كلية الهندسة بشبرا
FACULTY OF ENGINEERING AT SHOUBRA
ERJ
ISSN:1687-1340

ENGINEERING RESEARCH JOURNAL (ERJ)
Volume (52) , Issue (2)
April 2023, pp:37 - 43
https://erjsh.journals.ekb.eg

Strengthening of Short Reinforced Concrete Columns by using Pre-Tensioned Steel Jackets

N.S. Kozman[a] , M.M. El-Attar[a] , A.M. El-Nady*[a]

[a] Department of civil , Faculty of Engineering cairo University, Cairo, Egypt .
***** Corresponding author.
E-mail: mariammostafa20153@gmail.com,mnghali@gmail.com,engahmed77@yaho.com,beshlawys@yahoo.com.

Abstract: Columns are the most important structural elements in any building. When an increase in loads is expected as a result of a change in the use of the building or as a result of errors in design or construction, strengthening becomes essential to increase column capacity. One of the available strengthening techniques is pre-tension steel jackets

Therefore, the behavior of short reinforced concrete columns strengthened using this confining technique under uniaxial vertical load is investigated. Steel jacket consists of two u-shape steel parts connected by four angles back-to-back or plates using high strength bolts. External pretension load is applied using external high strength bolts of diameter 16 mm. This study focus on the behavior of columns strengthened using pre-tensioned steel jackets. The experimental program was achieved by testing ten short reinforced concrete square columns of dimensions 150x150 mm and 1500 mm in height. The columns were strengthened using pre-tensioned steel jacket. Columns were divided into five groups to accomplish the research objective. The following parameters affecting the behavior of the strengthened columns are considered; (1) thickness of steel sheets, (2) connections type of steel jacket, (3) value of pre-tension stresses, (4) surface conditions of columns, (5) value of applied vertical load during strengthening and (6) geometry of concrete columns. For the range of the studied parameters, the experimental results show that the use of this technique increases columns failure load by about 7 % to 55 % depending on the effect of each parameter.The experimental results were analyzed numerically and new design formula to predict the ultimate compressive strength of the strengthened concrete columns using this technique was proposed. The average and the standard diviation of the numerical ultimate load to the experimental failure load are 0.98 and 0.04 respectively for the range of the studied parameters.

1. Introduction

Column strengthening is generally used whenever the column suffers structural defects or the applied loads are increased. In both cases, different approaches are used for upgrading the column resistance. Strengthening of columns may be done using RC jackets, Steel jackets or FRP. Many studies have been made using different techniques. In this study, column strengthening using pre-tensioned steel jacket is discussed. Hussain et al. [1] carried out an experimental program on rectangular columns with steel jackets. An improved steel jacketing technique designed to enhance strength and improve ductility is tested. A jacket formed of welded thin steel plates is used for shear strength enhancement.Ductile behavior was ensured using additional stiffeners with the desired configurations at potential plastic hinge regions. Test specimens were subjected to cyclic lateral force in a double curvature condition while axial load was kept constant. Results showed the efficiency of rectilinear steel jacketing partially stiffened. In addition to preventing brittle shear failure, a significant improve in column ductility was noticed. Results of experimental program were used to develop a rational retrofit design procedure.

Samra [2] developed an approach for calculating the amount of transverse steel required in confined columns at various load levels. Idealized stress-strain diagrams and moment curvature curves were utilized in the suggested approach.

The suggested approach was compared to the approach employed by the American Concrete Institute (ACI) Building Code and found more realistic.

Mirmiran et al. [3] carried out an experimental program on columns retrofitted using high strength fiber wrapping and fiber reinforced plastic tube (FRP). Results showed that significant enhancement of strength and ductility are attained. The study provided accurate estimate of the enhancement in strength and ductility for columns strengthened using FRP tubes. Results were compared to old techniques available in the literature and it was proved that these methods overestimate the improvement

Saatciouglu et al. [4] provided an analytical model to construct a stress strain curve for confined columns. The parameters of the model were established using a huge amount of test data available in the literature. Both poorly and we confined concrete were studied. The relationship formed of a parabolic ascending branch and a linear descending segment. The suggested model was compared with experimental tests 306on strengthened square and circular columns with good agreement.

Saiidi [5] carried out a combination of experimental and theoretical study on

reinforced concrete flared bridge columns. The purpose of the study was to determine an appropriate retrofit technique for columns with inadequate shear capacity during earthquakes. Specimens were tested on a shaking table to failure. Column specimens were retrofitted using steel, GRP and FRP jackets. In all cases, it was noticed that seismic performance was improved. Similar results were obtained using different jacket types. The results showed that all jackets improved the seismic performance. The effectiveness of jackets was nearly the same for all materials. Many researchers [6-11] studied numerically, analytically and experimentally strengthening and retrofitting of reinforced concrete columns using different techniques

.

2- Experimental program

The main purpose of the current research is to study the effectiveness of using pre-tensioned steel jackets on improving the axial load capacity of rectangular reinforced concrete columns. To achieve that, an experimental program including 10 specimens is conducted to study the behavior of strengthened columns and the effect of different parameters on its axial compression capacity.

The technique used for strengthening is pre-tensioned sheets as follows; the column is strengthened using steel jacket consisting of two steel parts (U – shape) connected together by four angles back-to-back. The pre-tensioning is applied using four high strength bolts in the direction perpendicular to the direction of the vertical load applied. The parameters considered in this study are: thickness of steel jacket, connection of steel jacket, pretension value, contact surface area between column and jacket, stress level during pre-tension and geometry of tested column.

All test specimens are 150 x 150mm in cross section with 1100mm height. The specimens dimensions, longitudinal and lateral reinforcement were kept constant. All specimens were reinforced with 4 bars of 10mm diameter as longitudinal reinforcement and 5Y6/m as stirrups. Details of columns are shown in Figure (1). The average ratio of steel in square columns was about 1.4% and in circular columns were about 1.77%. External steel jacket used for strengthening composed of mild steel sheets of thickness 1.25, 1.5 and 2 mm and angles of dimensions 30 x 30 x 3mm. Strains are measured both mechanically (using extensometer) and electrically (using strain gauges).

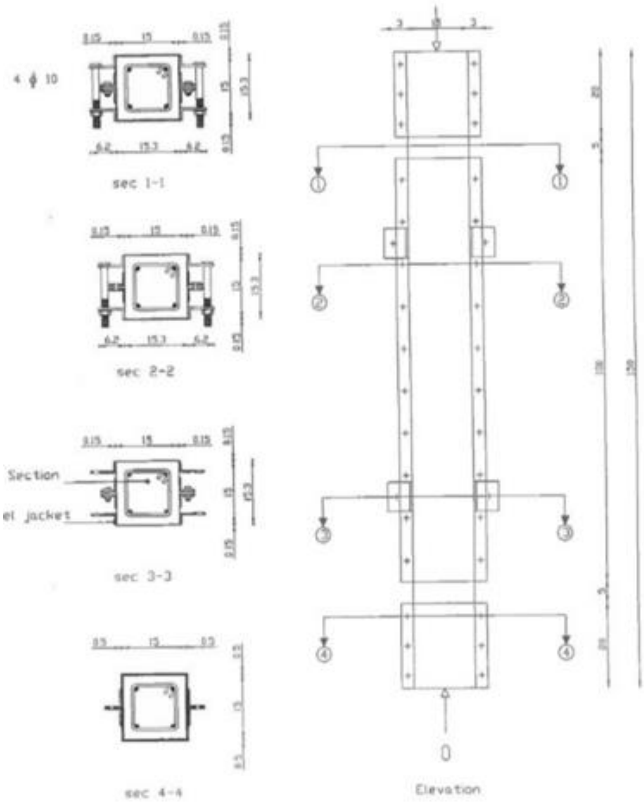

Fig (1) Specimens dimensions (in cm), reinforcement and strengthening.

Electrical strain gauges were placed on the selected places of the longitudinal and lateral reinforcement of the original columns. The strain gauge that mounted on the steel reinforcement embedded in concrete, so that covered by silicon layer to protect it from water and damage during casting concrete.Mechanical readings are taken by mechanical extensometer with gauge length 150mm and accuracy 0.02mm. In addition, mechanical extensometer with gauge length 50mm and 100mm to measure the transverse strains of steel jacket to set the value of pretension stress.The testing was conducted using Amsler 5000kN compression testing machines as showing in Figure (2). The applied load was increased gradually from zero to 550kN by constant interval equal to 50kN. Then, machine jack was stopped to measure the mechanical readings. Then, the interval of load was decreased to 20kN until the tested column attained its ultimate load capacity.

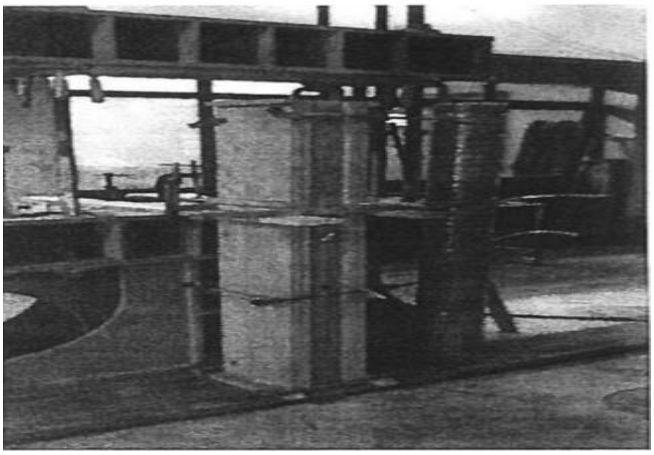

Fig (2) Testing setup

The specimens are mainly divided into a control specimen C_c in addition to 5 groups as shown in Table (1) and may be summarized as follows:

- C_c is a control specimen without strengthening;
- C1, C2 and C3 are all similar except for jacket thickness 2, 1.5 and 1.25 mm respectively;
- C4 is similar to C1 except for using plates instead of angles for strengthening of specimen;
- C5 and C6 are similar to C1 except for changing pre-tension stress to be 25, 13 and 50 respectively.
- C7 is similar to C1 except for using grout between column and strengthening angles for C7.
- C8 and C9 are similar to C1 except for the applied vertical load to be 30, 15 and 0 respectively.

Table 1 – Details of the tested Specimens.

Group type	Specimen	Section dimensions	Jacket Thinness	Connection type	Pre Tstress	Surface condition	Load level	Failure load
		(mm)	(mm)	(-)	(kN)	(-)	(kN)	(kN)
Control	C_c	150 x 150	---	---	500	Without	0	597
G1	C1	150 x 150	20.0	4-angles	500	Without	0	703
	C2	150 x 150	15.0	4-angles	500	Without	0	794
	C3	150 x 150	12.5	4-angles	500	Without	0	923
G2	C1	150 x 150	12.5	4-angles	500	Without	0	703
	C4	150 x 150	12.5	4-plates	500	Without	0	695
G3	C1	150 x 150	12.5	4-angles	500	Without	0	703
	C5	150 x 150	12.5	4-angles	250	Without	0	668
	C6	150 x 150	12.5	4-angles	150	Without	0	634
G4	C1	150 x 150	12.5	4-angles	500	Without	0	703
	C7	150 x 150	12.5	4-angles	500	With Grout	0	712
G5	C1	150 x 150	12.5	4-angles	500	Without	0	703
	C8	150 x 150	12.5	4-angles	500	Without	180	6.7
	C9	150 x 150	12.5	4-angles	500	Without	360	635

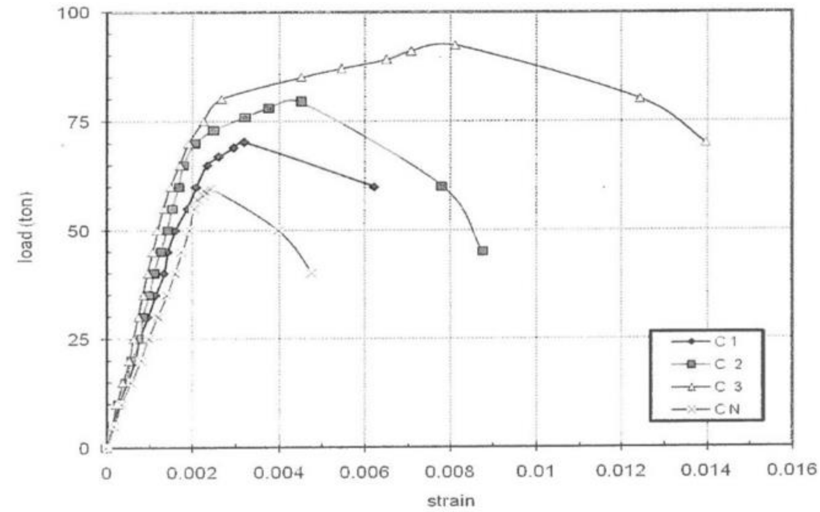

Fig (3) Load (ton)– vertical concrete strain for columns C_c, C1,C2 & C3.

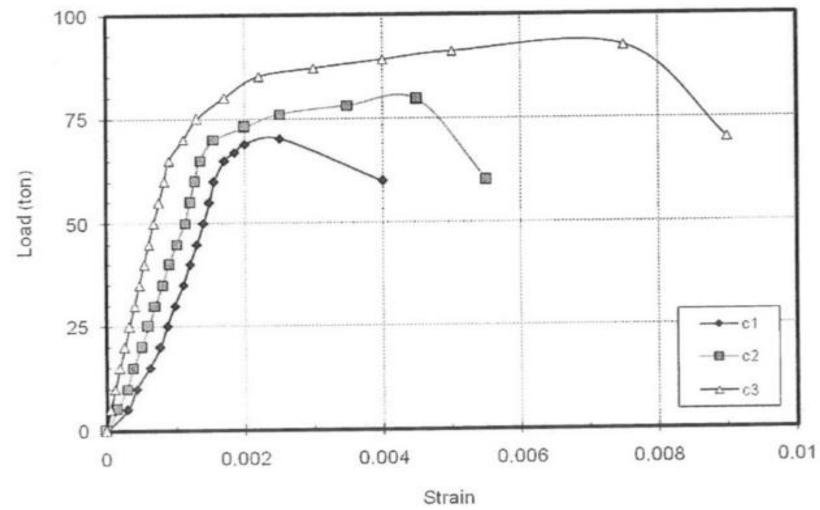

Fig (4) Load (ton) – horizontal jacket strain for columns C1, C2 & C3.

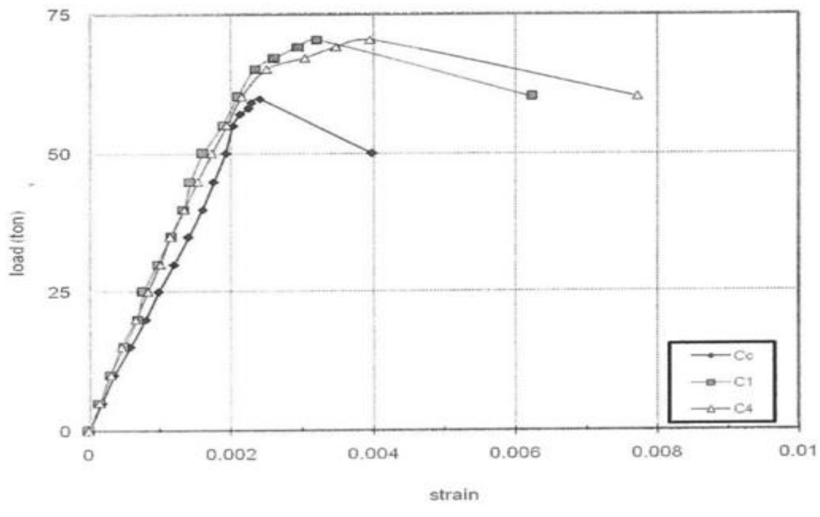

Fig (5) Load (ton)– vertical concrete strain for columns C_c, C1 & C4.

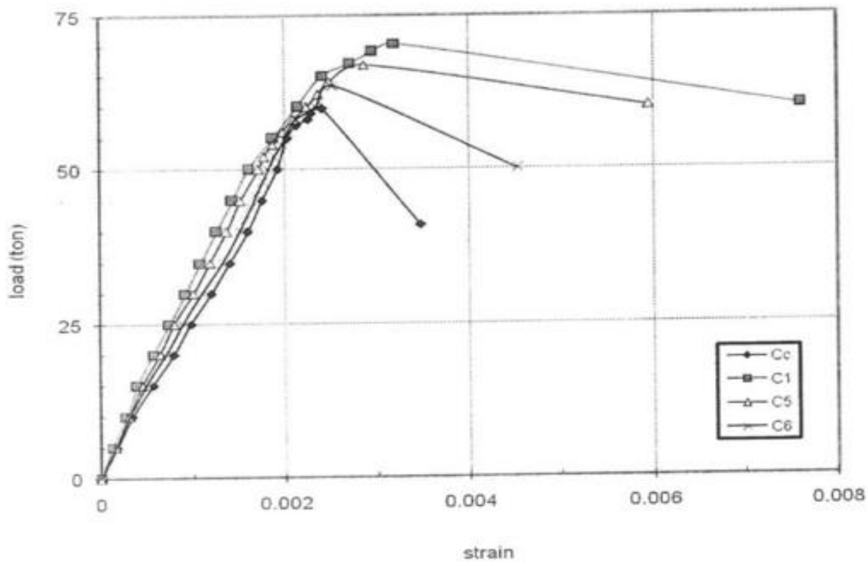

Fig (6) Load (ton) – vertical concrete strain for columns C_c, C1,C5 & C6.

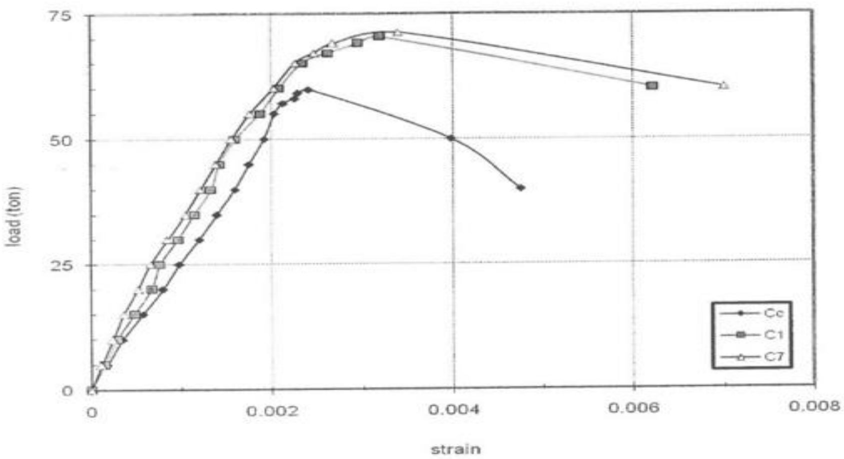

Fig (7) Load (Ton)– vertical concrete strain for columns C_c, C1 & C7.

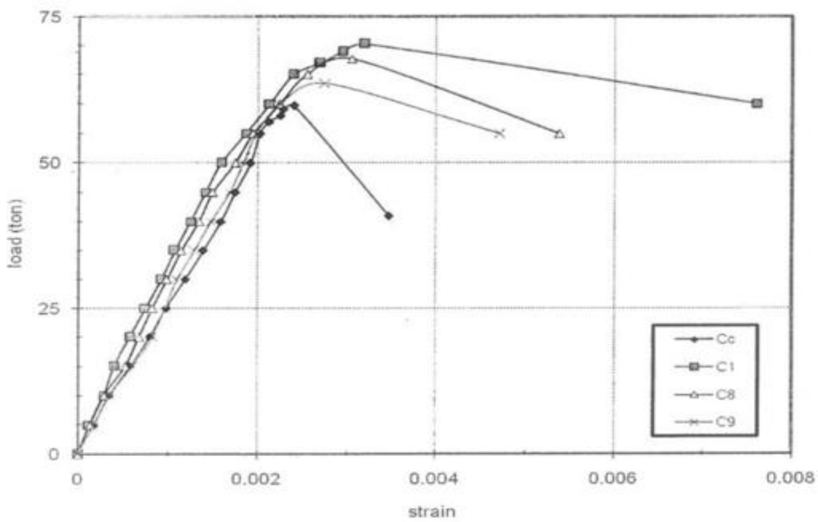

Fig (8) Load (ton)– vertical concrete strain for columns C_c, C1,C8 & C9.

3. Test Results

It was observed that by increasing the load, the stirrups started to yield and vertical crack initiated and propagated by increasing the load. This is followed by yielding of the vertical reinforcement and the concrete cover spall off. The inclined cracks initiated at the middle of column and propagated by increasing the load until the failure happen in the middle of column.

From the results of experimental study, the axial load carrying capacity of the confined columns was improved. This increment is due to the enhancement of the confined concrete by the confinement effect.

Figure (3) shows the load concrete strain curve for specimens C_c, C1, C2 & C3. C_c is the control specimen for rectangular columns and C1, C2 & C3 are rectangular specimens with different steel jacket thickness of 2, 1.5 and 1.25 mm respectively. As shown from the figure, the failure load of the specimens has increased with the increase in jacket thickness. An increase in maximum load of 54% has been achieved relative to the control specimen. It is also noted that the maximum concrete strain at failure has also increased with the increase in jacket thickness as shown in Figure (4).

Figure (5) shows the load concrete strain curve for specimens C1 and C4. Both Specimens are rectangular specimens with different steel jacket types; using 4 angles for C1 and 4 plates for C4. As shown from the figure, the change in failure load and concrete strain are very small and may be ignored. Using an angle or plate for stiffening the column has a minor effect on column capacity as long as both has the same thickness. Figure (6) shows the load concrete strain curve for specimens C1, C5& C6 which are rectangular specimens with different pretension stress of 50, 25 & 15 respectively. As shown from the figure, the failure load of the specimens has increased with the increase in pretension stress. An increase in maximum load of 11% has been achieved by increasing the pretension force by 285%. It is also noted that the maximum concrete strain at failure has slightly increased with the increase in pretension stress.

Figure (7) shows the load concrete strain curve for specimens C1 and C7. These specimens are rectangular specimens with different surface type between column and jacket; C1 without any finishing material while C7 has grout between column and jacket. As shown from the figure, the failure load of the specimens has increased with finishing the specimens surface with grout. However, the effect of finishing the specimens is considerably small. It is also noted that the maximum concrete strain at failure has slightly increased with finishing the specimen surface with grout.

Figure (8) shows the load concrete strain curve for specimens C1, C8 & C9. These are rectangular specimens with different loading condition during strengthening; C1 under no load, C8 strengthening is completed under vertical load of 30 t and C9 strengthening is completed under vertical load of 15 t. As shown from the figure, the failure load of the specimens decreased with the increase in load level during strengthening. An increase in load level from zero to 30 t leads to a decrease in column capacity of 10%. It is also noted that the maximum concrete strain at failure has also decreased with the increase in load level. This means that for existing buildings, actual improvements in load capacity is less than estimated.

Based on previous results, new proposed formula was suggested to design pretension steel jacketed columns taking into consideration the studied parameters. This equation is expressed as follows:

$P_u = P_o[(2383 (A_j/A_c)^{2.87} + 0.6133 (S_j/S_o) – 0.2278 (P_v/P_o) + 0.938]$

where:

P_o : Calculated ultimate load of non-strengthened column;
P_u : Ultimate load of strengthened column;
A_j : Cross sectional area of surrounding steel jacket;
A_c : Cross sectional area of concrete column;
P_v : Applied vertical load during strengthening process;
S_j : Applied pretension stresses on the strengthened column; and
S_o : Applied ultimate stresses on non-strengthened column.

This formula was tested against experimental results and then used to expand the parametric study. The comparison between the experimental and the numerical results prove the validity and accuracy of numerical analysis. Figure (9) shows the axial load capacity of the tested columns using both experimental and analytical procedures. The average and the standard diviation of the numerical ultimate load to the experimental failure load are 0.98 and 0.04 respectively for the range of the studied parameters.

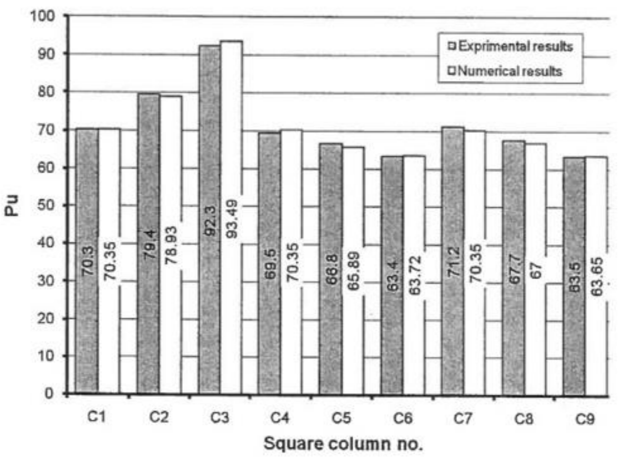

Fig (9) Comparison between the numerical and experimental results.

4. Conclusions

An experimental program was conducted to study the behavior of reinforced concrete columns strengthened using pretension steel jackets. In addition, a formula was reached to calculate the load carrying capacity of strengthened columns using this technique. The main parameters affecting the column behavior was studied. It was found that pretension steel jacket is an effective technique in strengthening columns. Increasing pretension force applied to jacket proportionally increases the column capacity. For the range of the studied parameters, the experimental results show that the use of this technique increases the columns failure load by about 7 % to 55 % depending on the value of the studied parameter. Based on experimental results, it is recommended to focus on thickness of stiffening steel sections as the main parameter in strengthening columns.

The proposed equation for calculating the columns ultimate capacity gives very good results compared to the experimental ones for the range of the studied parameters where the average and the standard diviation of the numerical ultimate load to the experimental failure load are 0.98 and 0.04 respectively. Extension of the experimental program and analytical formula for high strength concrete is suggested for future research.

References

[1] A. Hussain and R. Driver, " Retrofit of Reinforced Concrete Columns Using Partially Stiffened Steel Jacket", Journal of Structural Engineering, ASCE., vol. 129, no. 6, pp725-732., 2003.

[2] M. Samra, "Ductility Analysis of Confined Columns", journal of Structural Engineering, ASCE, vol. 116, no. 11, pp 3148-3161, 1990

[3] A. Mirmiran and M. Shahawy, "Behavior of Concrete Columns Confined by Fiber Composites" ,Journal of Structural Engineering, ASCE, vol. 123, no. 5, pp 583-590, 1997.

[4] M. Saatciouglu and R. Razvi, "Strength and Ductility of Confined Concrete", Journal of Structural Engineering, ASCE, vol. 118, no. 6, pp 1590-1607, 1992.

[5] M. Saiidi, "Assessment of Steel and Fiber Reinforced Plastic Jackets for Seismic Retrofit of Reinforced Concrete Columns with Structural Flares", Journal of Structural Engineering, vol. 130, no. 4, pp 609-617, 2004.

[6] A. Abdel-Hay and Y. Fawzy, "Behavior of Partially defected RC columns Strengthened using Steel Jackets", HBRC Journal, vol.11 , no.2, pp 194-200, 2015.

[7] T. Rousakis, G. Panagiotakis, E. Archontaki and A. Kostopoulos, "Prismatic RC Columns Externally Confined with FRP Sheets and Pre-Tensioned Basalt Fiber Ropes Under Cyclic Axial Load", Composites Engineering, vol. 163, no. 2, pp 96-106, 2019.

[8] N. Kozman, " Strengthening of Short Reinforced Concrete Columns by Using Pre-Tension Steel Jackets", Master thesis, Structural Engineering Department, Cairo University, 2009.

[9] Y. Xiao and H. Wu, " Discussion of Retrofit of Reinforced Concrete Columns Using Partially Stiffened Steel Jacket", Journal of Structural Engineering, ASCE., vol. 131, no. 2, pp 264-366, 2005.

[10] M. Demers and K. Neale, "Confinement of Reinforced Concrete Columns with Fiber-Reinforced Composite Sheets- An experimental Study", Canadian Journal of Civil Engineering, vol. 26, pp. 226-241, 1999.

[11] M. Priestley, F. Seible, Y. Xiao and R. Verma, "Steel Jacket Retrofitting of Reinforced Concrete Bridge Columns for Enhanced Shear Strength‘, ACI Structural journal, vol. 91, no. 4, 394-405, 1994.

[12] R. Park, M. Priestly and D. Gill, "Ductility of Square Confined Concrete Columns", Journal of Structural Division, ASCE, vol. 108, no.4, pp 929-950, 1982.

[13] R. Park and T. Paulay, "Reinforced Concrete Structures", John Wiley and Sons, New York, N.Y., 1975.