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Axially loaded RC columns strengthened by steel caging. Finite element modelling

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ABSTRACT

Reinforced concrete (RC) columns in buildings often need strengthening either due to defects in the columns themselves, having to support higher loads than those foreseen in the initial design of the structure, or as the result of ageing or accidental damage. The use of steel caging for this purpose is now a common practice in many countries throughout the world. Based on the results of an experimental study, this paper presents a parametric study using finite element models carried out with the aim of analysing the behaviour of RC columns strengthened by steel caging. The results of the study are used to analyse the influence that various parameters have on the behaviour of the strengthened column (size of the angles, the yield stress of the steel of the cage, the compressive strength of the concrete in the column, the size of the strips, the addition of an extra strip at the ends of the cage, the friction coefficient between the layer of mortar and the steel of the cage). The results obtained from the parametric study allow a series of guidelines to be established.

1. Introduction

It is often necessary to strengthen RC columns in a building either due to defective construction, or because higher loads than those foreseen in the initial design are imposed to the structure (possibly due to a change in building use) or as a result of accidents such as seismic loads.

Three principal methods are available for column strengthening: concrete jacketing, steel jacketing and composite jacketing (FRP). Steel caging is a variant of the second category and is known to be an easily applied and economical strengthening technique [1]. The method involves the use of longitudinal angle sections fixed to the corners of the column, to which transverse steel strips are welded [2,3]. The space between cage and column is filled with cement or epoxy mortar. At the present time it is a common practice [4] in countries such as the Czech Republic [5], Japan [6], Greece [7] and Spain [8]. As Wu et al. [7] have shown, this type of strengthening is fully effective in increasing the strength and ductility of RC columns. CEB-FIB [9] also confirms the effectiveness of this strengthening technique.

Although the use of steel cages is widespread and highly effective, there has been little research into RC columns strengthened by this technique. Fig. 1 compares the percentage of articles published in scientific journals relating to the most commonly used strengthening techniques. Fig. 2 shows the percentage use of each of the strengthening techniques in Spain. The data included in Figs. 1 and 2 were compiled by Adam [8] after an exhaustive review of the bibliography and a survey of 73 technical specialists in forensics and strengthening of structures. As Figs. 1 and 2 illustrate, the percentage of published articles concerning steel jacketing is very small, especially when compared to how much this is actually used in Spain. These data clearly indicate that there is a need for research into the behaviour of RC columns strengthened by steel cages, since this is currently the most used steel jacketing variant [10].

Among the strengthening with steel cages, there are different variants which provide a solution to the area nearest the ends of the column:

(a) Adding capitals welded to the steel cage so that they are in contact with the beam, in a similar way to the specimens studied by Ramírez [11], Ramírez and Bárcena [12], and Ramírez et al. [13]. This ensures a direct transmission of loads to the strengthening [14,15].
(b) Welding tubes to the angles of the strengthening, passing through the beam–column joint. This variant was proposed initially by Fernández [16] with the aim of ensuring the transmission of loads between two sections of strengthened column. This variant has also been studied by Adam [8] and Adam et al. [15].
(c) Not having any additional element at the ends of the strengthening. This variant coincides with one of the analyzed by Giménez [10] and Giménez et al. [17], and is similar to

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Nomenclature

A_c	cross-section area of concrete
A_s	cross-section area of reinforcement
A_L	cross-section area of steel angles
a	contact cohesion according to Coulomb's frictional law
COV	coefficient of variation
E_{ci}	elastic modulus of concrete
E_{co}	2.15e10^4 MPa according to CEB-FIB Model Code 90
E_s	elastic modulus of steel
f_c	compressive strength of concrete
f_{cmo}	10 MPa according to CEB-FIB Model Code 90
f_t	tensile strength of concrete
f_{yL}	yield stress of steel cage
f_{ys}	yield stress of reinforcement steel
N_c	load supported by column concrete
N_s	load supported by steel cage
P_{Exp}	ultimate load obtained from experimental study
P_{FEM}	ultimate load obtained from FE models
P	load applied by the hydraulic testing machine
p	contact normal pressure
β_c	shear transfer coefficient (closed cracks)
β_t	shear transfer coefficient (open cracks)
ξ_1	parameter which takes into account the effectiveness of the strengthening
ξ_2	parameter which takes into account the effectiveness of the strengthening
μ	friction coefficient
τ_{lim}	limit shear stress
υ	poisson ratio

the specimens studied by Dolce et al. [18] and Cirtek [5,19]. However, in the latter, the strengthening was welded to steel plates located at the ends of the column. Consequently, these specimens did not reflect the true behaviour of a strengthened column [8,10].

This paper studies the behaviour of strengthened columns in those cases where the ends of the strengthening are worked on using variant (c) described above. The Institute of Concrete Science and Technology (ICITECH) at the Technical University of Valencia is at present researching the behaviour of RC columns strengthened by this variant. Following the experimental study carried out by Giménez [10], all the laboratory-tested specimens are modelled by the finite element method (FEM). After validating the FE models, a parametric study is carried out which analyses the behaviour of RC columns strengthened by steel caging.

2. Summary of the experimental study

The experimental study on axially loaded RC columns strengthened by a steel cage was carried out in the ICITECH laboratories of the Technical University of Valencia. The tested specimens were considered to represent a full scale column in an actual building. Total length of each specimen was 3100 mm. The columns were 2500 mm long with a cross-section of 300×300 mm^2. The specimens had $300 \times 300 \times 600$ mm^3 concrete heads at both ends of the column, simulating the beam–column joint.

The reinforcement of the column consisted of four 12 mm diameter longitudinal rods with 6 mm diameter cross ties every 0.20 m. The steel yield stress was 400 MPa and the concrete cover was 35 mm. It should be emphasised that the reinforcement used was the minimum permitted under Spanish regulations [20] for RC columns and is very close to most international codes [21,22]. The reinforcement of the heads was designed with the objective of avoiding interruption of the tests by early failure of this component, as had occurred in the tests carried out by Ramírez [11], Ramírez and Bárcena [12], and Ramírez et al. [13]. The columns were strengthened by L80.8 angles (leg size 80×80 mm and thickness 8 mm) and rectangular strips measuring $270 \times 160 \times 8$ mm^3 and $270 \times 100 \times 8$ mm^3. The steel grade was Fe430 [23] with a yield stress of 275 MPa.

The concrete mix used in the columns was designed to simulate a column with low compressive strength in need of strengthening. Compressive strength was determined by the cylindrical specimen test carried out at the same time as the tests on the strengthened columns. It should be pointed out that high strength concrete (f_c = 90 MPa) was used for the heads at both ends of the specimens to avoid failure due to stress concentration in the zones near to the load application points. The cement mortar between cage and column had a cement/sand weight ratio of 1:2.

In order to measure strain and displacement in the steel cage and column concrete, a minimum of 14 strain gauges and eight LVDTs were attached to each of the specimens tested.

The tests were carried out in a steel frame and the axial load was applied by a hydraulic testing machine with a maximum capacity of 5000 kN. Load was applied in displacement control mode at a constant rate of 0.5 mm/min. This load was applied until failure of the specimen. In Fig. 3 a specimen can be seen in the steel frame ready for testing.

Five types of specimens were used in the experiments, and two specimens of each type were tested in the laboratory, giving a total of 10 tests. The differences between the five types of specimen were in the geometry of the cage and also in the strength of the

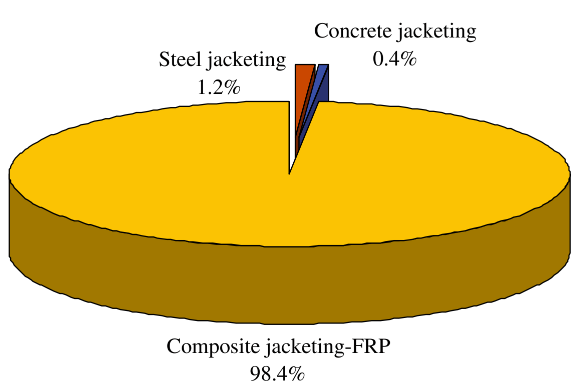

Fig. 1. Percentage of research papers related to each strengthening technique of RC columns.

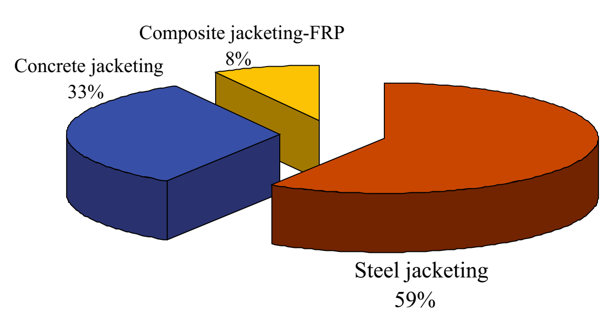

Fig. 2. Percentage use in Spain of each strengthening technique for RC columns.