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Experimental investigation on the axial capacity of reinforced concrete columns with steel jackets

Md. Zakaria Habib, Sudipto Khatib and Md. Meraj Uddin

Department of Civil Engineering
Uttara University, Dhaka, Bangladesh

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Abstract

The objective of this study is to evaluate the axial capacity of reinforced concrete (RC) columns made with crushed bricks strengthened by steel jackets. The experimental investigation studied the axial capacities of ten RC columns made of brick aggregate concrete strengthened and controlled,. A parametric study was conducted to evaluate the effect of different parameters: thickness of steel angle and strips and strip spacing were explored. Specimens were 150 mm × 150 mm in cross section and 750mm in height, reinforced with 4-8 mm dia. longitudinal bars. Strengthening was done by using four steel angles placed at the corners of columns and horizontal strips welded to the angles to form a steel case. The small gap left between the steel case and the surface of the columns was filled with non-shrink repair grout. The test results revealed that the axial capacity was increased by 41% to 64% of control specimens. It was also found that the capacity increases with decreasing the strip spacing and increasing the area of jacket. Moreover, 62% and 57% enhancement was obtained when the strip spacing was 100 mm and 160 mm respectively.

Keywords: Steel jackets, RC columns, brick aggregate concrete, strengthening, confinement.

1. Introduction

Reinforced concrete (RC) columns are the most important structural element of any structures. Due to a range of factors these elements are often needed to strengthened or repaired like aging of structures, usage of inferior quality materials, design deficiencies, poor construction and quality control, Reinforcement misplacement, damaged due to natural causes, vertical extensions to access of future anticipated loads etc. Steel jacketing is one of the most promising methods over the other available methods for strengthening and repairing of existing structures. Common methods for strengthening columns include concrete jacketing, fiber reinforced polymer (FRP) jacketing and steel jacketing. All these methods have been shown to effectively increase the axial load capacity of columns. Khair Al-Deen Isam Bsisu (Bsisu 2009) performed an experimental and theoretical study on 20 square reinforced concrete columns retrofitted with steel jacket technique. All tested specimens were tested under concentric axial loading. The author concluded that retrofitting square reinforced concrete columns with full steel jackets enhanced the compressive strength more than double the strength of the original column without retrofitting. Also, confinement of reinforced concrete columns with steel jackets enhanced the ductility of the column.

Hesham (Eldeen 2011) tested eleven columns with cross section 120 * 160 mm and 1000 mm length divided into three groups. The first group was strengthened using 4 steel angles 20 * 20 * 2 mm connected with 3, 5 and 7 straps. The second group was strengthened using 4 angles 40 * 40 * 2 mm connected with 3, 5 and 7 straps while the third group was strengthened using angles 60 * 60 * 2 mm. The obtained test results showed that increasing the covered area by the steel jacket with corresponding cross sectional area increased the load carrying capacity of the strengthened columns, while increasing strap number had minimal effect on the column carrying capacity. Usama (Seoud 1999) tests were carried out on fifteen columns of cross section 200 * 200 mm and total height of 1800 mm subjected to construction deficiencies such as poor quality of concrete and lack of stirrups in column. The test results showed that, the use of welded stirrups in the strengthening of defected part increases the load capacity to be (87–91%) of the original column load and it is recommended to use welded stirrups to the main reinforcement of the core of the column in the zone of the column without stirrups, and then recast the column cover. Nader (Kozmn 2009) presents an investigation of the behavior of short R.C columns strengthened using pre-tension steel jackets. The experimental program consisted of testing fifteen short R.C columns. Eleven of them were of 150 * 150 mm cross section and 1500 mm height, and four were circular R.C columns of diameter 150 mm and 1500 mm height. The test results showed excellent improvement in load capacity when compared to those before strengthening. Julio Garzon-Rocaet et al. 2010 presented the results of a series of experimental tests on full-scale specimens strengthened with steel caging including simulation of the beam-column joint under combined bending and axial loads. Capitals were applied to all the specimens to connect the caging with the beam-column joint either by chemical anchors or steel bars. It was observed that steel caging increases both the failure load and ductility of the strengthened columns. Giuseppe (Camione 2012) made a comparison between the analytical expressions for the prediction of the load carrying capacity of strengthened R.C columns by steel angles and strips with experimental data available in the literature. The comparison showed acceptable prediction of the experimental results mainly for the cases of angles directly connected to the heads.

2. Experimental testing

In order to investigate the effect of the above mentioned parameters on the behavior of strengthened RC column, an experimental program was carried out to test ten RC columns with concrete compressive strength of 24 MPa.

2.1 Test specimens

10 columns are selected in this experimental work. The columns are divided into two groups. First and second group includes 5 and 5 columns. The size of column are used in this experiment 150mm × 150mm × 760mm and 150mm × 150mm × 610mm. Table 2 gives the reinforced concrete column data for all specimens while Table 3 gives strengthening details for each specimen.

2.2 Concrete mix and casting

The concrete mix used for grade 24 MPa is shown in Table 1the concrete mixture used was prepared from ordinary Portland cement, natural sand and crushed natural dolomite aggregate with maximum nominal size of 10 mm. The test specimens were horizontally cast in wooden forms stiffened by battens to maintain the form and shape.

Table 1
Concrete mixing proportion

Fine & coarse aggregate ratio	Cement content, w (kg/m^3)	Water-cement ratio
1:2	250	0.48

Table 2
Reinforced concrete column data for all specimens

Specimen	Group	f'_c (MPa)	Dimensions (mm)	Reinforcement		
				Longitudinal bars		Stirrups
				Type	f_y	
SC1.0 SC1.1 SC1.2 SC1.3 SC1.4	01	24	150 × 150 × 750 150 × 150 ×750 150 × 150 × 750 150 × 150 × 750 150 × 150 × 750	4 - φ 8 mm @ corners	500 MPa	Φ6 mm @127mm C/C
SC2.0 SC2.1 SC2.2 SC2.3 SC2.4	02	24	150 × 150 × 600 150 × 150 × 600 150 × 150 × 600 150 × 150 × 600 150 × 150 × 600	………	………	………

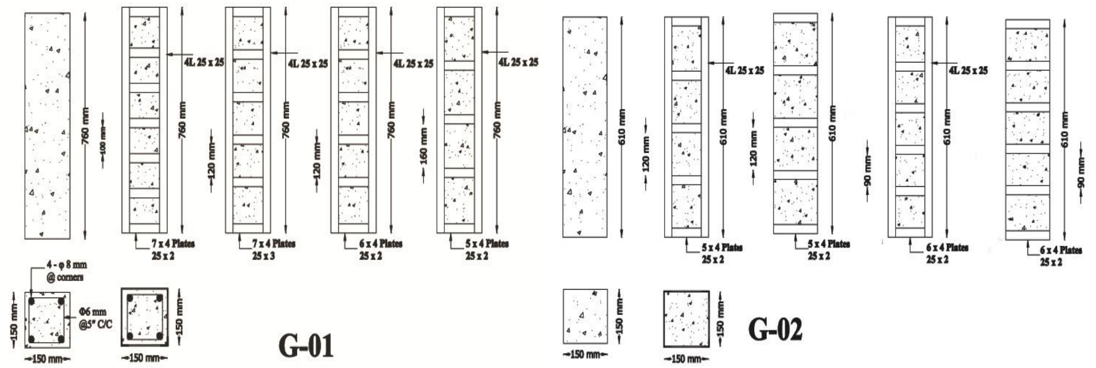

Fig. 1. Specimen dimensions and steel jacket configuration.

Fig. 2. Strengthened specimens after casting and jacket erection.

2.3 *Test procedure*

The specimens were placed in the testing machine between the jack head and the steel frame. The strain gages, load cell were connected to the data acquisition. The load was monitored by a load cell of 2000 kN capacity and transmitted to the reinforced concrete column through steel plates to provide uniform bearing surfaces. Figure 3 shows a schematic view of the test setup. A controlled data acquisition system was used to continuously record readings of the load cell, the one dial gauges of 0.01 mm accuracy that measure the column vertical deformations. All test records were manually recorded.

Table 3
Strengthening detail for each specimen

Specimen	Group	Angle bar size (mm)	Strip size (mm)	Strip Spacing (mm)	f_{sy}
SC1.0 (Ref.)		....	....	....	
SC1.1		25 x 25 x 2	25 x 2	120	....
SC1.2	01	25 x 25 x 3	25 x 3	120	
SC1.3		25 x 25 x 2	25 x 2	100	345 N/mm^2
SC1.4		25 x 25 x 2	25 x 2	160	
SC2.0 (Ref.)		....	....	....	
SC2.1		25 x 25 x 2	25 x 2	120	....
SC2.2	02	Without angles	25 x 2	120	
SC2.3		25 x 25 x 2	25 x 2	90	345 N/mm^2
SC2.4		Without angles	25 x 2	90	

Fig. 3. Schematic view of the test.

3. Experimental results

Table 4
Failure loads and the corresponding displacements for all specimens

Specimen	Failure Load P_u(kN)	Displacement Δ (mm)	Δ / $\Delta_{ref.}$	P_u/ $P_{ref.}$	Load Increase (%)
SC1.0(Ref.)	440	5.10	1.00	1.00	……….
SC1.1	620	7.92	1.55	1.41	41
SC1.2	720	4.01	0.79	1.64	64
SC1.3	712	4.69	0.92	1.62	62
SC1.4	692	5.67	1.11	1.57	57
SC2.0 (Ref.)	340	3.88	1.00	1.00	……..
SC2.1	620	3.69	0.95	1.82	82
SC2.2	380	5.05	1.3	1.12	12
SC2.3	548	2.83	0.73	1.61	61
SC2.4	388	1.69	0.43	1.14	14

3.1 Effect of steel plate thickness

Specimen SC1.1 has an ultimate load equal to 141% that of SC1.0 and specimen SC1.2 has an ultimate load equal to 164% that of SC1.0. This result indicated that, the ultimate load increased with increasing the steel plate thickness.

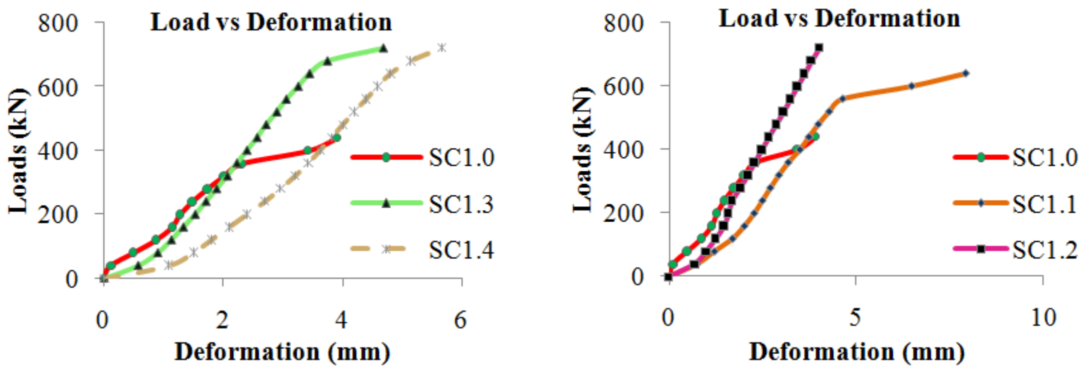

Fig. 4. Axial load vs axial deformation relationship.

3.2 Effect of strip spacing

Specimen SC1.3 has an ultimate load equal to 162% that of SC1.0 and specimen SC1.4 has an ultimate load equal to 157% that of SC1.0. This result indicated that, the ultimate load increased with decreasing the strip spacing.

3.3 Effect of confinement

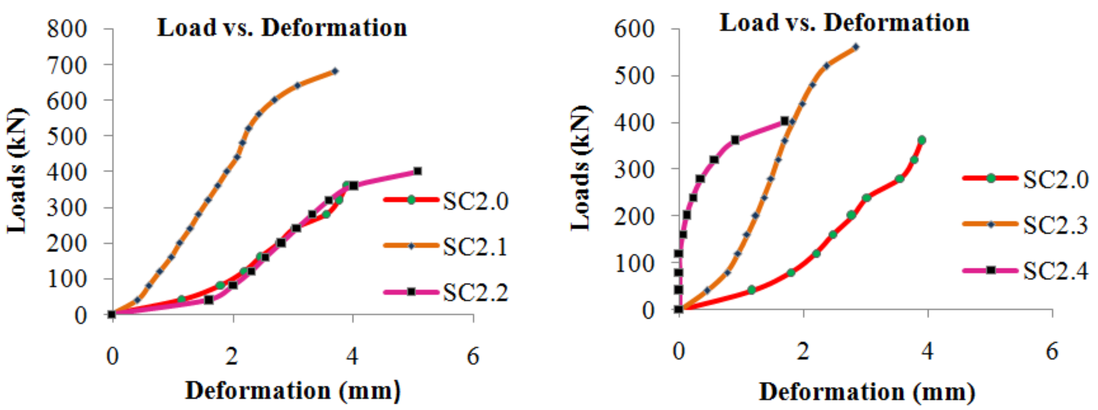

Fig. 5. Axial load vs axial deformation relationship.

Specimen SC2.1 and SC2.3 was strengthened by 4 steel angles with strips and specimen SC2.2 and SC2.4 was strengthened by only strips without angles. The obtained test result showed that, the angle bars increased the confinement and finally increased the column carrying capacity.

4. Conclusion

An experimental investigation has been conducted in the study 10 RC columns have been tested for evaluating the capacity. The enhancement of the axial capacity of RC columns jacketed with steel angles and strips as observed in the study ranges for 41% to 64%. It was also found that the axial capacity was increased with decreasing the strip spacing. More specifically, found to 62% and 57% enhancement in load carrying capacity was obtained when the strip spacing was 100 mm and 160 mm respectively. The failure mode of the control reinforced concrete column was brittle while strengthening with steel jacket changed failure mode to be more ductile. As the surface area of concrete covered by steel jacket increases the effect of confinement also increases.

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