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Behavior of Concrete Columns Reinforced with Steel Strip Ties

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Abstract: The effect of using steel strips as a tied reinforcement instead of bar ties to reinforce concrete columns was investigated. Five concrete columns with dimensions 150×150×1150 mm were reinforced with 4 bars of diameter 12 mm as the main reinforcement. One of these columns had a bar tie of diameter 8 mm used as a reference column. The other four columns had strip ties with different widths, 90, 50, 31 and 22 mm and thicknesses, 1-4 mm with an area equivalent to that of the regular ties in the reference beam. A good agreement was obtained between the experimental and theoretical results using the abaqus finite element program. It was found that, using 4 mm thickness plated ties could increase the ultimate load of concrete columns by 17%.

Key words: RC column, ties, steel strip, ABAQUS, finite element, obtained

INTRODUCTION

Because concrete columns are one of the important elements of framed structures, increasing the ultimate strength of columns is an important area for research. The methods used for increasing column capacity are either by increasing the compressive strength of concrete (using high strength concrete) during the design process or by using external steel angles and horizontal strips, adding a new concrete jacket with additional reinforcement and wrapping the column section with Fiber Reinforced Polymers (FRP).

Pallewatta *et al.* (1995) studied the behavior of concrete confinement by lateral reinforcement through concrete columns. Their aim was to define the efficacy of the confinement of lateral reinforcement and to obtain reliable data form the verification of non-linear, three-dimensional concrete constitutive laws, under non-uniform stress fields, produced in the confined concrete cores of columns. They also aimed to identify the influence of a variety of parameters on confinement phenomena for the purpose of developing and examining a behavior-oriented, macro-model. Their conclusion was that the increase in strength of the confined core was influenced by the increased average confining stress and the spacing of ties governing lateral confining stress uniformity.

Chikh *et al.* (2012) analyzed the load carrying capacity and strain data obtained from tests on circular plain concrete and steel reinforced concrete columns, strengthened with external, carbon fiber-reinforced polymer sheets. The parameters of the experimental tests included different concrete strengths, number of wrap layers and slenderness of the columns (L/∅). About 48 specimens were tested under axial compression and loaded to failure. Their results clearly demonstrated that composite wrapping can enhance the structural performance of circular RC columns in terms of both maximum strength and ductility. They concluded that increasing the amount of CFRP sheets produces an increase in the compressive strength of the confined column but with a lower rate compared to that of the deformation capacity which was almost proportional to the CFRP strengthening ratio.

Daugevicius *et al.* (2013) analyzed the behavior of eccentrically loaded, confined, rectangular, cross-section reinforced concrete elements. The 14 elements were tested, 6 of these strengthened with carbon fiber reinforced polymer. The influence of the eccentricity of vertical loading on the behavior of strengthened and non-strengthened elements was investigated. It was determined that, the influence of concrete confinement decreases when loading eccentricity increases. Their conclusion was that, the confinement of a compressed reinforced concrete element with CFRP restrains lateral deformation by increasing the maximum potential axial deformation thus increasing compressive resistance. The maximum axial deformation in centrically loaded strengthened elements increased up to 481% in comparison to ordinary concrete elements.

Holmes *et al.* (2015) investigated the advantages of using external active confinement to improve the compression load capacity of concrete cylinders by using mild steel band clamps. Passive and actively pre-stressed

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steel bands were attached to concrete cylinders to mimic real structural columns which may otherwise have to be removed and replaced due to poor strength performance. Their experimental program included the compression load testing of unreinforced concrete cylindrical specimens to establish the effect confinement had on compressive load-carrying capacity and stress-strain behavior. A number of parameters were investigated including the effect of varying band spacing, volumetric ratio and passive and active confining forces. They found that, the different levels of pre-stress used had no significant effect on strength but that this influenced the confined concrete stress-strain behavior with greater lateral stresses at peak strength. Increases in ductility were also observed for confined specimens, significant axial strains achieved with noticeable peak strength enhancements. Pre-stressing confinement yielded an increase in load capacity of 53% as the bands were fully activated.

Tarabia and Albakry (2014) studied the behavior and efficiency of reinforced concrete square columns, strengthened by steel angles and strips (steel cage), proposing an analytical model to predict the ultimate strength of concrete columns, including the confining effect of the outer steel cage. Their results showed that, strengthening square columns with steel angles and strips increased the ultimate capacity up to 1.35 and 2.1 times that of the unstrengthen columns.

Helles (2014) studied the effect of strengthening square RC columns by applying fibrous, ultra-high performance, self-compacting concrete as a jacketing material. He found that, column capacity could be increased between 2-4.4 times that of the unstrengthen columns.

No studies were found which examine the effect of using steel plates as an alternate reinforcement for concrete column. The present study therefore examines the effect of using steel strips of varying thickness and different widths on the ultimate capacity of concrete columns.

MATERIALS AND METHODS

Five concrete columns of dimensions 150×150×1150 mm were cast. All specimens were reinforced with 4 bars of diameter 12 mm as the main reinforcement. The ties used for the reference column (CB) were 8 mm diameter bar reinforcements spaced at 150 mm. The ties in the other columns were replaced by equivalent steel strips which have the same strength of the bar tie as shown in the spacing of the steel strips ties was also fixed at 150 mm. The labels used for these columns are CS1-CS4 where C refers to the Column, S refers to Strip, the number referring to strip thickness. Details of all columns reinforcements are listed in Table 1.

Properties of materials

Concrete: Portland cement, natural sand and crushed gravel was used in the concrete mix for the present study with ratios 1:1.34:2.66 and w/c (water/cement ratio) equal to 0.46. The average compressive strength of the 150×150×150 mm cubes for this mix was 39 MPa.

Steel bar reinforcement: All columns were reinforced with bars of diameter 4Φ12 mm. The reinforcement ties used for the reference column were positioned Φ10@150 mm apart. The properties of the steel bars are listed in Table 2.

Steel strips: Steel strip ties with different thicknesses and widths were used for the other columns. The properties and dimensions of the steel strips for each column are listed in Table 3. The width of the steel strips was calculated by equating the tensile strength of a 10 mm diameter bar with that for steel strip as follows:

$$(A_v \times f_y)_{tie} = (A_p \times f_{yp})\text{ plate}$$
$$A_p = w \times t$$

Where:

A_v = Area of ties
A_p = Area of steel plate
w = Width of steel plate
t = Thickness of steel plate

Experimental tests: All columns were tested in Al-Qadisiyah University, College of Engineering, laboratory using a 600 kN capacity hydraulic machine with

Table 1: Reinforcement details of columns

Column types	CB	CS1	CS2	CS3	CS4
Main reinforcement	4Φ12 mm	4Φ12 mm	4Φ12 mm	4Φ12 mm	4Φ12 mm
Bar ties	Φ8 mm	-	-	-	-
Strip thickness (mm)	-	1	2	3	4
Strip width (mm)	-	90	50	31	22
Spacing (mm)	150	150	150	150	150

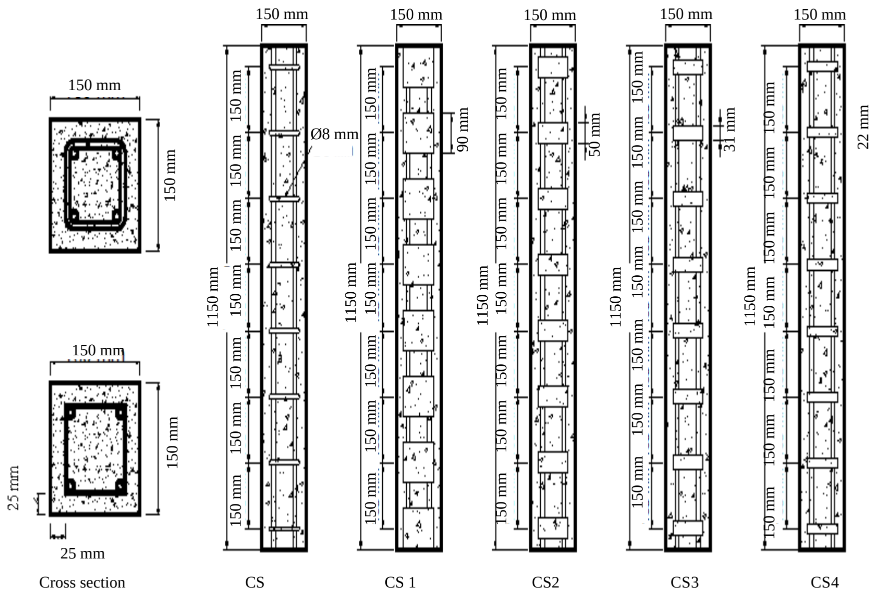

Fig. 1: Geometry and details of columns

Fig. 2: Reference column in testing machine

Table 2: Mechanical properties of steel bar reinforcement

Bar diameter (mm)	Elongation (%)	Tensile stress (MPa)	Yield stress (MPa)
12	9	630	730
10	8	380	450

Table 3: Properties of steel strips

Strip thickness (mm)	Tensile stress (MPa)	Strip width (mm)
1	380	90
2	380	50
3	408	31
4	431	22

a loading rate of 0.05 mm/sec. Figure 1 and 2 show the reference column in testing machine. The load was applied at the center of the cross section of the column to produce an axial load only. Two plates of thickness 16 mm were placed at thetop and bottom of the column to ensure application of a uniform load. Two dial gauges were used in the test process, one measuring displacement in a vertical direction and the other measuring lateral mid-column displacement.

RESULTS AND DISCUSSION

The results obtained from testing the five concrete columns reinforced with equal longitudinal reinforcement and different steel strip ties are shown in load-axial displacement curves for tested columns. The reference Column (CS), reinforced with steel bar ties, failed at an axial load of 400 kN while columns CS1-CS3, reinforced with steel strip ties of thickness 1-3 mm, respectively, failed at axial loadings of 380, 374 and 370 kN, respectively, less than the reference column. Column CS4 which has steel strip ties of thickness 4 mm and a width of 21 mm, failed at an axial load of 470 kN, this representing an increase in maximum strength of 17.5%. Compression failure occurred for all columns. The main reason for failure was crushing of the concrete near the concentrated load and cracking. Cracks were propagated over a distance of 0.25 L for all specimens except column CS1 which had cracks extending along the length of column on the concrete cover. This was because of the 1 mm wide steel strips, these relatively large, having a smooth surface, separating the concrete cover from the concrete core .

Finite element modeling: In order to verify the results obtained from experimental testing, a finite element analysis for all columns was carried out using the analysis for all columns was carried out using the ABAQUS FE. analysis program. The columns were modeled using an

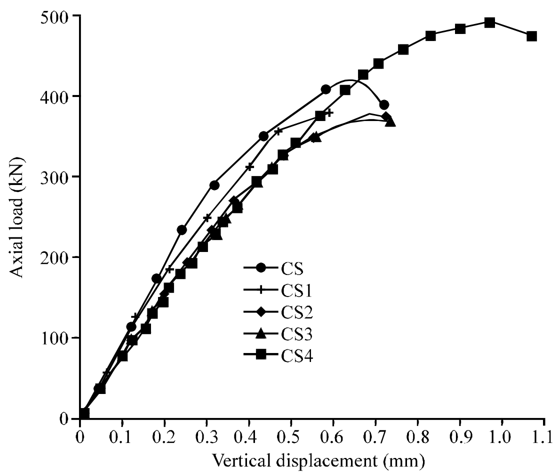

Fig. 3: Load-axial displacement cures for tested coloums

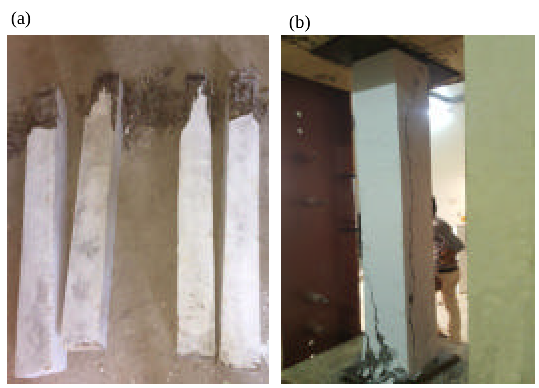

Fig. 4: Concrete columns after failure; a) Colums CS1-CS4 and b) Column CS1

8 noded, solid brick element for the concrete, a 4 noded shell element for both end plate and steel strip ties and a 2 noded truss element for the steel bar reinforcements as shown in. An incremental loading procedure using an arch length method for the numerical solution was adopted.

The load-axial displacement curves from both the experimental and finite element results were recorded and plotted for all columns as shown in Fig. 3-10. It can be seen that, there is good agreement between the experimental results and those obtained using the finite element program (ABAQUS). The differences in maximum load ranged from 1.7-10%, those for axial displacement ranging from 3-12% when compared to the finite element analysis program.

Effect of compressive strength: In order to investigate the effect of the compressive strength of the concrete on the

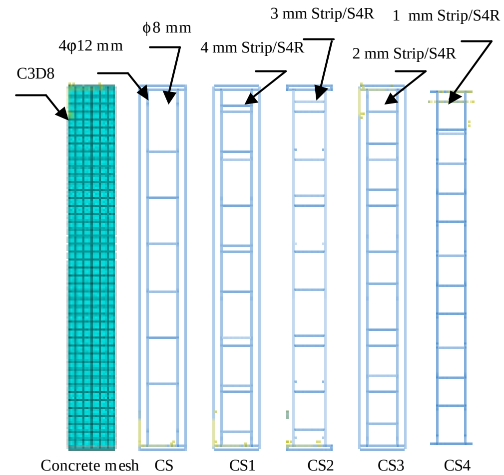

Fig. 5: Finite element modeling of the concrete columns

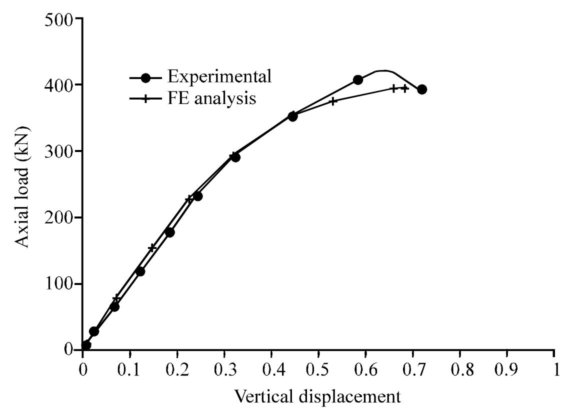

Fig. 6: Load-axial displacement curves for CS colums

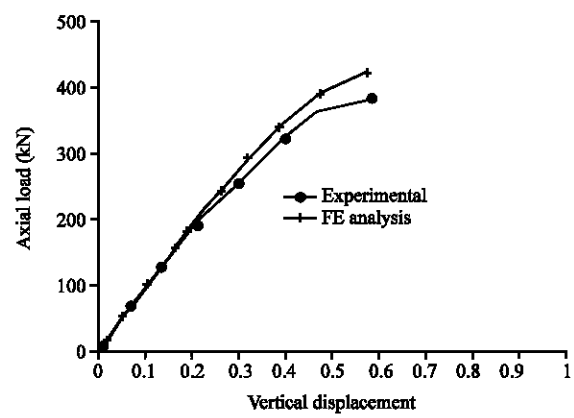

Fig. 7: Load-axial displacement curves for CS1 columns

maximum load capacity of concrete columns reinforced with ϕ 8 mm steel bars or 4 mm thickness steel strips of 22 mm width, a numerical analysis was carried out using finite element analysis. Compressive strength values of

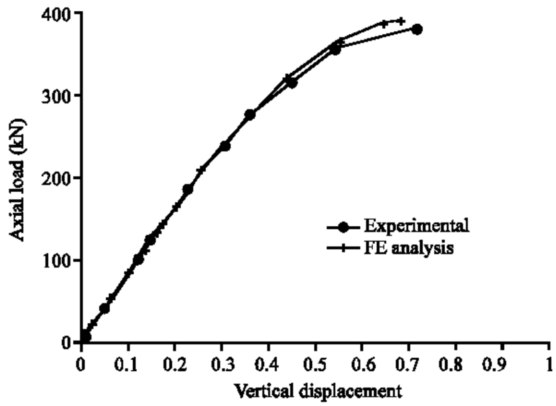

Fig. 8: Load-axial displacement curves for CS2 columns

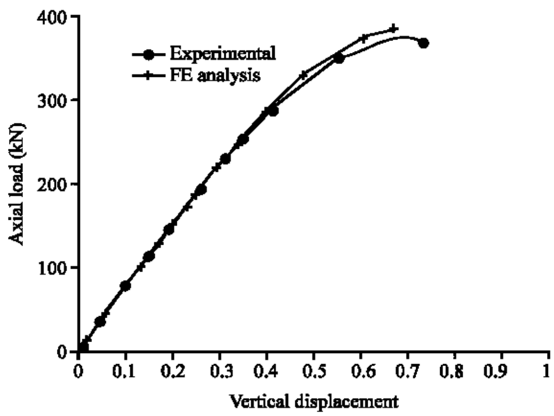

Fig .9: Load-axial displacement curves for CS3 columns

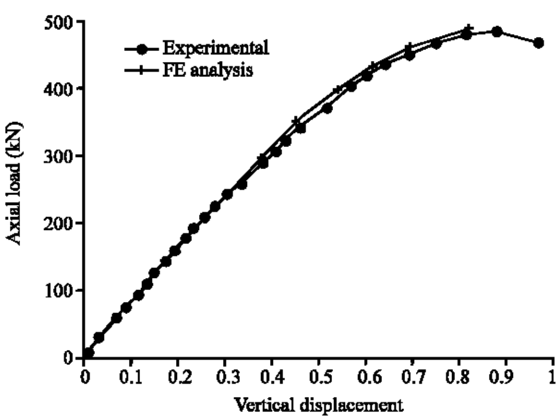

Fig. 10: Load-axial displacement curves for CS4 column

10, 20, 30, 40, 50, 60 and 70 MPa were taken for both columns. Figure 11 shows the maximum load-compressive strength curves obtained from the numerical analysis. The ratios between maximum loads of columns with 4 mm steel strips ties to columns with ϕ 8 mm steel bars are listed in Table 4. An increment in maximum load capacity of 11% was observed for all values of compressive strength.

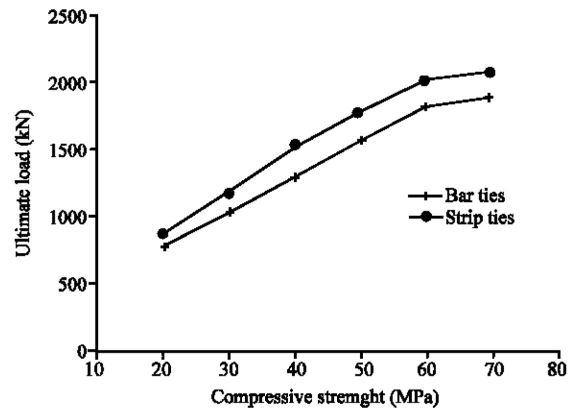

Fig. 11: Relation between compressive and ties type

Table 4: Pu_{strip}/Pu_{Bar} ratio for different compressive strength ratio

Compressive strength (Mpa)	Pu_{strip}/Pu_{bar}
20	1.11
30	1.15
40	1.18
50	1.06
60	1.10
70	1.09

CONCLUSION

According to experimental testing and finite element analysis, the following conclusions can be drawn; The use of wide width (strip) ties which have a tensile strength equivalent to a steel bar and a thickness equal to or <3 mm are of no benefit or may even reduce the maximum load capacity of concrete columns. The use of strip ties which have a tensile strength equivalent to a steel bar and a thickness equal to 4 mm have a positive effect on the maximum load capacity of concrete columns by up to 17.5% improvements in capacity. The general behavior observed for load-axial displacement curves, mode of failure and crack propagation of columns reinforced with strip ties is consistent with that of steel bar ties. An increment in maximum load capacity of concrete columns by approximately 11% can be gained for different values of concrete compressive strength.

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