Steel Jacketing Technique used in Strengthening Reinforced Concrete Rectangular Columns under Eccentricity for Practical Design Applications

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Abstract — *in the present study, the steel jacketing technique with variable vertical angles size connected with horizontal steel straps is used to upgrade the load carrying capacity of rectangular reinforced concrete columns under eccentric loads. Seventeen reinforced concrete rectangular columns were loaded and tested under different eccentricities until failure. Each column has 120x160 mm cross section and 1000 mm length with four normal mild steel bars 8 mm diameter as a vertical reinforcement and 6 mm diameter horizontal normal mild steel (stirrups) with 120 mm spacing. Five columns non-strengthened were tested under different eccentricities (e/t = 0, 6.25 %, 12.50 %, 18.75 % and 25.00 %) as control columns. However, twelve columns were divided into three groups strengthened with two external angles 20x20x2 mm, 40x40x2 mm and 60x60x2 mm in compression side respectively and two external angles 20x20x2 mm in tension side for all strengthened columns. The strengthened columns were tested under different eccentricities (e/t = 6.25 %, 12.50 %, 18.75 % and 25.00 %).*
Numerical analysis using the finite element technique has been conducted to simulate the response of control and strengthened columns. A finite element commercial package "ANSYS version 15" is used in the present analysis. The results of the finite element model have fair agreement with the experimental results. The validated finite element model was used to conduct parametric analysis for practical design applications.
Columns with cross sectional areas ranging from (25x30) cm to (25x120) cm; strengthened with different angles size subjected to eccentricity (e/t) 10% , 20% and 30% were investigated. The columns were 300 cm in height and have vertical reinforcement 1 % of the concrete cross sectional area; 8 mm stirrups spaced at 20 cm were provided for all columns. The columns were strengthened using 2 vertical angles of different size in tension side and 2 vertical angles of different size in compression side welded by horizontal straps 50 cm apart. The dimensions and thicknesses of the angles were identified for each column according the needed level of strengthening. Each column is strengthened to reach the original column carrying capacity. The results showed that increasing the covered area of the steel jacket as well as increasing cross sectional area of the steel angles increases the load carrying capacity of the strengthened columns. The relationships between the strengthened columns and the corresponding dimensions of the angles are presented in tables for practical applications.

Keywords — *Column, Eccentricity, Practical Design Applications, Reinforced Concrete, Steel Jacket, Strengthening.*

1. INTRODUCTION

The strengthening of reinforced concrete columns with angles and straps has been recently used.

Montuori, R. and Piluso, V. [1] presented a theoretical fiber model able to predict the moment curvature behaviour of RC columns confined by means of angles and battens. The pro-posed model has been used for predicting the load carrying capacity of both unstrengthened and strengthened columns

Elsamny, M.K et al. [2] used steel jacketing technique in strengthening reinforced concrete square columns subjected to eccentric loading conditions. The steel jacket consists of four longitudinal steel angles placed at each corner of the column. These longitudinal angles are connected together in a skeleton with transverse steel straps. Columns have a cross section of (120x120mm) and lengths of (1000mm). The columns were strengthened with different steel angle dimensions and tested under different eccentricities. The obtained test results show that the forces in the vertical angles in compression side are higher than that in tension side of the column. In addition, the forces in the upper straps are higher than that in the second and middle straps.

Yuyong Fu, Shuwang Yan and Chuang Du [3] developed a nonlinear finite element model to study the behavior of square concrete-filled steel tubular (CFST) column and reinforced concrete (RC) column with the same quantity of material and cross-section sizes under eccentric load using ANSYS software.

Garzón-Roca, J. et al. [4] presented a finite element model of a RC column strengthened with steel caging subjected to bend-ing moments and axial loads. In addition the model is used to perform a parametric study in which it investigated the influence of several parameters, some related to the steel cage and others related to the column itself.

Hadi, M. N. S. and Widiarsa, I. [5] presented the results of an experimental study on the performance of carbon fiber reinforced-polymer (CFRP) wrapped square reinforced concrete (RC) columns under eccentric loading. The influence of the number of CFRP layers, the magnitude of eccentricity, and the presence of vertical CFRP straps were investigated. The results of this study showed that CFRP wrapping enhanced the load-carrying capacity and ductility of the columns under eccentric loading. Furthermore, the application of the vertical CFRP straps significantly improved the performance of the columns with large eccentricity

Elsamny, M. K. et al. [6] conducted an experimental study of square reinforced concrete, RC, columns strengthened using a steel jacketing technique. The jacketing technique consisted of four steel vertical angles installed at the corners of the column joined by horizontal steel straps confining the column externally. The effectiveness of the technique was evaluated by testing the RC column specimens under eccentric monotonic loading until failure occurred. Strain gauges were installed to monitor the strains in the internal reinforcement as well as the external jacketing system. The effectiveness of the jacketing technique was demonstrated, and the parameters affecting the technique were studied.

Abd-ELhamed, M. K. and Ezz-Eldeen, H. A. [7] tested six rein-forced concrete rectangular columns with a cross section 120x160 mm and 800 mm length until failure. Two control columns were tested under axial load and four columns were tested under different eccentricities e/t= (6.30%, 12.5%, 18.75% and 25%). All specimens were retrofitted by replacing the loose concrete part by grout mortar. Strengthening was carried out using four vertical steel angles, two angles 30x30x3mm in eccentricity direction and two angles 15x15x3 mm in the re-verse direction all wrapped with expanded three plies steel wire mesh. However, the steel wire mesh jacket was injected by cement mortar. The test results showed that columns strengthened with four vertical steel angles wrapped with three plies steel wire mesh tested under different eccentricity recorded a higher failure load than that wrapped with three plies steel wire mesh only. The increase in column carrying capacity ranged from 102.5% to 112%.

Elsamny, M.K. et al. [8] used wire mesh jacketing technique to strength rectangular RC column under eccentric loads. A total of thirty seven specimens having a column cross section of (120x160) mm and a length of (800) mm were tested. Five specimens were chosen to be control columns and tested under different eccentricity. However, sixteen specimens were chosen to be strengthened with a sandwich made of different numbers of steel wire mesh plies (2,3,4,6) with external vertical steel bars 3Ø8 in compression side and confined with transverse straps (2 straps30*3mm). In addition, sixteen specimens were chosen to be strengthened with different numbers of steel wire mesh plies (2,3,4,6) without external vertical steel bars and confined with transverse straps (2 straps 30*3mm) . All specimens were tested under different eccentricities from e/t= 6.3% up to 25%. The test results showed that using wire mesh jacketing technique gives an increase in the load carrying capacity up to (23%) from the control ultimate capacity (e/t=0). However, using sandwich wrapping system technique which made of steel wire mesh and external vertical steel bars in compression side gives an increase in the load carrying capacity up to (54%) from the control ultimate capacity (e/t=0). In addition, increasing number of steel wire mesh plies increases the load carrying capacity of the strengthened columns under eccentricity.

Campione, G., Monaco, A. and M. Papia [9] developed equations for a hand calculation of moment–axial force domain in the presence of shear for R.C. beam/column externally strengthened with steel angles and strips. The analytical derivation was made assuming, the equivalent stress-block parameters for internal forces, considering the confinement effects induced in the concrete core by external cages both in the cases of strips or angles yielding.

Alwash, N. A. and Al-Zahid, A.A. [10] presented a derivation of a solution that controlled the behaviour of reinforced concrete short rectangular column strengthened by steel lattice frame jacket. An exact displacement field was derived utilizing the principle of minimum strain energy following Euler –Cauchy formula. Stress -strain diagram for confined concrete by internal reinforcement and external steel jacket is suggested. An empirical equation that controls the effect of inter-face spring stiffness between concrete and steel jacket is found through experimental investigation. A computer program is prepared using visual basic language. The validity and efficiency of the finite element is tested through comparison with others experimental results.

2. EXPERIMENTAL PROGRAM

In this study, the steel jacketing technique with variable vertical angles size is used to upgrade the load carrying capacity of rectangular reinforced concrete column under eccentric loads. Seventeen column specimens with cross section 120x160 mm and 1000 mm length were casted. Each column has concrete heads at both ends. All columns have four normal mild steel bars 8 mm diameter as a vertical reinforcement and 6 mm diameter horizontal normal mild steel with 120 mm spacing as shown in figure (1). Epoxy-bonded electrical resistance strain gauges were located at the maximum, expected, strain in internal vertical and horizontal reinforcement as well as, external vertical angles and horizontal straps.

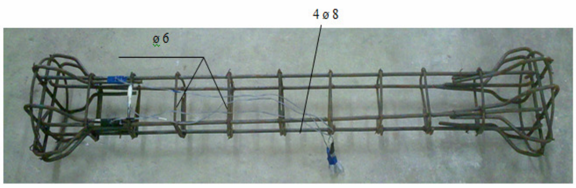


Fig. 1. Location of strain gauges on internal Reinforcement of column specimen (details)

The column specimens were divided into four groups as follows:

Group 1: Five columns non- strengthened were tested under different eccentricities (e = 0, 6.25 %, 12.50 %, 18.75 % and 25.00 %) as control columns.

Group 2: Four columns strengthened with two external angles 20x20x2 mm in both compression and tension side. The columns were tested under different eccentricities (e = 6.25 %, 12.50 %, 18.75 % and 25.00 %).

Group 3: Four columns strengthened with two external angles 40x40x2 mm in compression and two external angles 20x20x2 mm in tension side. The columns were tested under different eccentricities (e = 6.25 %, 12.50 %, 18.75 % and 25.00 %).

Group 4: Four columns strengthened with two external angles 60x60x2 mm in compression and two external angles 20x20x2 mm in tension side. The columns were tested under different eccentricities (e = 6.25 %, 12.50 %, 18.75 % and 25.00 %).

Table (1) shows all details of the tested column specimens as well as ultimate failure load. Figure (2) shows the strengthened column specimens.

TABLE 1
DETAILS OF THE CONTROL AND STRENGTHENED COLUMN SPECIMENS AS WELL AS ULTIMATE FAILURE LOAD.

Specimen No.	Steel jacket			eccentricity		Failure load (kN)	Control Failure load (kN) at e/t = 0
	straps	Angles tension side	Angles compression side	e (mm)	e/t %		
CS0e0	control			0	0	554	554
CS0e1	control			10	6.25	490	
CS0e2	control			20	12.50	422	
CS0e3	control			30	18.75	371	
CS0e4	control			40	25.00	322	
CS22e1	5 straps 20 x 2 mm	2 angles 20 x 20 x 2mm	2 angles 20 x 20 x 2mm	10	6.25	643	
CS22e2				20	12.50	552	
CS22e3				30	18.75	474	
CS22e4				40	25.00	420	
CS24e1			2 angles 40 x 40 x 2mm	10	6.25	755	
CS24e2				20	12.50	692	
CS24e3				30	18.75	627	
CS24e4				40	25.00	579	
CS26e1			2 angles 60 x 60 x 2mm	10	6.25	816	
CS26e2				20	12.50	781	
CS26e3				30	18.75	700	
CS26e4				40	25.00	621	

2 angles 20x 20 x 2mm in compression side and 2 angles 20x 20 x 2mm in tension side

2 angles 40x 40 x 2mm in compression side and 2 angles 20x 20 x 2mm in tension side

2 angles 60x 60 x 2mm in compression side and 2 angles 20x 20 x 2mm in tension side

Fig. 2. The strengthened column specimens

2.1. TEST SETUP AND PROCEDURE

All column specimens were tested under static load using a 1000 kN capacity hydraulic jack mounted on a steel frame at faculty of engineering, Al-Azhar University, Cairo, Egypt. The column head steel plates shown in figure (3) were used to control the required eccentricity. The test setup is shown in Figure (4).

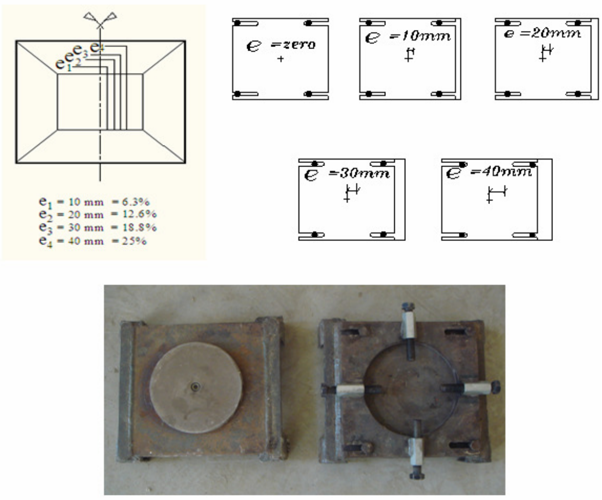


Fig. 3. Column head steel plates and eccentricity values

Fig. 4. Test setup

2.2 TEST RESULTS

Figure (5) shows the maximum failure load for control columns as well as the effect of strengthening on the column carrying capacity for different eccentricities. However, the results are presented in table (1).

The relationship between the covered area of external steel jacket to surface area of column and the relationships between the cross sectional area of steel angles to cross sectional area of column versus the column carrying capacity are shown in tables (2) and figures (6), (7).

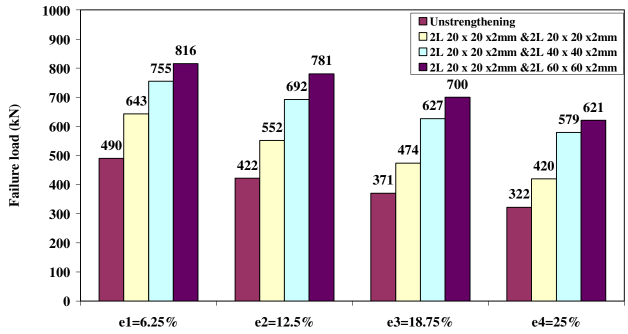


Fig. 5. The maximum failure load for control columns (unstrengthened) and strengthened columns under different eccentricity

TABLE 2
INCREASE IN LOAD CARRYING CAPACITY FROM CONTROL ZERO ECCENTRICITY DUE TO INCREASE EXTERNAL STEEL ANGLES DIMENSION.

Specimen No.	Steel jacket: straps	Steel jacket: Angles tension side	Steel jacket: Angles compression side	eccentricity: e (mm)	eccentricity: e/t %	Increase in load carrying capacity from control zero eccentricity %	Covered area of external steel / Surface area of column %	Cross sectional area of external steel / Cross sectional area of column %
CS0e0	control			0	0	0	-	-
CS0e1	control			10	6.25	-11.55		
CS0e2	control			20	12.50	-23.83		
CS0e3	control			30	18.75	-33.03		
CS0e4	control			40	25.00	-41.88		
CS22e1	5 straps 20 x 2 mm	2 angles 20 x 20 x 2mm	2 angles 20 x 20 x 2mm	10	6.25	16.06	35.71	1.67
CS22e2				20	12.50	-0.36		
CS22e3				30	18.75	-14.44		
CS22e4				40	25.00	-24.19		
CS24e1			2 angles 40 x 40 x 2mm	10	6.25	36.28	48.57	2.50
CS24e2				20	12.50	24.91		
CS24e3				30	18.75	13.18		
CS24e4				40	25.00	4.51		
CS26e1			2 angles 60 x 60 x 2mm	10	6.25	47.29	61.43	3.33
CS26e2				20	12.50	40.97		
CS26e3				30	18.75	26.35		
CS26e4				40	25.00	12.09		

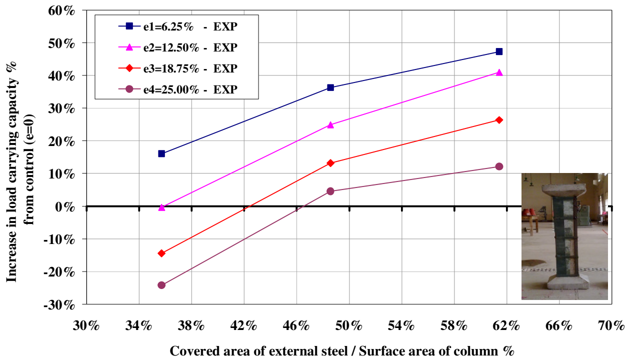


Fig. 6. The relationship between covered area of steel jacket to surface area of column and the increase in column carrying capacity under different eccentricities for experimental test

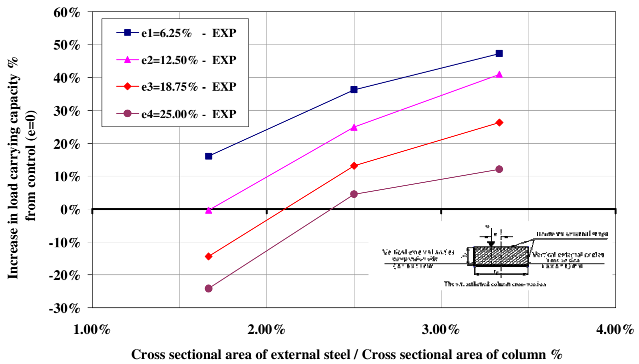


Fig. 7. The relationship between cross sectional area of steel jacket to cross sectional area of column and the increase in column carrying capacity under different eccentricities for experimental test.

3. Finite Element Model

3.1. The Elements Used To Represent Finite Element Model

Three-dimensional finite element models were developed to simulate the response of rectangular reinforced concrete column with length (1000 mm) and cross sectional dimensions (120x160mm) under eccentric loading using the commercial finite element program ANSYS version 15. The columns were provided with concrete heads at both ends with 260x300 mm cross section and 140 mm height. The 3D solid element (SOLID65) was selected to perform this analysis using ANSYS
Version 15. The element (SOLID65) is defined by 8 nodes having three degrees of freedom each. Eight integration points were used for evaluating element stiffness. The three dimensional spar element (LINK 180) is a uniaxial tensioncompression element with three degrees of freedom at each node. It was used to model the reinforcing steel bars. No bending is considered for this element. The element is also capable of plastic deformation, creep, swelling, and stress stiffing. The external steel angles and straps were modeled using quadrilateral shell elements (SHELL63), with four nodes and six degrees of freedom per node. This element is appropriate for modeling thin and moderately thick plate and shell elements allowing the simulation of buckling.

3.2 Mesh Configuration

The model used a mesh of element size ranging from a minimum of 10x10x10 mm to a maximum of 20x20x20 mm. The finite element mesh is shown in figure (8). Due to symmetry about the X-Y plane only one half of the model was used in the analysis.

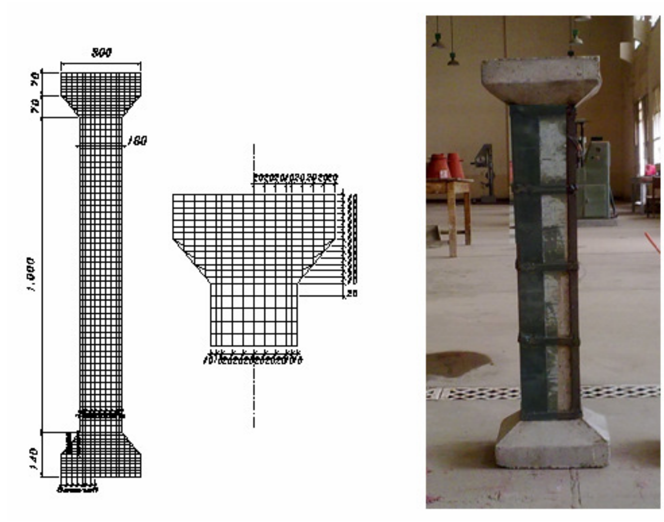


Fig. 8. The finite element mesh and dimensions (All dimensions in mm)

3.3. Model Restraints

Details of column restrains are shown in figure (9). The lower end of the column was restrained in the vertical direction and the horizontal direction.

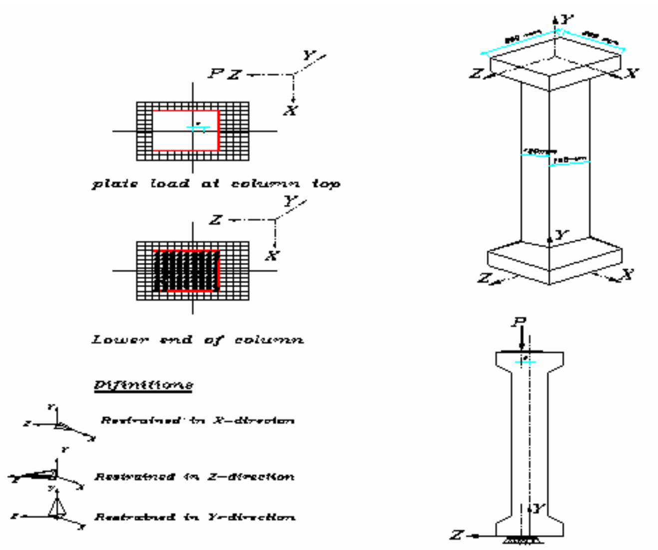


Fig. 9. The details of column restrains

3.4. Loading Scheme and Loading Increments

The column is exposed to eccentric load located over the nodes at the upper end of the column. In (ANSYS) the load can be applied in steps. The (ANSYS) solution requires the user to define a maximum number of iterations for each load increment. Within this number of iterations the solution will continue to the next load step if the out of balance forces are within a prescribed limit. The load on the column is gradually increased until the failure occurred. The size of the load increments has been chosen to help achieve convergence and at the same time attains an acceptable level of accuracy. Small load increments usually lead to better accuracy and improved convergence with the penalty of more computational cost.

3.5 Material Properties

3.5.1 Concrete

In the finite element model, the Young's modulus for concrete was taken $2.5x10^7$ (kN/m^2) and Poisson's ratio was assumed to be (0.16). Additional concrete material data needed for (SOLID65) are the shear transfer coefficients, tensile stresses, and compressive stresses. Typical shear transfer coefficients rang from 0.0 to 1.0, with 0.0 representing a smooth crack (complete loss of shear transfer) and 1.0 representing a rough crack (no loss of shear transfer). This specification may be made for both the closed and open crack.

In the current analysis, the crushing capability of concrete was omitted, and the stress-strain relationship was used instead, to simulate the crushing of concrete.

3.5.2. Internal Reinforcement

The idealized stress-strain curve for the internal vertical and horizontal reinforcement used in the finite element model is shown in Figure (10). The yield strength, Fy = $2.6x10^5$(kN/m^2).

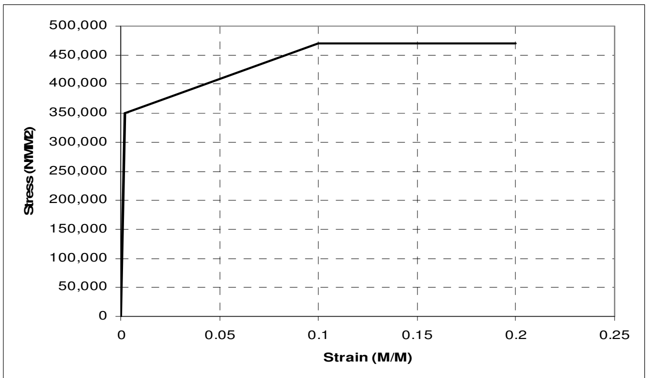


Fig. 10. Idealized stress-strain for internal reinforcing steel bars

3.5.3. External Steel Angles and Straps

The idealized stress-strain curve for the steel straps used in the finite element model is shown in Figure (11). The yield strength, Fy = $3.8x10^5$ (kN/m^2).

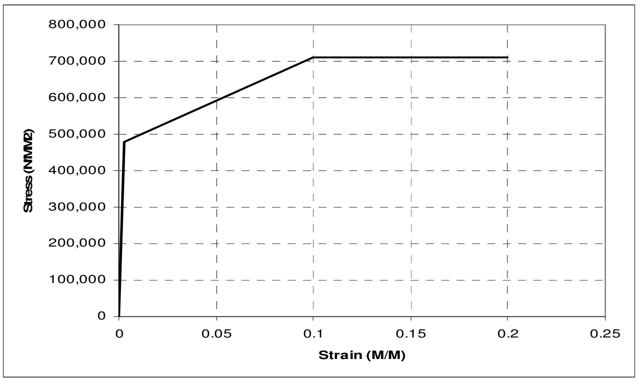


Fig. 11. Idealized stress-strain for steel angle and steel straps

3.6. Comparison between Failure Load of Columns from Finite Element Model (FEM) and Experimental Test (EXP)

Table (3) shows the failure load of control and strengthened column specimens in experimental test (EXP) and finite element model (FEM). However, comparisons show that failure load obtained from (FEM) for control and strengthened column specimens is lower than obtained from experimental study by 2.75% to 7.45%.

TABLE 3
COMPARISON BETWEEN THE FAILURE LOAD OF CONTROL AND STRENGTHENED COLUMN SPECIMENS IN EXPERIMENTAL TEST (EXP) AND FINITE ELEMENT MODEL (FEM).

Specimen No.	Steel jacket: straps	Steel jacket: Angles tension side	Steel jacket: Angles compression side	eccentricity: e (mm)	eccentricity: e/t %	Failure load (kN) EXP	Failure load (kN) FEM
CS0e0	control			0	0	554	530
CS0e1	control			10	6.25	490	459
CS0e2	control			20	12.50	422	399
CS0e3	control			30	18.75	371	345
CS0e4	control			40	25.00	322	298
CS22e1	5 straps 20 x 2 mm	2 angles 20 x 20 x 2mm	2 angles 20 x 20 x 2mm	10	6.25	643	614
CS22e2				20	12.50	552	526
CS22e3				30	18.75	474	453
CS22e4				40	25.00	420	394
CS24e1			2 angles 40 x 40 x 2mm	10	6.25	755	727
CS24e2				20	12.50	692	673
CS24e3				30	18.75	627	605
CS24e4				40	25.00	579	553
CS26e1			2 angles 60 x 60 x 2mm	10	6.25	816	792
CS26e2				20	12.50	781	758
CS26e3				30	18.75	700	673
CS26e4				40	25.00	621	598

3.7. THE RELATIONSHIPS BETWEEN COVERED AREA OF EXTERNAL STEEL JACKET TO SURFACE AREA OF COLUMN AND THE COLUMN CARRYING CAPACITY FOR FINITE ELEMENT MODEL (FEM) AND EXPERIMENTAL TEST (EXP)

Table (4) shows the relationships between covered area of external steel jacket to surface area of column and the column carrying capacity for finite element model (FEM) and experimental test (EXP). Figure (12) shows fair agreement between (FEM) and experimental test results.

TABLE 4
THE RELATIONSHIPS BETWEEN COVERED AREA OF EXTERNAL STEEL JACKET TO SURFACE AREA OF COLUMN AND THE COLUMN CARRYING CAPACITY FOR FINITE ELEMENT MODEL (FEM) AND EXPERIMENTAL TEST (EXP).

Specimen No.	Steel jacket: straps	Steel jacket: Angles tension side	Steel jacket: Angles compression side	eccentricity: e (mm)	eccentricity: e/t %	Increase in load carrying capacity from control zero eccentricity % EXP	Increase in load carrying capacity from control zero eccentricity % FEM	Covered area of external steel / Surface area of column %
CS0e0	control			0	0	0	0	-
CS0e1	control			10	6.25	-11.55	-13.40	
CS0e2	control			20	12.50	-23.83	-24.72	
CS0e3	control			30	18.75	-33.03	-34.91	
CS0e4	control			40	25.00	-41.88	-43.77	
CS22e1	5 straps 20 x 2 mm	2 angles 20 x 20 x 2mm	2 angles 20 x 20 x 2mm	10	6.25	16.06	15.85	35.71
CS22e2				20	12.50	-0.36	-0.75	
CS22e3				30	18.75	-14.44	-14.53	
CS22e4				40	25.00	-24.19	-25.66	
CS24e1			2 angles 40 x 40 x 2mm	10	6.25	36.28	37.17	48.57
CS24e2				20	12.50	24.91	26.98	
CS24e3				30	18.75	13.18	14.15	
CS24e4				40	25.00	4.51	4.34	
CS26e1			2 angles 60 x 60 x 2mm	10	6.25	47.29	49.43	61.43
CS26e2				20	12.50	40.97	43.02	
CS26e3				30	18.75	26.35	26.98	
CS26e4				40	25.00	12.09	12.83	

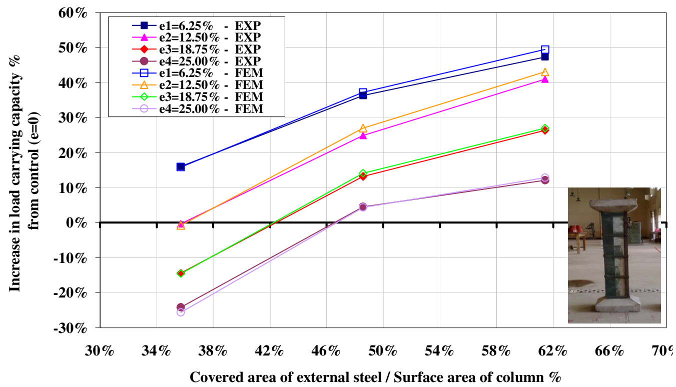


Fig. 12. The relationship between covered area of steel jacket to surface area of column and the increase in column carrying capacity for experimental test and finite element model

3.8. The Relationships Between Cross Sectional Area of Steel Jacket Angles to Cross Sectional Area of Column and the Column Carrying Capacity for Finite Element Model (FEM) and Experimental Test (EXP)

Table (5) shows the relationship between cross sectional area of external steel jacket angles to cross sectional area of column and the column carrying capacity for finite element model (FEM) and experimental test (EXP). Figure (13) shows fair agreement between (FEM) and experimental test results.

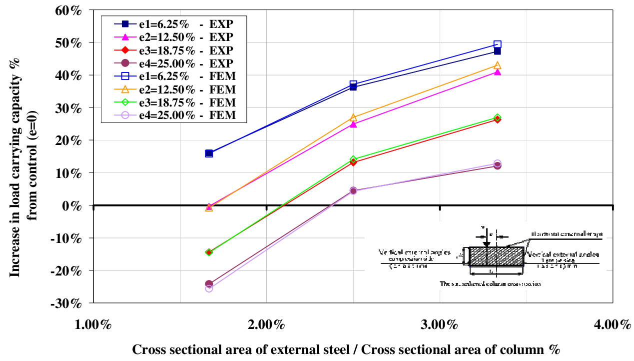


Fig. 13. The relationship between cross sectional area of steel jacket to cross sectional area of column and the increase in column carrying capacity for experimental test and finite element model.

TABLE 5
THE RELATIONSHIPS BETWEEN COVERED AREA OF EXTERNAL STEEL JACKET TO SURFACE AREA OF COLUMN AND THE COLUMN CARRYING CAPACITY FOR FINITE ELEMENT MODEL (FEM) AND EXPERIMENTAL TEST (EXP).

Specimen No.	Steel jacket: straps	Steel jacket: Angles tension side	Steel jacket: Angles compression side	eccentricity: e (mm)	eccentricity: e/t %	Increase in load carrying capacity from control zero eccentricity % EXP	Increase in load carrying capacity from control zero eccentricity % FEM	Cross sectional area of external steel / Cross sectional area of column %
CS0e0	control			0	0	0	0	-
CS0e1	control			10	6.25	-11.55	-13.40	
CS0e2	control			20	12.50	-23.83	-24.72	
CS0e3	control			30	18.75	-33.03	-34.91	
CS0e4	control			40	25.00	-41.88	-43.77	
CS22e1	5 straps 20 x 2 mm	2 angles 20 x 20 x 2mm	2 angles 20 x 20 x 2mm	10	6.25	16.06	15.85	1.67
CS22e2				20	12.50	-0.36	-0.75	
CS22e3				30	18.75	-14.44	-14.53	
CS22e4				40	25.00	-24.19	-25.66	
CS24e1			2 angles 40 x 40 x 2mm	10	6.25	36.28	37.17	2.50
CS24e2				20	12.50	24.91	26.98	
CS24e3				30	18.75	13.18	14.15	
CS24e4				40	25.00	4.51	4.34	
CS26e1			2 angles 60 x 60 x 2mm	10	6.25	47.29	49.43	3.33
CS26e2				20	12.50	40.97	43.02	
CS26e3				30	18.75	26.35	26.98	
CS26e4				40	25.00	12.09	12.83	

4. Parametric Analysis for Practical Design Applications

The validated finite element model was used to conduct parametric analysis for practical design applications. Columns with cross sectional areas ranging from (25x30) cm to (25x120) cm were analyzed using the finite element program ANSYS.

4.1. Details of the Strengthened Columns for the Finite Element Analysis for Practical Applications

Columns with cross section 25 x (30, 40, 50, 60, 70, 80, 90, 100, 110 and 120) cm and 300 cm in length were modelled. All columns have vertical internal reinforcement of area that is approximately 1 % of concrete cross sectional area. All columns were provided with horizontal normal mild steel 8 mm diameter stirrups at 20 cm spacing. Figure (14) shows the strengthened columns using two external vertical steel angles in compression side with dimensions (a x a x t) or (a x b x t) mm and two external vertical steel angles in tension side with dimensions (a x a x t), respectively, and horizontal steel straps 5 cm in width at a spacing of 50 cm welded to the angles and having the same thicknesses of the smaller angles. Each column was strengthened to resist different eccentricities (e/t = 10%, 20% and 30%). The strengthened rectangular columns for practical applications were presented in table (6).

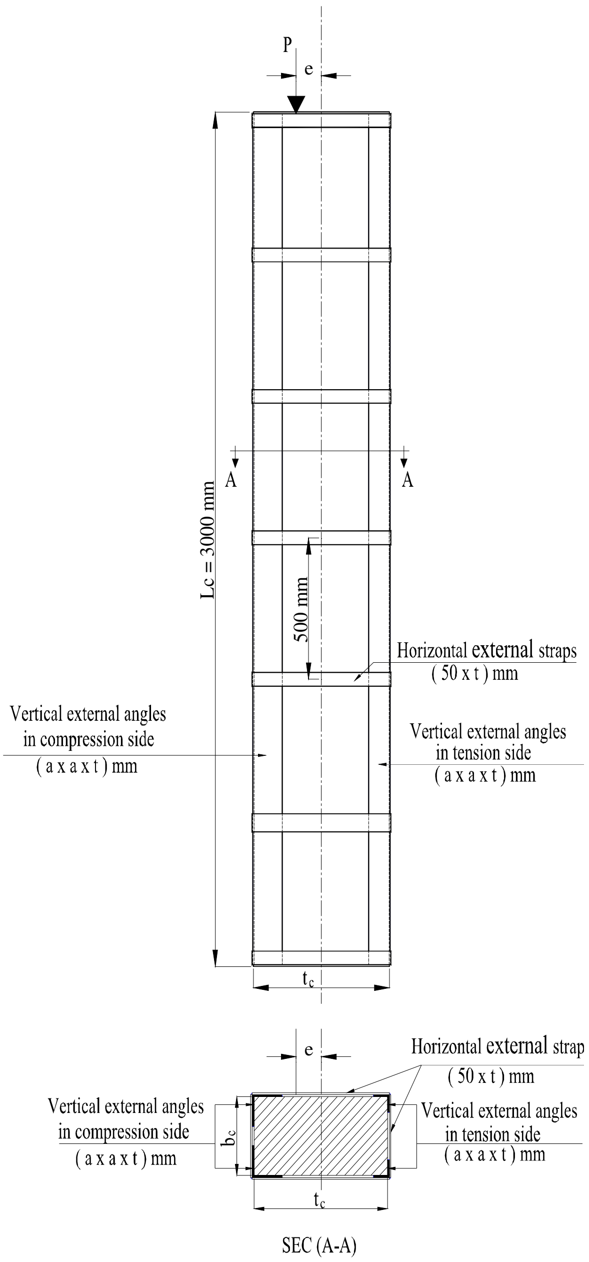
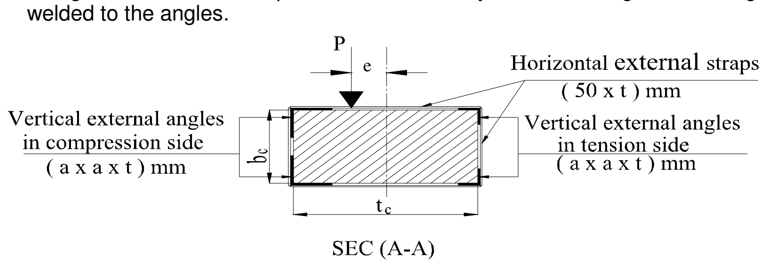


Fig. 14. Modelling of actual column

TABLE 6
PRACTICAL USED DIMENSIONS FOR STRENGTHENING COLUMNS SUBJECTED TO DIFFERENT ECCENTRICITIES (E/T %)

column Dimensions (mm)	e/t %	Two Vertical external angles in two sides	Vertical external steel angles dimensions (mm) in compression side	Vertical external steel angles dimensions (mm) in tension side
bc x tc x Lc			a x a x t	a x a x t
25x30x300	10 %	2 ∟	35 x 35 x 5	30 x 30 x 5
25x40x300			45 x 45 x 5	35 x 35 x 5
25x50x300			50 x 50 x 6	40 x 40 x 6
25x60x300			60 x 60 x 6	50 x 50 x 6
25x70x300			65 x 65 x 7	50 x 50 x 7
25x80x300			70 x 70 x 9	55 x 55 x 8
25x90x300			75 x 75 x 10	60 x 60 x 8
25x100x300			80 x 80 x 10	65 x 65 x 8
25x110x300			90 x 90 x 11	65 x 65 x 9
25x120x300			90 x 90 x 13	70 x 70 x 9
25x30x300	20 %	2 ∟	50 x 50 x 7	35 x 35 x 5
25x40x300			60 x 60 x 7	40 x 40 x 6
25x50x300			70 x 70 x 7	45 x 45 x 7
25x60x300			75 x 75 x 8	50 x 50 x 7
25x70x300			80 x 80 x 8	55 x 55 x 8
25x80x300			80 x 80 x 10	60 x 60 x 8
25x90x300			90 x 90 x 11	65 x 65 x 9
25x100x300			100 x 100 x 12	70 x 70 x 9
25x110x300			130 x 90 x 12	75 x 75 x 10
25x120x300			150 x 100 x 12	80 x 80 x 10
25x30x300	30 %	2 ∟	55 x 55 x 8	40 x 40 x 6
25x40x300			60 x 60 x 8	45 x 45 x 6
25x50x300			70 x 70 x 9	50 x 50 x 7
25x60x300			75 x 75 x 10	55 x 55 x 8
25x70x300			90 x 90 x 9	60 x 60 x 8
25x80x300			90 x 90 x 11	65 x 65 x 9
25x90x300			100 x 100 x 12	70 x 70 x 9
25x100x300			130 x 90 x 12	75 x 75 x 10
25x110x300			150 x 100 x 12	80 x 80 x 12
25x120x300			160 x 80 x 14	100 x 100 x 10

- Using horizontal steel straps 50 mm width every 500 mm along column height welded to the angles.



5. CONCLUSIONS

i- The use of steel jacketing technique is proved to be valid to upgrade the columns carrying capacity for column subjected to eccentric loading.

ii- Increasing the covered area of the steel jacket by increasing angles dimensions increases the load carrying capacity of the strengthened columns.

iii- Generally, a fair agreement has been obtained between experimental results and finite element analysis.

iv- Tables are presented for strengthening eccentrically rectangular column for practical applications.

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