International Journal of Emerging Engineering Research and Technology
Volume 3, Issue 11, November 2015, PP 127-134
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

Non-Linear Finite Element Analysis of Eccentrically Loaded RC Columns Strengthened using a Steel Jacketing Technique

Adel A. Hussein[1], Mohamed K. Elsamny[2], Amr M. Nafie[3], Mohamed K. Abd-Elhamed[4]

[1]*Civil Engineering Department, Azhar University, Cairo, Egypt*
[2] *Civil Engineering Department, Azhar University, Cairo, Egypt*
[3] *Civil Engineering Department, Azhar University, Cairo, Egypt*
[4] *Civil Engineering Department, Azhar University, Cairo, Egypt*

ABSTRACT

A 3D finite element model was developed to study the behavior of strengthened reinforced concrete columns under eccentric loads. The model consisted of 3D solid elements to represent the concrete, 3D truss element to represent the reinforcement and shell elements to model the strengthening steel straps and angles. The 3D solid element had a non-linear behaviour to represent concrete cracking in tension and crushing in compression. The non-linear finite element model was verified by comparing the results to that obtained experimentally. The comparison showed that the finite element results followed the same trend as the experimental results, but the capacity values obtained using the finite element analysis was slightly higher. The finite element model was used to evaluate the columns strengthening technique using an external steel jacketing consisting of vertical angles connected with horizontal straps. The effect of the angle size and the load eccentricity on the capacity of the columns was studied. It was observed that the capacity of the columns increased as the size of the vertical external angles increased. The forces in the internal reinforcement and the external angles were also studied.

Keywords: Reinforce Concrete, Column, Strengthening, Steel Jacketing, Finite element Analysis

INTRODUCTION

Strengthening of concrete columns is often needed in practice to correct deficiencies in design or construction, to handle additional loads that were not anticipated during the design phase, or to repair columns that were degraded due to special circumstances such as fire or earthquakes. Although, columns are primarily axial load carrying elements, they may also be subjected to eccentric loads due to accidental eccentricity arising from minor misalignment during construction, due to reduction of the column size in multistory buildings, or due to lateral drift. Many researchers investigated the strengthening of columns subjected to eccentric loads. The basic idea in most of the research conducted was to increase the concrete confinement in order to achieve increased strength. This was done most of the time by wrapping the concrete column using Fiber Reinforced Polymer, FRP, sheets [1-5], steel sheets [6, 7]or steel cages [8-11]. While most of the research in this area was done experimentally, some researchers used analytical methods such as finite element analysis to study the behavior of strengthened columns [2, 12, 13].

A comprehensive study of strengthened reinforced concrete columns subjected to eccentric loads should investigate the true behavior of the column with respect to different parameters affecting the column, such as, the different values of eccentricity, and different configurations of steel jackets used for column strengthening. Due to the high cost of experimental studies and the time involved in preparing test specimens, it is very hard and costly to carry out a large scale parametric investigation using experimental tests. Therefore, Finite Element Analysis, FEA, is considered as a tool that enhances and complements the experimental studies. In this research, a 3D finite element model was constructed to represent the strengthened reinforced concrete column. A 3D solid element which has the capability of cracking and crushing was used in the model because it is very suitable for modeling concrete elements. In order to gain confidence in the results obtained through the finite element model, it was necessary to validate the results using experimental data. The experimental research presented in [14, 15] was used for this purpose.

Address for correspondence:

anafie60@hotmail.com

FINITE ELEMENT MODEL

The finite element model was constructed using ANSYS [16] finite element program. The model consisted of 3 types of elements. The 3D solid element (SOLID65) was selected to represent concrete because it is capable of both cracking in tension and crushing in compression. SOLID65 allows for four different materials within the element, one matrix material and a maximum of three independent reinforcing materials. In this research, the reinforcement was modeled using another element (LINK 8), a 3D truss element, which was used to model the discrete reinforcing bars. In this way, the reinforcing bars were more accurately represented.

SOLID65 is defined by 8 nodes having three degrees of freedom each. Eight integration points were used for evaluating the element stiffness. The element material is assumed to be isotropic and the most important aspect of this element is the treatment of nonlinear material properties where concrete is capable of directional cracking and crushing besides incorporating plastic and creep behavior.

The cracking and crushing are the most significant factors contributing to nonlinear behavior of the concrete. If the material at an integration point fails in compression, the material is assumed to crush at this point. Crushing is defined as the complete deterioration of the structural integrity of the material, i.e. under the crushing conditions, the material strength is assumed to be degraded to an extent such that the contribution of the element stiffness at the integration point in question can be ignored. There are two techniques of crack representation in any finite element program. Smeared crack modeling and the discrete modeling. The first type occurs by adjusting of the material properties to introduce a plane of weakness in a direction normal to the crack face. The second type occurs by separation of appropriate nodes of adjoining elements. The crack modeling adopted by the program is the smeared crack representation.

The strengthening steel straps and angles were modeled using shell elements. A sketch showing the column and the corresponding finite element model is shown in Fig. 1. The stress-strain relationship of the concrete and steel used in the FEA is shown in Fig.2.

The column was subjected to an eccentric load located over the nodes at the upper end of the column as shown in Fig. 3. The eccentricity ratio was represented by the parameter e/t, load eccentricity / column depth. The load is applied in steps. Each load step is divided to load increments. The user is required 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. For the analysis under hand only one load step was used to define the load on the column. The load on the column was gradually increased until the failure occurred. Failure was indicated by excessive loss of stiffness which caused large displacement values and hindered the ability of the analysis to reach a converged solution. The size of the load increments were 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. The column was loaded eccentrically by offsetting the applied loads as well as the supports as shown in Fig. 3.

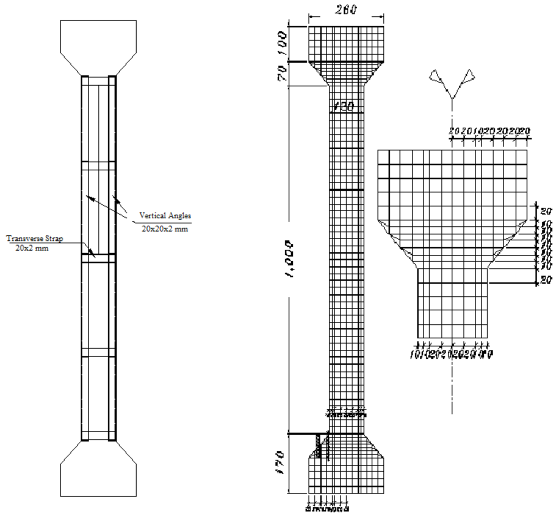

Figure1. *Finite Element Model of the Strengthened Column*

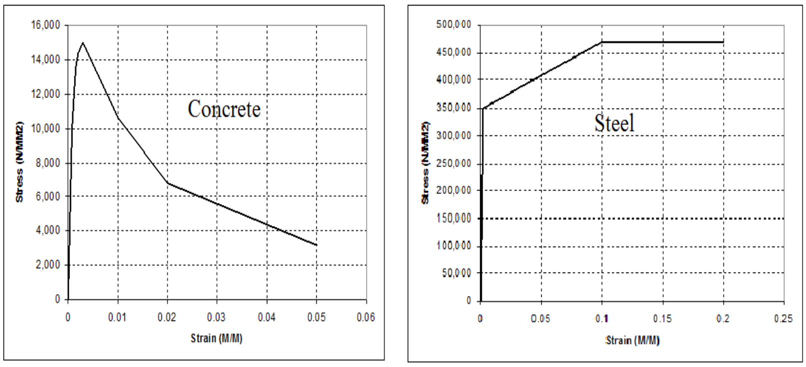

Figure2. *Stress-Strain Relationship of Concrete and Steel*

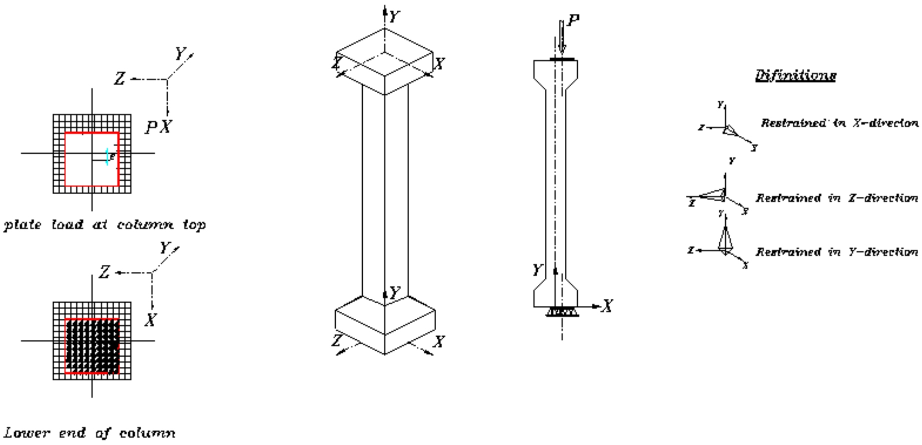

Figure3. *Eccentric Loading of the Finite Element Model*

VERIFICATION OF THE FINITE ELEMENT MODEL

In order to gain confidence in the results obtained by the Finite Element Model, FEM, it was necessary to verify it by comparing the FEA results to the results obtained through experimental testing. The experimental research presented in [14,15] was used for this purpose. Fig. 4 shows the comparison of the failure load between the FEM and the experimental results for the control columns (unstrengthened columns) subjected to different eccentricities. It is observed that the magnitude of the failure loads is very near in both cases. Fig. 5 shows a typical case for the failure loads of the strengthened column. The particular case depicted in the figure is for a column strengthened using 4 vertical angles and 5 straps. The figure shows a comparison between the experimental failure load and that obtained using the FEM. The failure loads of the unstrengthened control columns are also included for reference. It is clear from the figure that the finite element results follow the same trend as the experimental results, but are consistently higher by a value ranging from 10 to 30%.

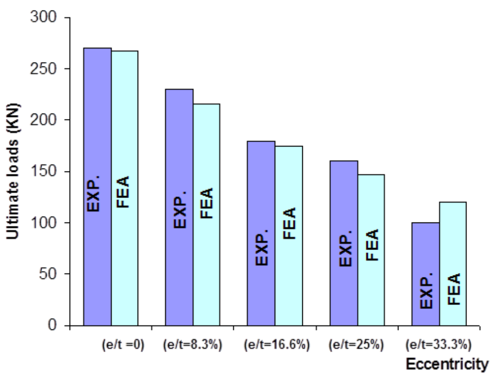

Figure4. *Failure Load of the Unstrengthened Control Columns*

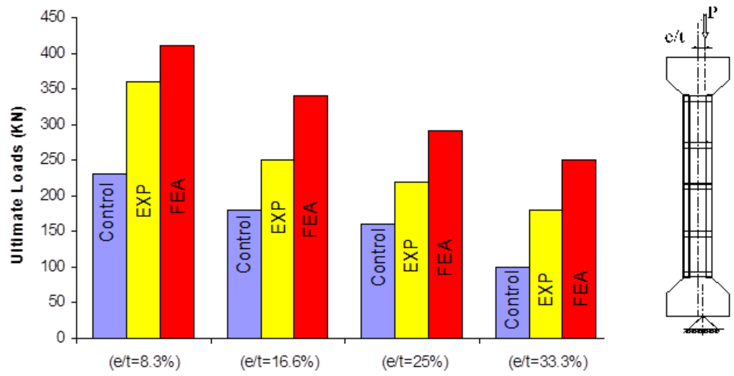

Figure5. *Failure Load of a strengthened Column*

Fig. 6 shows the force in the vertical reinforcing at failure load for the column strengthened using 4 vertical angles and 5 straps. The figure illustrates that the force in the longitudinal bar is considerably higher in the case of the experimental results, but the same trend was shown in both cases where the force increased with the increase of the eccentricity.

The force in the horizontal straps used for strengthening is shown in Fig. 7. A comparison between the FEM results and the experimental results showed that the results in both cases were very near. The same conclusion was also obtained for the values of the force in the vertical angles.

From the above comparison it can be deducted that the FEM model produced results that have the same trend as the experimental results, but the predicted failure loads were higher when the FEA was used with a difference of up to 30%. The measured strain in the experimental specimens were also higher than that experienced in the FEM, and this can explain the higher forces in the reinforcing bars as shown in Fig. 6. It was also shown that the discrepancy in the results between the experiments and the FEA was lower in case of the unstrengthened control columns.

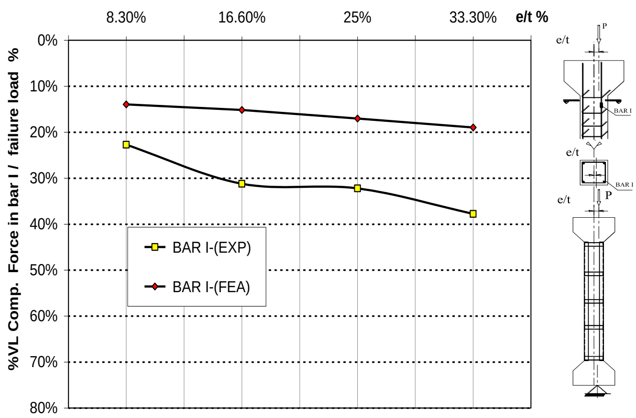

Figure6. *Force in the Vertical Longitudinal Reinforcement*

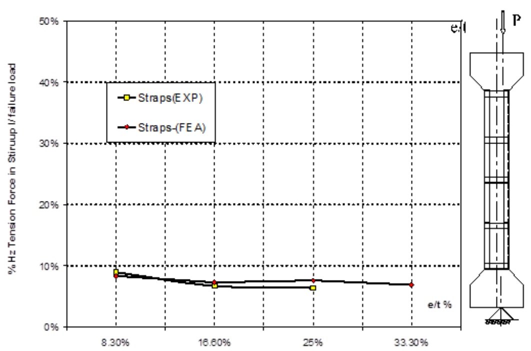

Figure7. *Force in the Horizontal Straps*

EFFECT OF DIMENSION VARIATION OF THE VERTICAL STEEL ANGLES

In order to evaluate the effect of the dimensions of the vertical steel angles on the behaviour of the strengthened columns, 3 different sizes, 10x10mm, 20x20mm and 40x40mm were used for the angle with a constant thickness of 2 mm. The angles were connected using 3 straps. 2 eccentricity values were considered in the analysis e/t= 25% and 33.3%. Both FEA and experimental study were performed to complement each other.

Ultimate Capacity

Fig. 8 shows the column carrying capacity for strengthened columns with three straps and four different vertical angle dimensions for the eccentricity e/t = 25%. The size of the angle is represented by the parameter 2L/B which is evaluated as double the width of the angle divided by the column width. Three values of 2L/B were compared, 16.6%, 33.3% and 66.6. The figure shows that the ultimate capacity of the column increases as the parameter 2L/B increases and the relationship is nearly linear. The figure also indicates that the FEA produces ultimate capacities that are consistently higher than the experimental results. The figure also shows the increase in the ultimate capacity due to strengthening. As the parameter 2L/B increases the effect of the strengthening technique is increased in a linear fashion, reaching a value of 59% increase in capacity for 2L/B of 66.6%. The same result is obtained for an eccentricity e/t of 33% but with a maximum increase in capacity reaching 80%.

Behavior of Internal Longitudinal Steel Reinforcement

Fig. 9 shows the ratio of the force in the vertical reinforcement compared to the failure load for the strengthened column. Both finite element results and experimental results are compared in the figure. For the FEA, the ratio between the forces in the longitudinal reinforcement to the failure load showed a slight and steady decrease as the parameter 2L/B increased indicating a lower share of the internal reinforcement as the size of the strengthening vertical angle increased. This relationship was not very clear in the case of the experimental results. The same trend was observed for the eccentricity e/t= 33.3%.

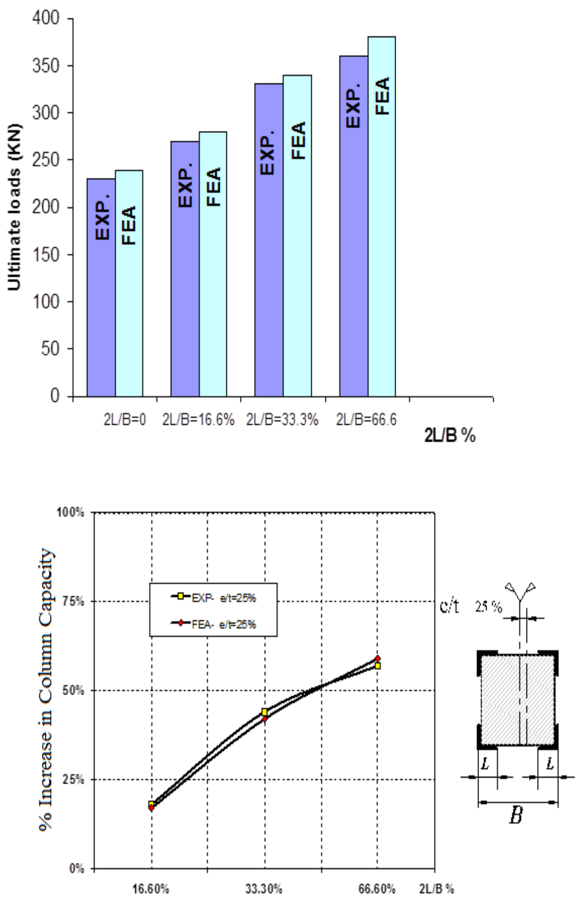

Figure8. *Effect of Vertical Angle Dimensions on Failure Load*

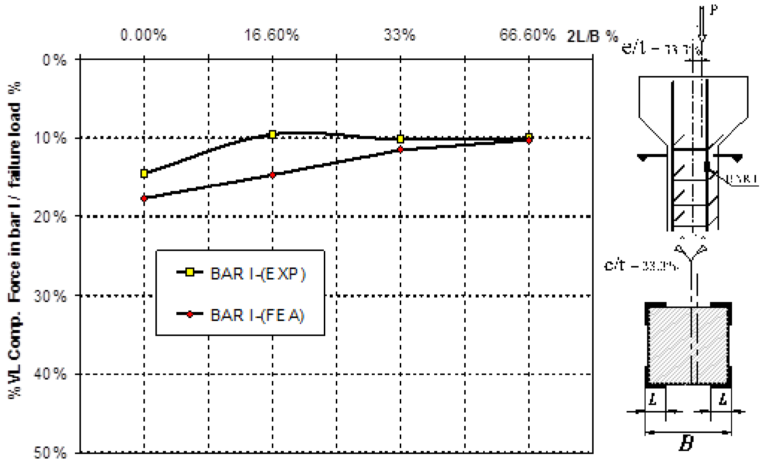

Figure9. *Effect of Vertical Angle Dimensions on Longitudinal Reinforcement*

Behavior of Internal Longitudinal Steel Reinforcement

Fig. 10 shows the ratio of the force in the horizontal stirrups compared to the failure load for the strengthened column subjected to eccentric load with an eccentricity ratio of 25%. Both finite element results and experimental results are compared in the figure. In both cases the size of the vertical strengthening angles didn't show any noticeable effect on the forces in the horizontal stirrups. The same trend was observed for the eccentricity e/t= 33.3%.

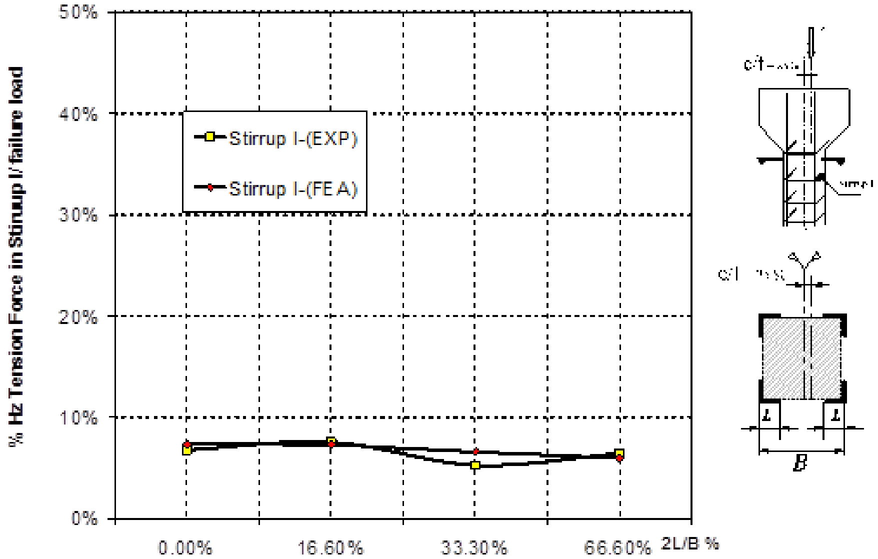

Figure 10. *Effect of Vertical Angle Dimensions on Stirrups*

4.4 Behavior of External Steel Angles

Fig. 11 shows the ratio of the force in the vertical angles compared to the failure load for the strengthened column subjected to eccentricity value of e/t= 25%. Both finite element results and experimental results are compared in the figure. The ratio of the force carried by the vertical angles increased in a linear manner as the value 2L/B increased indicating a higher contribution of the vertical angles to the strength of the column. Both the experimental research and the FEA produced the same trend, but with higher values for the FEA. The same trend was observed for the eccentricity e/t= 33.3%.

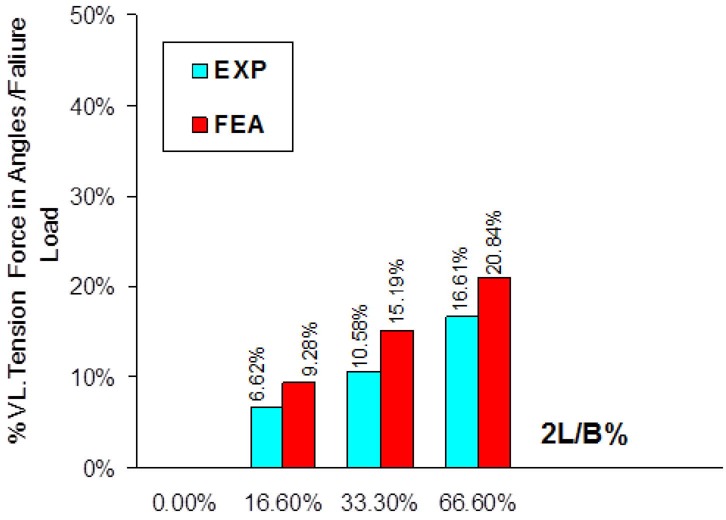

Figure11. *Force in the Vertical Angles for Different Values of 2L/B*

.CONCLUSION

A 3D FEM was developed to study the behavior of reinforced concrete columns subjected to eccentric loads. The model was verified by comparing the results to that obtained experimentally. The comparison showed that the finite element results followed the same trend as the experimental results, but the capacity values obtained using the FEA was higher with a difference of up to 30%. The strains at failure were generally higher in the experimental results. The FEM was used to study the behavior of the columns strengthened using an external steel jacketing consisting of vertical angles connected with horizontal straps. The effect of the angle size on the capacity of the columns was studied. The parameter 2L/B (double the angle width / the column width) was used to represent the angle size. Values of 2L/B= 16.6%, 33.3% and 66.6% respectively gave an increase of the ultimate load carrying capacity of columns reaching 59% and 80% for load eccentricities of e/t= 25% and 33.3% respectively. It was also observed that the capacity of the columns increased linearly as the parameter 2L/B increased. The analysis also showed that as the parameter 2L/B increased the ratio of the load carried by the vertical angles increased while the ratio carried by the vertical internal reinforcement decreased. The percentage of the force carried by the external steel angles increased from about 6% to about 20% as the parameter 2L/B increased from 16.6% to 66.6%. It was also observed that the forces in the horizontal stirrups were not affected by the parameter 2L/B.

REFERENCES

[1] J. Li, M.N.S. Hadi, "Behaviour of externally confined high-strength concrete columns under eccentric loading", Composite Structures, vol. 62, pp. 145–153, 2003.

[2] A, Parvin, and W. Wang, "Behavior of FRP jacketed concrete columns under eccentric loading." J. Composites for Construction, vol. 5 issue 3, 146–152, 2001.

[3] T. M. Bahaa and H. Z. El-karmouty, "Behavior of sandwich FRP wrapped RC columns under eccentric loading", Housing and Building Research Center, HBRC Journal, vol. 3 No. 2, 2007.

[4] X. Yuan, S. Xia, L. Lam and S. T. Smith, "Analysis and behaviour of FRP-confined short concrete columns subjected to eccentric loading", Journal of Zhejiang University SCIENCE, vol. 1, pp. 38-49, 2007.

[5] R. Benzaid, N. E. Chikh and H. Mesbah, "Study of the compressive behavior of short concrete columns confined by fiber reinforced composite", Arabian Journal for Science and Engineering, vol. 34(1B), pp. 15-26, 2009.

[6] J. L. Ramírez, J. M. Bárcena, J. I. Urreta, J. A. Sanchez, "Efficiency of short steel jackets for strengthening square section concrete columns", Construction and Building Materials, vol 11, pp 345-352, 1997.

[7] K. Sakino and Y. Sun, "Steel jacketing for improvement of column strength and ductility", 12WCEE 2000: 12th World Conference on Earthquake Engineering, Auckland, New Zealand, 2000.

[8] M. R. Badr, "Experimental Behavoir Of Reinforced Concrete Columns Strengthened By Steel Jacket", HBRC Journal, Housing And Building National Research Center, Cairo, Egypt, vol.2, No. 2, 2006.

[9] P. A. Calderón, J. M. Adam, S. Ivorra, F. J, Pallarés and E. Giménez, "Design strength of axially loaded RC columns strengthened by steel caging", Journal of Materials and Design, vol. 30, pp. 4069–4080, 2009.

[10] E. Giménez, J. M. Adam, S. Ivorra and P.A. Calderón, "Influence of strips configuration on the behaviour of axially loaded RC columns strengthened by steel angles and strips", ", Journal of Materials and Design, vol. 30, pp. 4103–4111, 2009.

[11] M. K. Elsamny, M. A. Ibrahim, H. H. Elesnawi and H. K. Oudah, "Behaviour of steel jackets used in strengthening columns subjected to eccentric loading", Journal of Al Azhar Universty Engineering Sector vol. 6 No. 19, pp. 493-514, 2011.

[12] J. M. Adam, S. Ivorra, F. J. Pallarés, E. Giménez and P. A. Calderón, "Axially Loaded RC Columns Strengthened By Steel Caging. Finite Element Modeling", J. Of Construction And Building Materials 23, PP. 2265–2276, 2009.

[13] T. Majewski, J. Bobinski and J. Tejchman. (2007), "FE Analysis of Failure Behaviour of Reinforced Concrete Columns under Eccentric Compression", Science Direct- Engineering Structures 30 – 300-317.

[14] M. K. Abd-Elhamed, "Study of reinforced concrete columns due to eccentric and lateral loads" Ph. D. Thesis, Civil Engineering Department, Azhar University, Cairo, Egypt, 2010.

[15] M. Elsamny, A. Hussein, A. Nafie, M. Abd-Elhamed, "Experimental Study of Eccentrically Loaded Columns Strengthened Using a Steel Jacketing Technique", World Academy of Science, Engineering and Technology, International Science Index 84, International Journal of Civil Science and Engineering, Vol. 7, No. 0,pp. 12 – 20, 2013.

[16] ANSYS, Inc., "ANSYS User Manual," SAS IP, U.S.A.