. [17,18] carried out experiments on the behaviour of steel-caged columns subjected to a combination of an axial load and a bending moment, considering the influence of the beam–column joint and several possible ways of solving the strengthening in the zone nearest to the joint.

As far as we are aware, no study has been published to date dealing with a numerical simulation of an RC column strengthened by steel caging subjected to a combination of axial and bending forces. This paper describes an analysis by the finite element method (FEM) of the behaviour of RC columns strengthened by a steel cage under a combination of axial loads and bending moments while considering the influence of the beam–column joint. The work is a continuation of previous studies carried out in the Institute of Concrete Science and Technology (ICITECH) at the Universidad Politécnica de Valencia [1,8–10,12,13,15–18] using the finite element software ABAQUS v. 6.8 [19]. The specimens tested by Garzón-Roca et al. [17,18] were first modelled and the finite element (FE) model was validated. This involved ensuring that the models of the different specimens adequately reproduced the following characteristics: behaviour and failure patterns, maximum applied load value and the evolution of the forces on the angle pieces used in the strengthening.

The models thus created were then used to obtain the axial load-bending moment (N-M) diagrams of the specimens in order to study the improved resistance provided by the strengthening

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and to compare the different ways of connecting it to the beam–column joint. A parametric study was conducted to analyse the influence of different parameters in the behaviour of RC columns strengthened by a steel cage under axial loads and bending moments, including: angle-piece dimensions, number of strips, yield stress of the steel used in the strengthening, dimensions of the capitals placed at both ends of the steel cage, the concrete strength and the size of the reinforcement used in the columns. It is noteworthy that a total of around 750 FE models were needed to carry out the study. Finally, the numerical results obtained were compared with the proposals of Eurocode No. 4 [20], Li et al. [6] and Montuori and Piluso [7].

2. Summary of previous experimental work

Previous experimental work [17,18] had been carried out at the ICITECH laboratories at the Universidad Politécnica de Valencia and consisted of a test on 24 full-scale specimens simulating the beam–column joint zone in a reinforced concrete building structure. Each of the specimens was 2950 mm long and was shaped as shown in Fig. 1: two lengths of RC column with a central transverse element representing a beam, with the beam–column joint situated at the centre of the specimen. A steel box was built around each end of the columns to absorb the axial load transmitted by the press to the specimen and to connect the specimens to the test frame.

The column lengths were reinforced by four steel bars 12 mm in diameter with 6 mm stirrups every 0.20 m. This reinforcement is slightly stronger than that recommended by most international standards [21,22]. The transverse reinforcement of both column lengths was strongest at the ends of the specimens, with the aim of avoiding possible failure due to high shear stresses and local effects. The longitudinal reinforcement of both column lengths was welded to the steel box. Beam reinforcement was determined by the normal residential-building slab design requirements.

Of the 24 specimens, four were designated as controls and were not strengthened. The remainder were strengthened by steel caging built with L60.6 angles (leg size 60×60 mm and thickness 6 mm) and rectangular strips measuring $230 \times 140 \times 8$ mm and $230 \times 100 \times 8$ mm. The geometry of the two types of strengthening used is shown in Fig. 2a and Fig. 2b. Four different methods of connecting the steel cage to the beam–column joint were also tested (Fig. 2c):

– Type T specimens: the steel cages that strengthened the two column lengths were connected by steel tubes, as recommended by Fernandez-Cánovas [23], ensuring the transmission of loads between the two sections of the strengthened column.
– Type C specimens: connection was by capitals made of steel angled pieces L70.7, 70 mm wide and 7 mm thick, with three 8 mm stiffeners, welded to the end strips and in contact with the beam.
– Type A specimens: included the same type of capital as used in Type C but connected to the beam–column joint by means of 16 mm chemical anchors embedded in the concrete.
– Type B specimens: included the same type of capital as used in Type C but the capitals on each side of the joint were joined by 16 mm diameter corrugated steel bars.

The concrete mix used was designed to simulate a column with low compressive strength in need of strengthening. On testing the simulated columns specimen, the compressive strength value was between 10 and 12 MPa. The yield stress in reinforcement steel and steel cage was 500 MPa and 275 MPa, respectively. The cement mortar between cage and column had a cement/sand weight ratio of 1:2.

Each of the specimens under test was instrumented with strain gauges and linear variable displacement transducers (LVDTs) to measure strain and displacement in the steel cage and column concrete. Between 26 and 28 strain gauges were arranged around the angles and strips of the steel cage and four were placed on the concrete at the joint. They also had between 7 and 13 LVDTs [17,18].

The test structure consisted of a steel frame containing the length of column in a horizontal position with the beam vertical (Fig. 3). The steel boxes at each end of the column were attached to the test structure by two hinges that allowed rotation in the vertical plane. Total distance between the two hinges was 3310 mm. An axial load was firstly applied to the specimen by means of a hydraulic jack with a maximum capacity of 2500 kN. Axial loads were applied at values of 300, 400, 800, 1000 and 1200 kN. When these values had been reached, a shear load was applied to the upper section of the beam and the axial load was then kept constant for the duration of the test. The shear load was introduced as imposed displacement and was gradually increased until failure by a hydraulic jack with a maximum capacity of 500 kN.

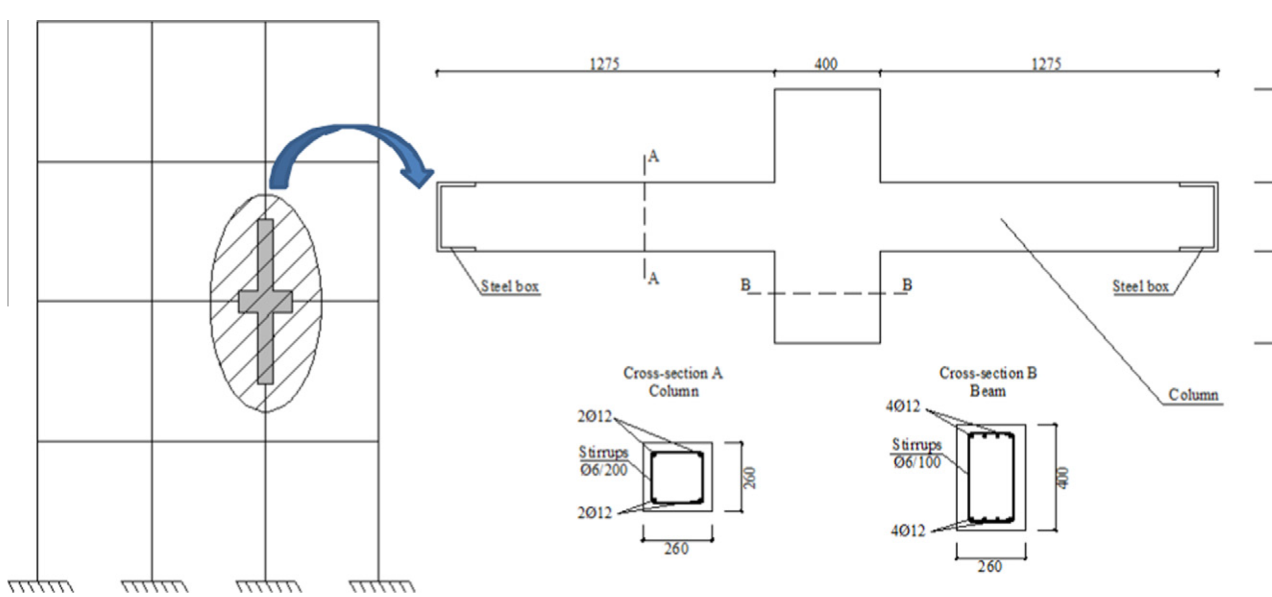

Fig. 1. Specimen geometry and reinforcement (dimensions in mm).