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BEHAVIOR OF STEEL JACKETED REINFORCED CONCRETE COLUMN UNDER ECCENTRIC FORCES

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الملخص العربى:

يهدف هذا البحث الى دراسة سلوك القميص الحديدى للأعمدة الخرسانية تحت تأثير قوى الضغط الغير مركزية. تم دراسه عدد ثلاث عينات من الخرسانه المسلحة مكونه من عمود مدعم بقميص حديدى. وتم التأثير بحمل غير مركزى من أعلى عند رأس العمود حتي الأنهيار وكان المتغير بين هذة العينات هو شكل التدعيم (قميص حديدى بكامل ارتفاع العمود& قميص حديدى جزئى بأستخدام 4 زوايا حديد لأركان العمود ورابطه بينهم 5 شرائح فى كل جنب فى العمود& قميص حديدى جزئى بأستخدام 4 زوايا حديد لأركان العمود ورابطه بينهم 3 شرائح فى كل جنب فى العمود) حيث لها نفس شكل التسليح ونسبة التسليح ولها نفس الأبعاد تم تعيين حمل الأنهيار للثلاث عينات والترخيم والحركه الأفقيه والأنفعال بالحديد الرئيسي وتم عمل تحليل بطريقة العناصر المحددة للتحقق من النتائج التى تم الحصول عليها معمليا. و بصفة عامة، كان هناك توافق كبير بين كل من النتائج المعملية و العددية.وتم عمل أستنتاجات ومقترحات من هذا البحث.

ABSTRACT

In recent decades, the use of RC columns strengthened using a steel jacketing technique for the construction of high-rise buildings, bridges, warehouses, etc. has become widespread. This is mainly due to the combination of the advantages of steel and concrete. The former has high specific strength, and is easy to construct while the latter has large damping capacity and is economical. The enhanced mechanical properties of RC columns strengthened using steel jacketing techniques are obtained by interaction between the steel jacket and the concrete core. Due to the discrepancy of Poisson's ratios between steel and concrete, the volume increase of the concrete core is confined by the exterior steel jacket. Consequently, both strength and ductility of the concrete are enhanced. On the other hand, the local buckling of the steel jacket is prevented by the filled concrete.

The presented paper introduces an experimental and analytical study in order to investigate the effect of strengthening using steel jacketing subjected to eccentricity, a total three specimens were tested under vertical load. All specimens were tested up to failure and the behavior was fully monitored. Moreover, . A numerical investigation utilizes the non-linear finite element modeling (FEM) was performed in ANSYS® to validate the experimental results. Overall, the numerical results agreed very well with the corresponding experimental results at all stages of loading.

KEYWORDS

Columns, Strengthening, steel jacketing, Eccentricity, Finite element modelling.

1 INTRODUCTION

In recent years, much attention has been paid to the behaviour of RC columns strengthened using steel jacketing techniques under eccentric loading. The basic idea in most of the research conducted was to increase the concrete confinement in order to achieve increased strength. This was done by wrapping the concrete column using different materials like FRP and GFRP for strengthening columns subjected to eccentric loading. Some researchers used steel as a confinement material by completely wrapping the column with steel sheets and others used partial confining by using steel cages. Some researchers used only steel collars for the confinement. It is observed that more research is needed to determine the factors that affect the efficiency of the material used versus the requirements in both strength and ductility.

In this research, the behavior of RC columns with and without strengthening using steel jacketing subjected to different eccentricity of loads until the failure were studied. This program of study was carried out experimentally and theoretically using ANSYS computer package ver.14. The research was intended to examine the effect of eccentricity on the carrying capacity of the column and to study the effect of column strengthening using steel jacketing. The jacketing techniques consisted of three types of steel jackets, first type is steel tube in filled concrete, second type is four steel vertical angles installed at the corners of the column joined by horizontal five steel straps and third type is four steel vertical angles installed at the corners of the column joined by horizontal three steel straps . The steel jackets were fully bonded to the original RC column using epoxy mortar. The columns where loaded monotonically until failure occurred using different values of eccentricity, and different parameters of the strengthening mechanism. A comprehensive study of the behaviour of the column was conducted in each case to assess the effectiveness of the strengthening mechanism.

2 EXPERIMENTAL PROGRAM

The experimental work of the present study consists of testing three reinforced concrete columns strengthening using steel jacketing technique.

2.1 Test Specimens

All specimens have the same dimensions of RC column and also the concrete compressive strength. The height of column is 1000 mm with cross section 200 mm × 200 mm with concrete compressive strength(fcu)= 38 N/mm^2 and yielding stress(fy) = 360 N/mm^2 .Table (1) below lists all details and strengthening techniques of all specimens. All tested specimens details shown as fig.(1).

Table (1): *Dimension details and strengthening details of all tested specimens*

specimens	RC. Dim.(mm)	R F T		eccentricity(e)	strengthening configuration			
		long bars	stirrups		steel jacket	type	size	confinement
C 1	200×200×1000	4Φ12	6 ϕ 8/ḿ	e = 15 cm	fully height fully steel jacket	plates	Plate @ 4 sides	Plates 2.5*1000*200
C 2					fully height partially steel jacket	angles	4L 50*50*5	2.5*80*150 4L*5plates
C 3					fully height partially steel jacket	angles	4L 50*50*5	2.5*80*150 4L*3plates

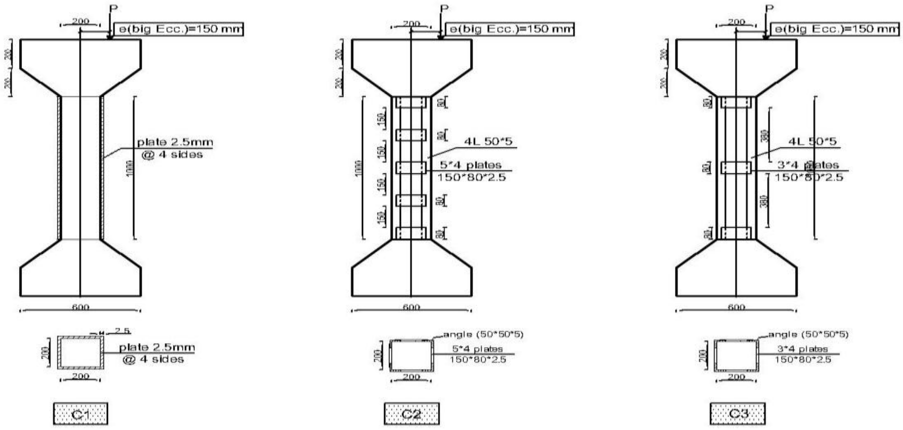


Fig.(1): *Details and strengthening techniques of all specimens C1,C2,C3*

2.3 Test Setup and General Instrumentation

Column specimens were tested in the RC laboratory of Ain Shams University. All specimens were tested under static eccentric load applied using a hydraulic jack. Load eccentricities were controlled using a column head steel device to accurately control the value of the eccentricity. The load was applied in regular increments from zero up to the failure load. At the end of each load increment, readings from the load cell and strain gauges were recorded through the data acquisition system. Fig. (2) shows all details of test setup used in testing the specimens in the laboratory and also sketch demonstrates that.

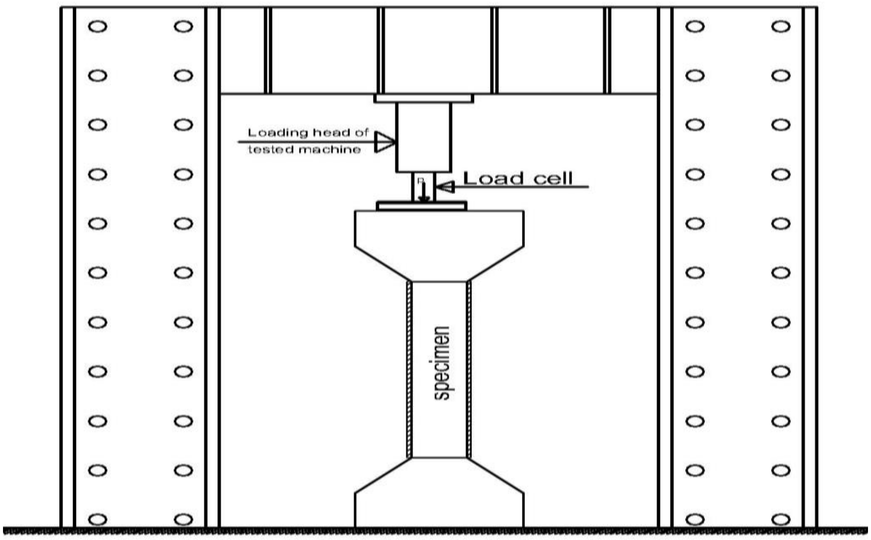


Fig.(2): *Testing Set-Up For columns C1, C2, C3*

2.3.1. Measuring devices:

The strains of concrete were measured using electrical strain gauge with 60 mm fixed on the extreme compression fiber. The strains in steel bars were measured using electrical strain gauges, with 6 mm. These gauges were fixed on the steel bars before casting, using special glue, and then covered with a water proofing material to protect them. The strains in steel jacket were measured using electrical strain gauges, with 6 mm. Deflections of the different points of the columns were measured using four deflectometers.. Fig.(3) show general arrangement for electrical strain gauges for steel bars , steel jacket,concrete and deflectometers.

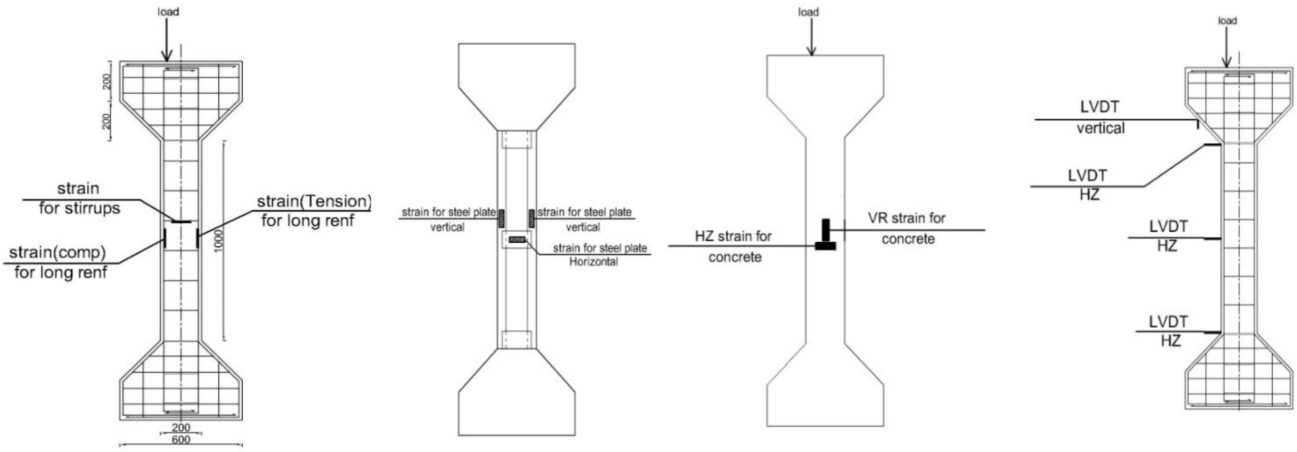


Fig.(3): *show general arrangement of electrical strain gauges for steel bars, steel jacket,concrete and deflectometers*

3. EXPERMENTAL RESULTS.

3.1 Crack Patterns, Cracking Loads and Failure Loads

For the tested three columns. Fig.(4) show the general crack pattern for the tested columns.

Fig. (4): General Crack patterns of columns C1,C2,C3

From fig.(4), the following remarks could be concluded:

For specimen (C1),The cracks appear in column head under loading plate and at the lower part of column (base). As load increases the cracks have become wider at different loads. Due to of the steel plate covering all four faces of concrete; it was not possible to see concrete cracks. At the failure load (791.57 kN), the buckling occurs for one side of specimen in the upper part.

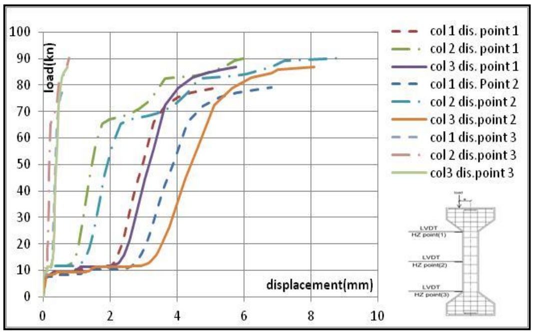
For specimen (C2),The cracks appear in column head under loading plate and at the lower part of column (base). As load increases the cracks have become wider at different loads. Cracks also appear between straps as load increase at different load stages. At the failure load (900.5 kN) , specimen in the upper part causing failure.

For specimen (C3), The cracks appear in column head under loading plate and at the lower part of column (base). As load increases the cracks have become wider at different loads. Cracks also appear between straps as load increase at different load stages. At the failure load (867.39 kN), specimen in the upper part causing failure.

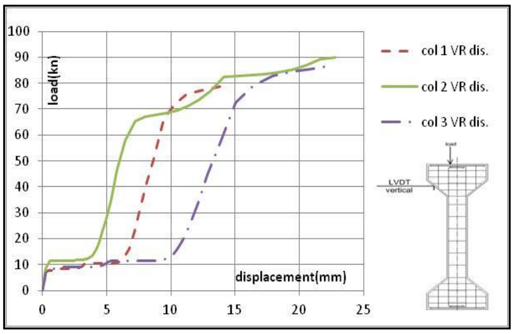
3.2. load- displacement for tested specimens :

Fig.(5) shows the relationship between load and column lateral displacements,vertical displacements. The lateral displacements (at point's 1-top, 2-middle and 3-bottom) of specimens decreases from C2 with percentage 4.5 % with respect to C3 then decreased for C1 with percentage 8.74 % with respect to C3. Also The vertical displacement of specimens decrease from C2 with percentage 1.15 % with respect to C3 then decreased for C1 with percentage 37.2 % with respect to C3.

it can be noted the effects of strengthening technique shape on the behaviour of RC columns under eccentric loads on the lateral displacements & vertical displacement that when the strengthening technique shape changes from C1 to C2 to C3 the failure load increased and consequently the lateral deflections & vertical displacement decreased from C2 to C3 to C1. As the size and stiffness of concrete column are the same for all specimens; the main affecting factor on the lateral displacements & vertical displacement is the strengthening technique shapes of specimen columns.



Lateral displacements at point (1,2,3)



vertical displacement

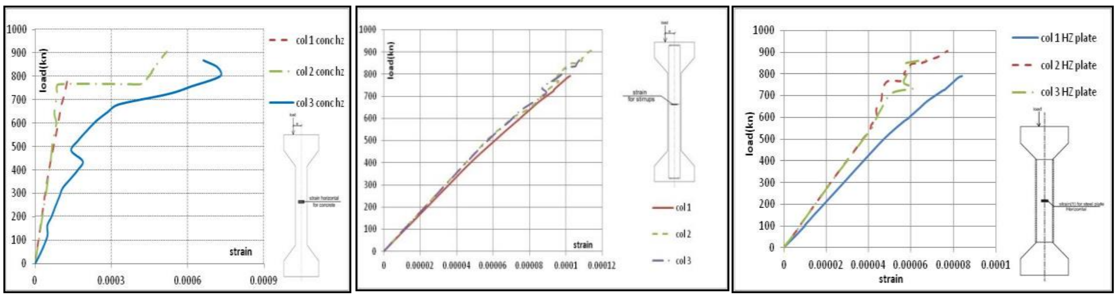
Fig.(5):*Exp result of load- displacement curve for specimens C1,C2,C3*

3.3 Strains

Fig.(6) shows the load lateral strain relationship of concrete,stirrups and steel jacket of specimens together (C1, C2 and C3) at middle part of column. By comparing the maximum strain values of concrete for C1, C2 and C3, it is revealed that: tensile lateral strains of concrete of C1 is 0.00013 increased with percentage 300% with respect to C2 and 438.46 % with respect to C3. This means when strengthening technique shape changes from C1 to (C2 & C3), lateral strains of concrete at steel strap (middle point of column) increase due to concentration of strains below confining parts of strengthening (straps). Moment resulting from big eccentricity (15 cm) of load contributes in existence of that type of strain. Due to moment resulted from eccentricity of load on column (big eccentricity), strains of stirrup of column at middle part of column were tension and

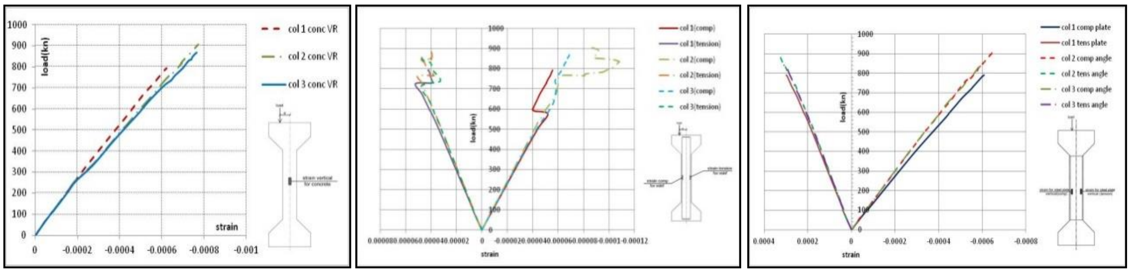
almost constant throughout the different shapes. Strains for C1, C2 and C3 are 0.00010, 0.00011 and 0.00011 respectively. This means that the moment resulted from eccentricity of load on column (big eccentricity 15 cm) caused tension on stirrups.
Due to moment resulted from eccentricity of load on column, lateral strains of steel jacket of column at middle part of column were tension and almost constant throughout the different shapes. Strains for C1, C2 and C3 are 0.00008, 0.00008 and 0.000072 respectively. This means that the moment resulted from eccentricity of load on column caused tension on steel jackets.

Fig.(7) shows the load vertical strain relationship of concrete,main reinf and steel jacket of specimens together (C1, C2 and C3) at middle part of column. By comparing the maximum strain values of concrete for C1, C2 and C3, it is revealed that: Compression vertical strains of concrete of C1 is -0.0007 increased with percentage 14.3% with respect to C2 and C3 which approximately equal. This means when strengthening technique shape changes from C1 to be (C2 & C3), vertical strains of concrete at middle point of column are the same with no effect.
Compression strains of vertical reinforcement of column at middle part of column strain for C1 is -0.000062 decreases with percentage 45.2 % than C2 and 12.9 % than C3. This means when strengthening technique shape changes from C1 to be (C2 & C3), Compression strains of main steel reinforcement at middle point of column are increasing. Tensile strains of main longitudinal reinforcement of column at middle part of column strain for C1 is 0.000045 increases with percentage 9.76 % than C2 and decreased with percentage 13.3% than C3. This means when strengthening technique shape changes C1 to be (C2 & C3), tensile strains of main steel reinforcement at middle point of column are decreasing with respect to C1.
Compression strains of steel jacket of column at middle part of column strain for C1 is -0.0007 and approximately equal to C2 and C3. This means when strengthening technique shape changes from C1 to be (C2 & C3), Compression strains of steel jackets at middle point of column are the same with no effect. This attributed to the location of strainer at middle part of column for all models.Tensile strains of steel jacket of column at middle part of column strain for C1 is 0.00033 and approximately equal to C2 and C3. This means when strengthening technique shape changes from C1 to be (C2 & C3), tensile strains of steel jackets at middle point of column are the same with no effect. This attributed to the location of strainer at middle part of column for all models although there is big eccentricity of load (15 cm).



(concrete) *(stirrups)* *(steel jacket)*

Fig.(6):*Exp result of load-lateral strain curve for concrete,stirrups and steel jacket*



(concrete) *(main reinf.)* *(steel jacket)*

Fig.(7):*Exp result of load-lateral strain curve for concrete,main reinf. and steel jacket*

4. FINITE ELEMENT ANALYSIS

4.1 Methodology

The main aim of performing a finite element analysis of the models was to extend the investigations carried out experimentally to have better understanding of the behavior of all tested specimens.

4.2 Modeling Of Specimens

4.2.1. Model Description

The RC column contains three models subjected to eccentric loads with big eccentricity 15 cm. The 3D finite element model of the (C1,C2,C3) shown in fig.(8).

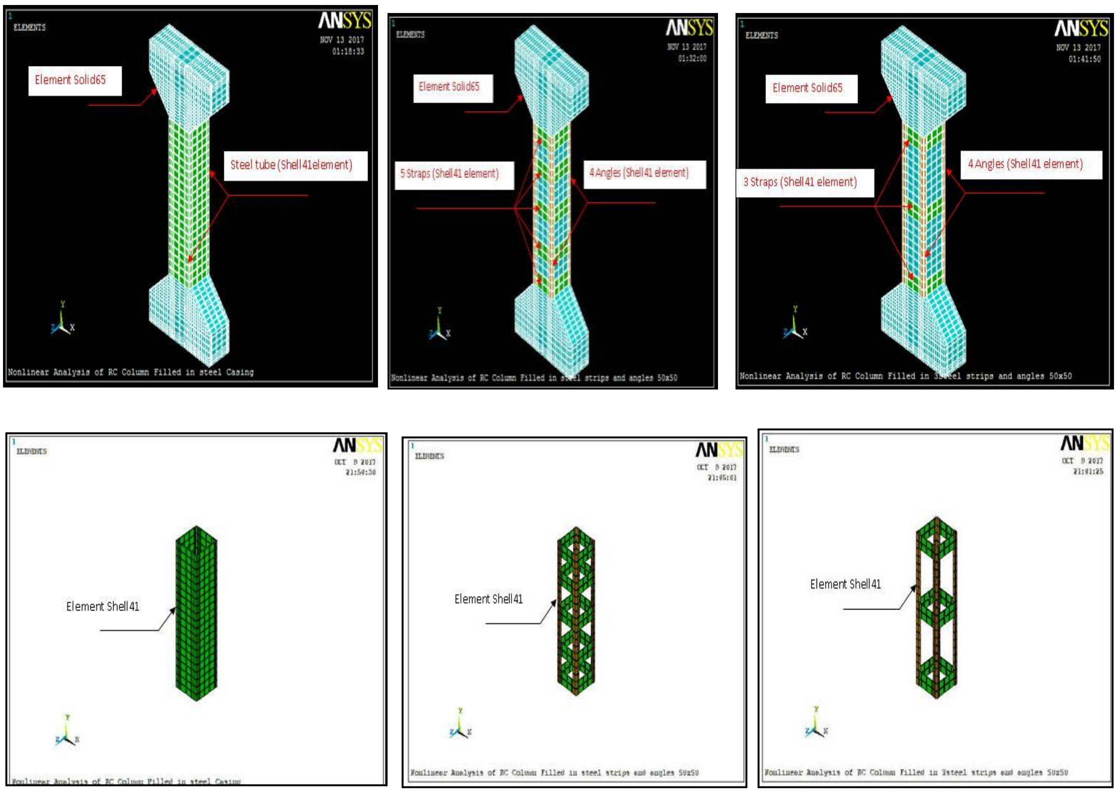


Fig.(8): *The 3D finite element for models C1,C2,C3*

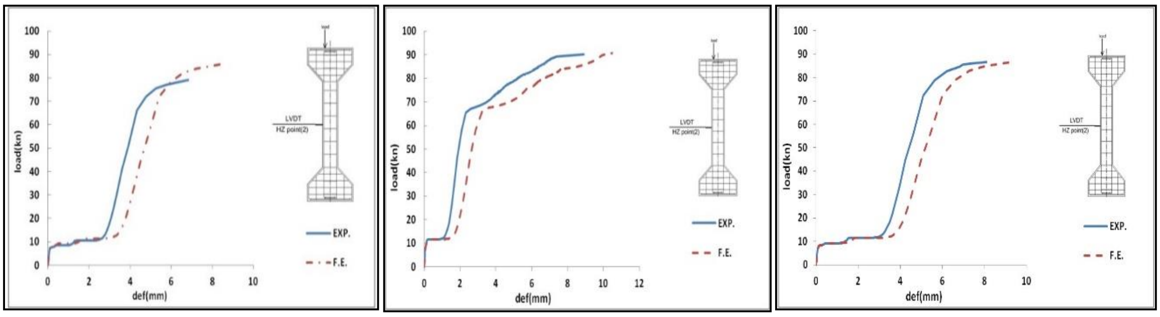
4.3 Results and Verification of FE Models

To verify the FE model, a comparison of the results from tests and those from the FE analyses was made; as shown in Table (5). The F.E models gave higher ultimate load compared to their in experimental.

Table (5): *Comparison for failure moments in Exp. and FE analysis*

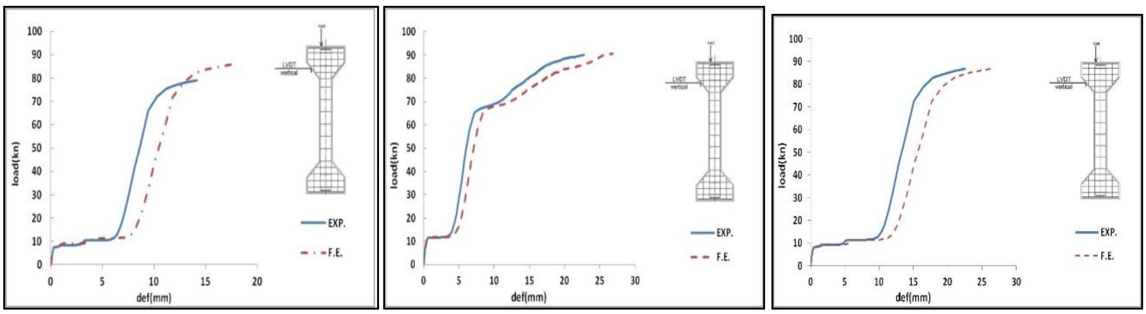
Model	failure loads (kn)		
	Exp.	F.E.	$p_{Exp.}/p_{F.E.}$
C 1	791.57	860.4	0.92
C 2	900.5	906	0.99
C 3	867.39	870	0.99

Fig.9,10 shows the Comparison of lateral displacements and vertical displacements of F.E and EXP for the Models. The ratio between finite element displacements and experimental displacements are approximately 85%. This gives us a high degree of confidence that ANSYS can predict non-linear structural response with a high degree of accuracy.



(C1) (C2) (C3)

Fig.(9): *Comparison of lateral displacement of FE and EXP for the Models C1,C2,C3 at mid column*



(C1) (C2) (C3)

Fig.(10): *Comparison of vertical displacement of FE and EXP for the Models C1,C2,C3*

5. Conclusions

- Steel jacketing techniques used in the strengthening of columns increased the column ultimate capacity to a value ranging from 27.4% to 28.8% with respect to big eccentricity of load.
- It was observed that the number of horizontal straps have negligible effects on the ultimate capacity of the columns due to the wide spacing between the straps which is concrete only that reduces the confinement of concrete throughout the height of column.
- Specimens strengthened with angles and straps recorded higher ultimate load than strengthened using steel tube. This could be attributing to the buckling in thin steel sections.
- Ductility of the tested columns was enhanced after jacketing due to the ductility of steel jackets.
- Four angles strengthened models encountered less displacement than concrete models and the less displacement in all models was steel tube models.
- As the failure load of four angles & straps models more than steel tube models and also the failure behavior, it was observed economically that four angles models less expensive than steel tube models.
- Results of the F.E. analysis showed good agreement with the experimental results with difference in rang of 8 %.

6. References

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