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Behavior of partially defected R.C columns strengthened using steel jackets

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KEYWORDS

Steel;
Jacket;
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Abstract The aim of this work is to study the effect of partial strengthening of partially defected columns on its capacity, and global behavior. There are two types of defects on R.C columns, the first is decreasing the characteristic compressive strength of a part of R.C column, and the second is bad stirrup arrangement.

External FRP jacketing and steel jacketing have been widely used for strengthening R.C columns. The cost effectiveness and convince of applying the steel jacketing strengthening technique have been demonstrated through various strengthening applications.

Few studies have been carried out on partial strengthening of defected columns. In this research, the efficiency of short steel jackets for strengthening of R.C defected columns was studied. The experimental program consists of testing of seven R.C columns with dimensions 200 * 200 * 1500 mm and having stirrups in top and bottom thirds only, while the middle third was without stirrups.

The main parameters studied were the type of steel jacket used and height of partial strengthened part of column. One of the tested specimens was a control specimen and the other six were partially strengthened with different types of steel jackets such as using 4 steel angles at corners connected with straps, using external ties with different spacings, and using 4 steel plates with different thicknesses welded together and connected to column by anchor bolts. Finally, the experimental results were analyzed and compared with results obtained from finite element analysis using ANSYS program.

Introduction

Reinforced concrete (RC) columns are the primary load-bearing structural components in the building. Overtime these columns may need to be repaired or strengthened due to material deficiencies, design deficiencies, poor construction and quality control, chemical and physical actions, corrosion of steel reinforcement, shrinkage and creep, fire risk, poor maintenance and overloading above the admissible level [1]. Steel jacket technique is widely used on strengthening of columns, especially non ductile columns. This technique has many advanta-

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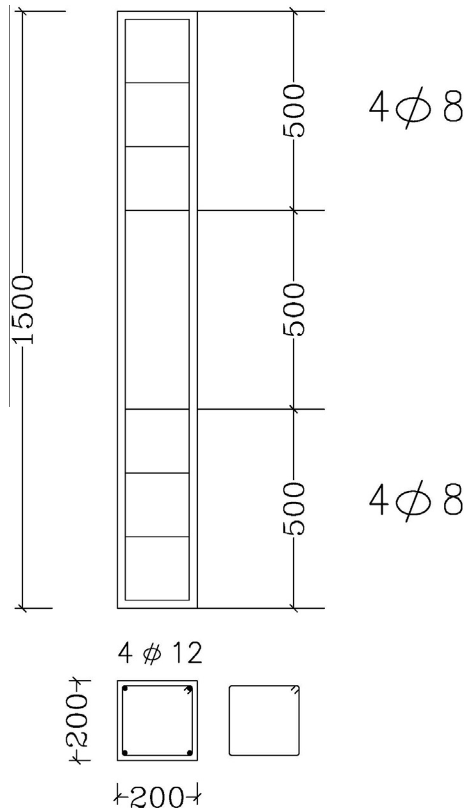

Fig. 1 Details of tested R.C columns.

Fig. 2 R.C columns after jacketing.

ges such as, small thickness compared with concrete jacket, very light weight, increased confinement of columns and load capacity, increased shear strength and lateral load resistance and increased ductility and stiffness.

Many researchers studied the behavior of steel jacketed R.C columns, while few of them studied the behavior of partially strengthened R.C columns using this technique.

Partial strengthening of columns was used in case of partially defected columns such as bad stirrup arrangement.

The aim of this work is to study the efficiency of partial strengthening of columns with bad stirrup arrangement using different types of steel jackets, including 4 steel angles connected with straps, steel plates, and external ties without angles.

Hesham [1] 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.

R.K.L. Su et al., [2] investigated the behavior of pre-loaded rectangular concrete columns strengthened with pre-cambered steel plates. Eight specimens of cross section 100 mm * 150 mm and clear height of 600 mm were tested. The experimental results demonstrated that external steel plates can considerably enhance the strength, deformation and ductility of plate-strengthened columns under axial compressive loads.

A theoretical model was also developed to predict the axial load capacity of plate – strengthened columns.

Giuseppe [3] 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.

The effect of partial strengthening of R.C columns using concrete jackets was studied by Usama [4]. 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 [5] 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.

Rosario, et al., [6] presented a theoretical model able to predict the moment – curvature behavior of R.C columns confined by means of angles and battens. The results of this model were compared with the experimental tests of 13 prismatic specimens characterized by a square section with a side length of 150 mm and height equal to 500 mm. Eight specimens were strengthened with angles (30 * 30 * 3 mm) and battens (15 * 3 mm), and all specimens were subjected to eccentric axial load.

Julio, et al., [7] conducted 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 chem-

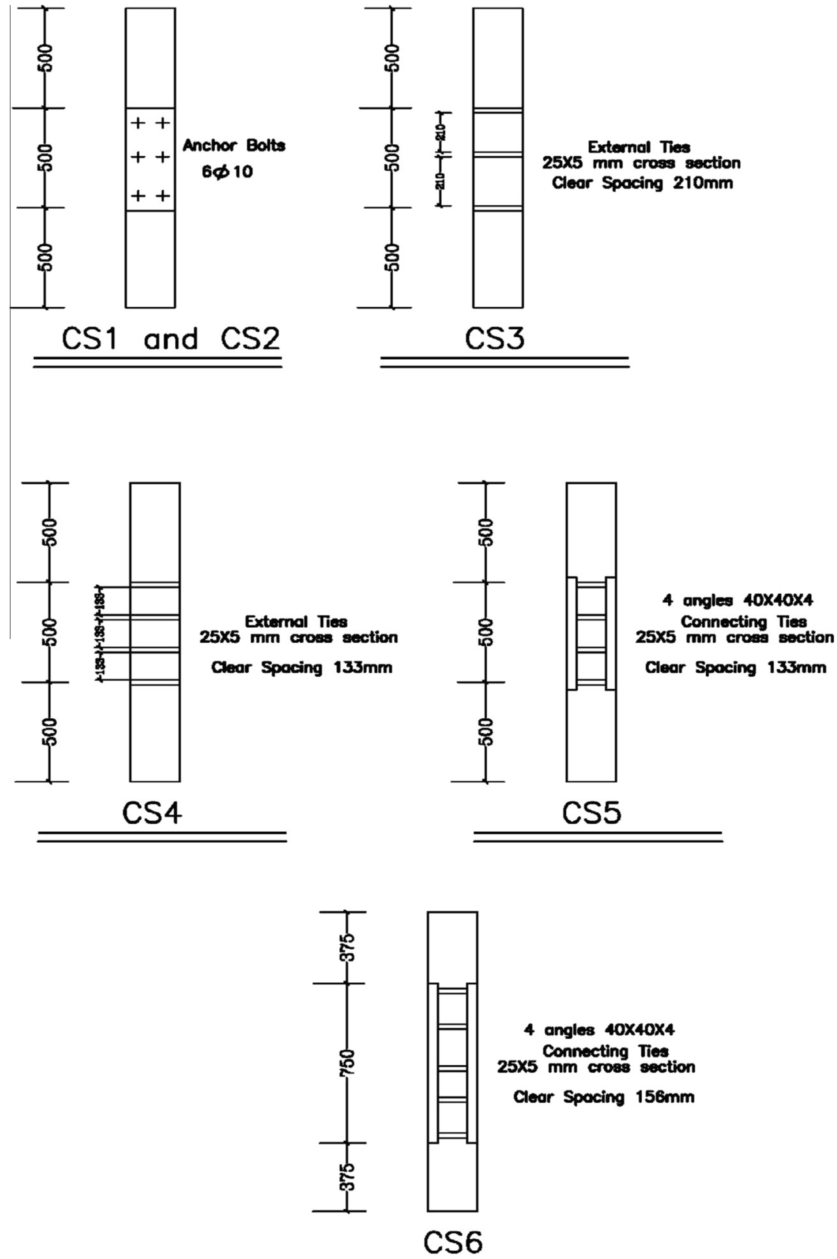

Fig. 3 Details of strengthened columns.

Table 1 Tested specimens.

Column	Fcu	Strengthening technique	Steel jacket height (mm)
C1	25 Mpa	Control specimen	
CS1		4 Plates–1.5 mm thickness	500
CS2		4 Plates–3.0 mm thickness	500
CS3		3 Ties (25 * 5 mm-X section) clear spacing 210 mm	500
CS4		4 Ties (25 * 5 mm-X section) clear spacing 133 mm	500
CS5		4 Angles 40 * 40 * 4 and battens 25 * 5 mm	500
CS6		4 Angles 40 * 40 * 4 and battens 25 * 5 mm	750

Fig. 4 Injection of tested specimens.

Fig. 5 Test set-up and measuring devices.

ical anchors or steel bars to improve the transmission of forces. It was observed that steel caging increases both the ultimate load and ductility of the strengthened columns.

Strengthening of R.C columns using steel jackets was studied by Julio et al. [8], Ramiroz et al. [9], Giuseppe [10], Pedro et al. [11], Jinbo et al. [12], Yijie et al. [13], and Julio et al. [14]. The results showed excellent improvement in load capacity and ductility of strengthened columns.

Experimental program

Tested specimens

The experimental program consists of testing seven R.C columns of cross section 200 * 200 mm, height 1500 mm, concrete strength (fcu) of 25 Mpa, and vertical reinforcement 4Ø12 with stirrups in top and bottom thirds only, while the middle third was without stirrups as shown in Fig. 1.

One of the tested specimens was a control one without stirrups in the middle third and the other six specimens were partially strengthened using different types of steel jackets such as strengthening using 4 steel angles at corners connected with strips (CS5 and CS6), external ties without angels (CS4 and CS3), and steel plates with different thicknesses welded together and connected to column by anchor bolts 6Ø10/side (CS1 and CS2) as shown in Figs. 2 and 3, and Table 1.

After fixing steel jackets to the strengthened columns, the gaps between the steel jackets and the concrete were filled with an injection plaster, forming a layer of binding material between the steel jackets and the concrete. The injection plaster was composed of aluminum hydroxide and kemapoxy 150 with a proportion of 3:1 by weight as shown in Fig. 4.

Test setup and measurements

All columns were loaded with 500 ton hydraulic machine in the material laboratory of Housing and Building National Research Center, HBRC. The applied load was read out on the load cell scale. LVDTs were placed at middle third of two perpendicular sides of columns to measure the longitudinal concrete strains. Fig. 5 shows the test set up and measuring devices of the tested columns.

Test results of experimental program

Failure behavior and failure load

The failure mode of all tested specimens was brittle failure with crushing of concrete. It was observed that the failure of non-strengthened column (specimen C1) was at the middle of the column height, but for the other specimens (strengthened columns) the failure occurred outside the strengthened part. This means that strengthening of defected part changes the failure location. Also it was observed that the welded part of CS1 was cracked during failure without buckling of plate. Fig. 6-a through (6-f) show the failure mode of tested specimens.

Ultimate loads of tested specimens are shown in Fig. 7. It is clear that specimen CS4 has an ultimate load equal to 131% that of the control one and specimen CS6 has an ultimate load equal to 121% that of C1. Also for other specimens, this ratio was 95%, 97%, 91% and 83%, for specimens CS1, CS2, CS3 and CS5 respectively.

This indicated that we can improve the ultimate load of a defected column by using external ties with spacing not less than the spacing of stirrups in non-defected part. Also using 4-angles 40 * 40 * 4 mm with length 1.5 the height of the defected part will give good results for ultimate load. On the other hand, increasing the thickness of the used plates (CS1, CS2) did not affect the ultimate load.

Load strain response

Vertical strains of concrete in two perpendicular sides of the column were measured and plotted against load for tested specimens, Fig. 8. Comparing these curves, it can be noticed that:

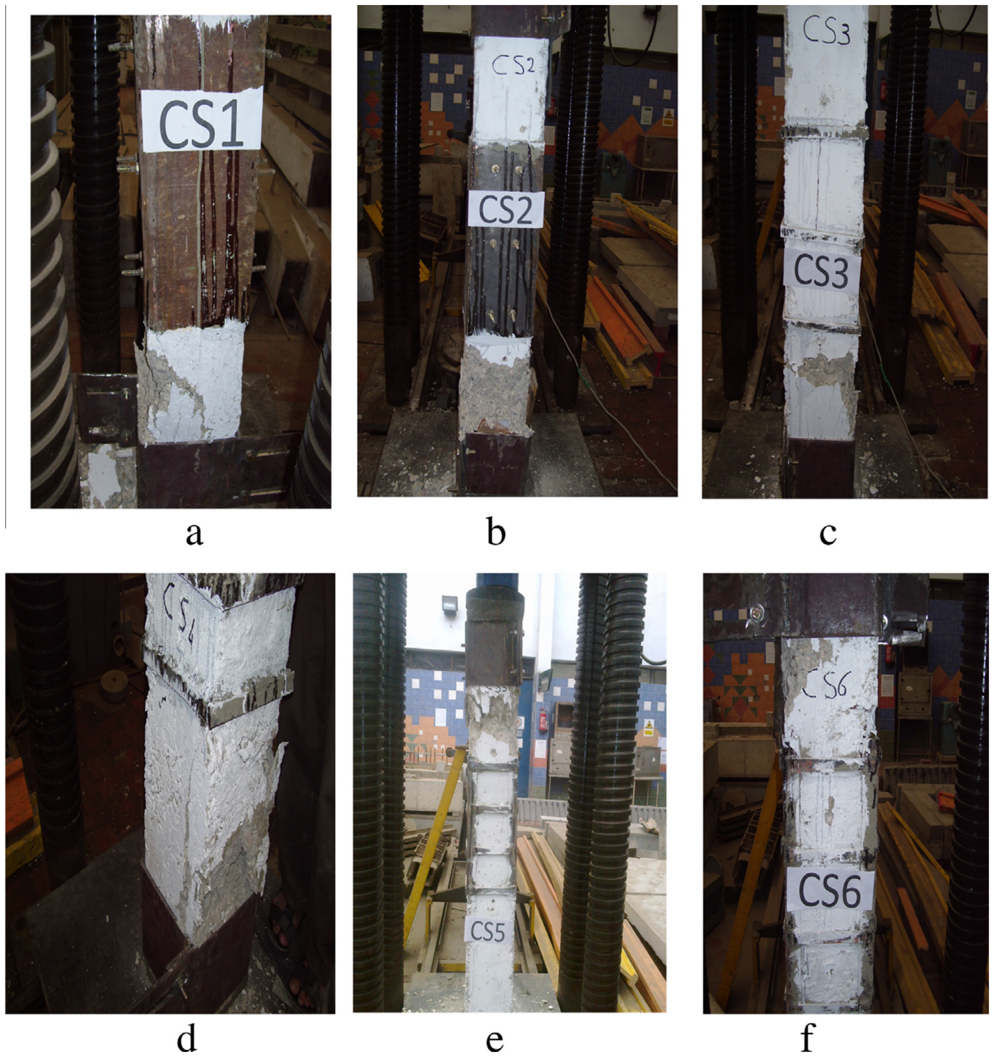

Fig. 6 Mode of failure of tested specimens.

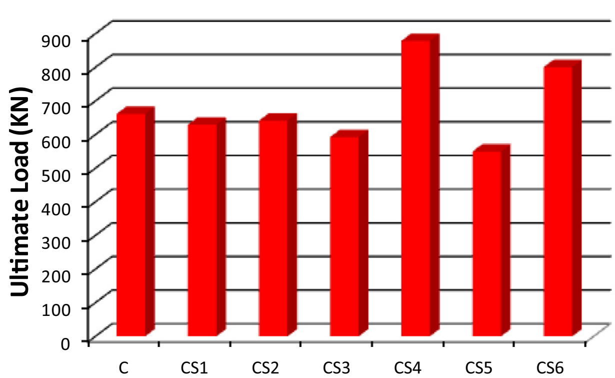

Fig. 7 Ultimate loads of tested specimens.

- Increasing the thickness of strengthening plates (CS1 and CS2), will improve the overall behavior and ductility.
- Increasing the number of external ties (CS3, and CS4) or decreasing the spacing will cause a significant effect in improving the behavior and ductility.
- Increasing the length of external angles (CS5, and CS6) causes an increase in ductility of strengthened column.

Finite element analysis

Numerical analysis using the finite element method has been conducted to simulate the response of tested columns. A finite element program ANSYS was used in the present analysis. The 3D solid element (SOLID 65) was used to model concrete element while the 3D spar element (LINK 8) was used to model the reinforcing steel bars. The model used a mesh of element size ranging from $10 \times 10 \times 10$ mm to $20 \times 20 \times 20$ mm. The column was exposed to centric load which was gradually increased until failure occurred. Fig. 9 shows the FEM of one of tested specimens.

Correlation between theoretical and experimental results

The comparison of the ultimate load between the theoretical and experimental values is shown in Fig. 10. It can be noticed

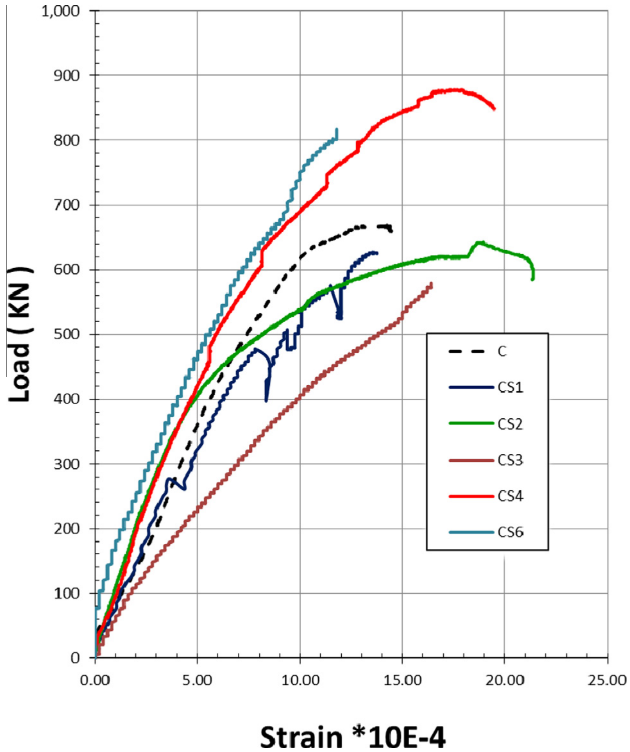

Fig. 8 Load-vertical strain curves of tested specimens.

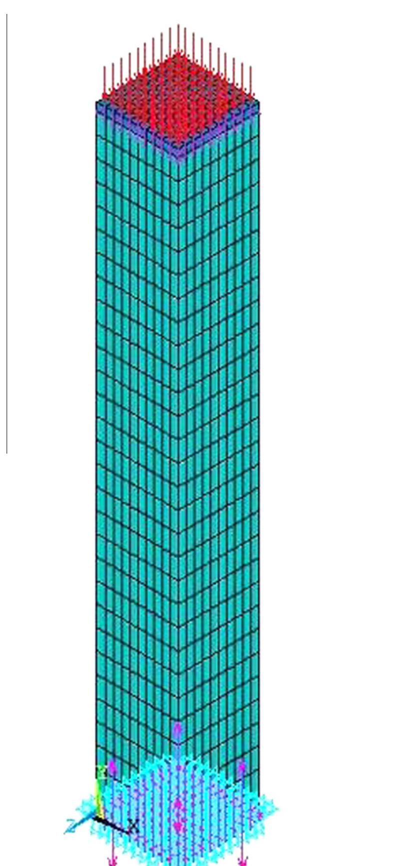

Fig. 9 FEM of one of tested specimens.

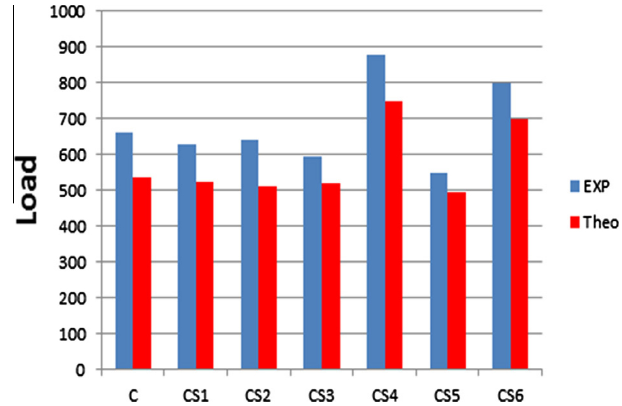

Fig. 10 Comparison between experimental and theoretical ultimate loads.

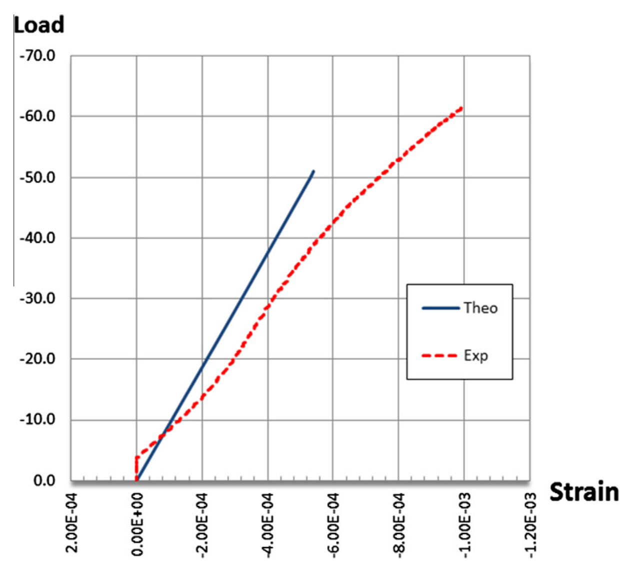

Fig. 11 Comparison of load-vertical strain curves.

that the theoretical ultimate loads were about 80.8–91.3% that of corresponding experimental results for all columns. Also, the finite element model gave a good agreement with the experimental results in vertical deformation measurements as shown in Fig. 11.

It is clear from the above discussion that the experimental and finite element model results of the tested columns were in good agreement.

Conclusion and recommendations

The following conclusions are drawn from this work:

1. The deficiencies of stirrups in R.C column can be compensated by adding external ties with minimum clear spacing not less than 150 mm (the original spacing between stirrups) which gave good results in column capacity and strain behavior.
2. Increasing the thickness of external plate improves the strain behavior and ductility of strengthened column.

3. Increasing the number of external ties significantly increases the ultimate load of the strengthened column.
4. Increasing the strengthened part height using steel angles improves the overall behavior of the strengthened column.
5. It is not recommended to use plates with small thickness (less than 3 mm) in strengthening columns.
6. It was observed that the failure of strengthened columns occurred outside the strengthened part.
7. The finite element model performed using ANSYS program and the obtained theoretical results had fair agreement with the experimental results.

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