Rehabilitation of Structural Columns by Using Steel Angles

Dr. Ragheed Fatehi Makki, Dr. Salah Talib Nimnim

Abstracted- Reinforced concrete (RC) columns in buildings often need rehabilitation either due to defects in the columns themselves, having to support higher loads than those foreseen in the initial design of the structure, or as the result of ageing or accidental damage. The use of steel caging for this purpose is now a common practice in many countries throughout the world. In this paper, experimental works is presented to investigate the behavior of of reinforced concrete columns strengthened externally with steel jacket under axial loads. This experimental work comprises of twelve square reinforced concrete columns with same cross section of (120x120)mm and height of 1000mm. These columns divided to four groups, the first group (includes three columns) represents the control samples i.e without any type of strengthening, second group (includes three columns) strengthened by various sizes of four vertical steel angles at column corners linked by horizontal battens, third group (includes three columns) strengthened by constant sizes of four vertical steel angles at column corners linked by various sizes of steel plates at top and bottom of columns, while fourth group (includes three columns) strengthened by constant sizes of four vertical steel angles at column corners linked by (various sizes of steel plates at top and bottom of columns besides horizontal battens).The results show that the rehabilitation technique (strengthening) of R.C. columns by using external steel jacket can increase the ultimate load from (42.2-121.7)%.

Index Terms- Rehabilitation, R.C.columns, Steel angles, Steel jacket.

1.Introduction

Strengthening of reinforced concrete columns using steel angles and steel plates is becoming a widely accepted technology in the construction industry. The composite concrete-steel materials, as exhibiting high stiffness, appeared as innovated solutions adapted for strengthening and repair of the structural columns. The best benefit of using steel angles and steel plates in strengthening of RC columns is not only for increasing the load-carrying capacity but also for the pronounced effect on the column stiffness and ductility **(Khalifa & Al-Tersawy, 2014).** In the last three decades, many important researches performed in this area of strengthening RC columns, first for experimental studies **(Ramirez et al., 1997, Adam et al., 2008, Li & Gong, 2009, Campione & Minafo, 2010)**. Also many theoretical models have been conducted to investigate the behavior of confined and unconfined axially loaded reinforced concrete columns **(Critek, 2001, Barga et al., 2006, Campione, 2008, Adam et al., 2009)** focused on the behavior of strengthened reinforced concrete composite columns subjected to failure. However, most of the studies addressed separately the increase in load carrying capacity to the confinement of concrete core or to the composite action if angels are directly loaded.

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2. Experimental work

The main purpose of the test program is to generate data and provide information about the structural behavior and the ultimate strength of reinforce concrete columns strengthened by steel jacket subjected to axial compressive load through a series of twelve columns, in order to use these type of columns in many applications. The experimental work is carried-out in the Structural Laboratory of the College of Engineering, University of Kufa. The parameters considered are :

1- Change of dimensions of angles.
2- Change of dimensions of plates.
3- The effect of using battens.

3- Materials used to fabricate the specimens

The materials used in this paper are commercially available materials, which include cement, reinforcing bars, natural gravel and sand.

3.1- Cement

Ordinary Portland cement manufactured by TASLUJA BAZIAN CEMENT COMPANY (Product of SULAYMANIYAH-IRAQ) is used throughout the investigation. The cement was kept in closed plastic containers throughout the experimental work to keep the cement in good condition to minimize the effect of humidity. The cement properties conform to the Iraqi Specifications limits (I.O.S. 5/1984) **(Iraqi Specification No. 5, 1984)** for ordinary Portland cement.

3.2- Coarse aggregate (gravel)

Natural gravel obtained from Al-Badra-wa-Jasan is used throughout the experimental work. Its grading satisfied the

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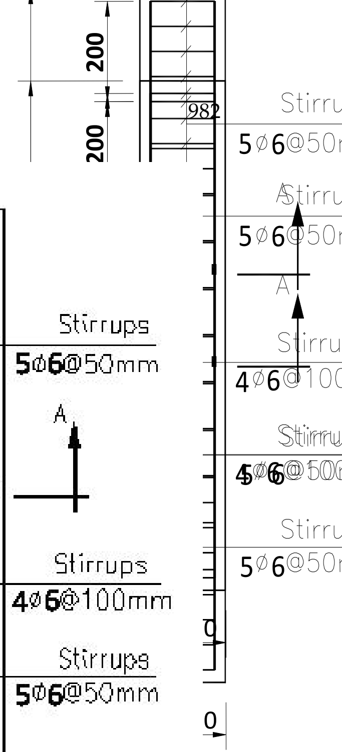

limits of Iraqi standard (No.45/1984) **(Iraqi Specification No. 45, 1984)** for graded gravel with maximum size of 19 mm.

3.3- Fine aggregate (sand)

Natural sand from Al-Najaf region in Iraq is used as fine aggregate for concrete mixes in this study. The fine aggregate was sieved at sieve size (4.75mm) to separate the aggregate particle of diameter greater than (4.75mm). The obtained results indicated that the fine aggregate grading and the sulfate content were within the limits of Iraqi specification No. 45/1984 **(Iraqi Specification No. 45, 1984)**.

3.4- Steel reinforcing bars

For all columns, two sizes of steel reinforcing deformed bars are used, 10mm and 6mm. The 10mm diameter of bar is used as longitudinal steel, while 6mm diameter bar is used as tie reinforcement. The properties of these steel bars are shown in Table (1) that tested in strength of material laboratory (Mechanics Engineering Department in Engineering College, Kufa University).

Table (1) Properties of steel reinforcement

Bar Size	Yield Stress (MPa)	Yield Strain	Ultimate Strength (MPa)	Ultimate Strain
Φ10mm	485	0.0025	590	0.0305
Φ6mm	465	0.0029	528	0.0326

3.5- Concrete mix

A typical concrete mix proportion by weight is used throughout the present study, the mix used is 1: 2: 4 (cement: sand: aggregate) with a water/cement ratio of 0.5. This mix yielded average compressive strength after 28 days is 25 MPa.

4- Specimens description

In the present study a total of (12) R.C. columns are cast and cured under laboratory conditions, all specimens have the same cross section of 120 x 120 mm and height of 1000 mm reinforced with (4) vertical high grade steel bars (485MPa) with diameter of 10 mm and ties of mild steel bars of 6 mm diameter. Figures (1) and (2) shows specimen dimensions and reinforcement details.

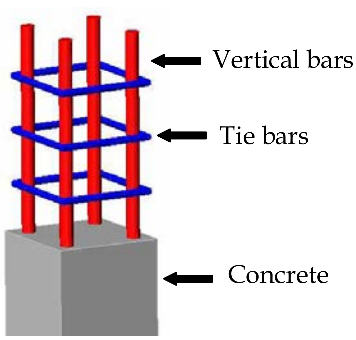

Figure (1) Details of reinforced concrete column

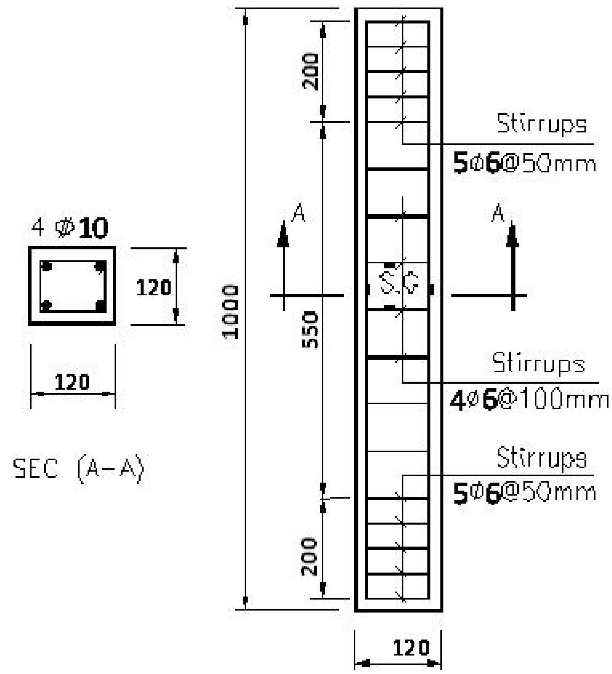

Figure (2) Geometry and cross-section of specimen

5- Specimen identification and strengthening schemes

In order to identify the test specimens with different strengthening schemes, the variables includes the change of dimensions of angles, the change of dimensions of plates, the effect of using battens, the participate effect of using steel angles and steel plates together in strengthening. The twelve RC specimens are divided into four groups (A, B, C and D), each models include three columns. The first group (A) includes three columns with square cross sections with dimension (120×120× 1000)mm reinforced with (4Φ10) as longitudinal bars and 14Φ6 as tie reinforcement. The second group (B) includes also three columns with square cross sections with dimension (120×120× 1000)mm reinforced also with (4Φ10) as longitudinal bars and 14Φ6 as tie reinforcement but strengthened with external steel jacket comprising of (4 steel angles with different sizes as [(1"x1"x1/8"), (1.25"x1.25"x3/16") and (1.5"x1.5"x3/16")] at column corners linked by horizontal battens of dimensions (1") with thickness of 3mm.The third group (C) includes also three columns with square cross sections with dimension (120×120× 1000)mm reinforced also with (4Φ10) as longitudinal bars and 14Φ6 as tie reinforcement but strengthened with external steel jacket comprising of (4) steel angles with constant sizes as (1"x1"x1/8") at column corners besides use of different sizes of steel plates (100, 200, 300)mm with thickness of 3mm as height from top and bottom of specimen, while the fourth group (D) includes also three columns with square cross sections with dimension (120×120x 1000)mm reinforced also with (4Φ10) as longitudinal bars and 14Φ6 as tie reinforcement but strengthened with external steel jacket comprising of (4) steel angles with constant sizes as (1"x1"x1/8") at column corners besides use of different sizes of steel plates (100, 200, 300)mm with thickness of 3mm as height

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from top and bottom of specimen linked by horizontal battens of dimensions (1") with thickness of 3mm.Table (2) illustrates the specimen identification system used based on the specimen identification described above, Strengthening schemes are chosen carefully based on the practical needs and the field conditions.

Table (2) Details of samples

Group		A		
Specimen Symbol		A1	A2	A3
Dimensions (mm):				
Length		120	120	120
Width		120	120	120
Height		1000	1000	1000
Compressive Strength		25 MPa		
Jacket Type		-----------		
Steel Reinforcement	Ver.	4 Ø 10		
	Tie	Ø 6 @ two space (100 and 50)mm		
Group		B		
Specimen Symbol		B1	B2	B3
Dimensions (mm):				
Length		120	120	120
Width		120	120	120
Height		1000	1000	1000
Compressive Strength		25 MPa		
Jacket Type		Angles with battens		
Steel Reinforcement	Ver.	4 Ø 10		
	Tie	Ø 6 @ two space (100 and 50)mm		
Group		C		
Specimen Symbol		C1	C2	C3
Dimensions (mm):				
Length		120	120	120
Width		120	120	120
Height		1000	1000	1000
Comp. Streng.		25 MPa		
Jacket Type		Angles and plates		
Steel Reinforcement	Ver.	4 Ø 10		
	Tie	Ø 6 @ two space (100 and 50)mm		
Group		D		
Specimen Symbol		D1	D2	D3
Dimensions (mm):				
Length		120	120	120
Width		120	120	120
Height		1000	1000	1000
Comp. Streng.		25 MPa		
Jacket Type		Angles and plates with battens		
Steel Reinforcement	Ver.	4 Ø 10		
	Tie	Ø 6 @ two space (100 and 50)mm		

6- Results and discussion

All specimens are tested in a universal testing machine with a capacity of 2000 kN at the laboratory of structures in Engineering college of Kufa University. The test columns are rested on stiff steel frame, the load is applied axially and monotonically increasing up to failure. Firstly control columns are tested up to failure and the data corresponding to it is recorded through data acquisition system, the results are illustrated in Table (3).

Table (3) Ultimate load capacity and failure mode for tested columns

Group	A		
Specimen Symbol	A1	A2	A3
Ultimate Load (kN)	410	420	415
Mean Load (Am) (kN)	415		
Increase of ultimate load	-----	-----	-----
Failure mode	crushing of concrete		
Group	B		
Specimen Symbol	B1	B2	B3
Ultimate Load (kN)	760	885	920
Mean Load (kN)	855		
Increase of ultimate load %	83.1	113.3	121.7
Failure mode	Concrete splitting out + local buckling of steel angles		
Group	C		
Specimen Symbol	C1	C2	C3
Ultimate Load (kN)	590	635	740
Mean Load (kN)	655		
Increase of ultimate load %	42.2	53.1	78.3
Failure mode	Concrete splitting out + local buckling of steel plates		
Group	D		
Specimen Symbol	D1	D2	D3
Ultimate Load (kN)	700	730	820
Mean Load (kN)	750		
Increase of ultimate load %	68.7	75.9	97.6
Failure mode	Concrete splitting out + local buckling of steel angles and plates		

For the three control specimens (A1, A2 and A3), the experimental results show that the ultimate axial load capacity are recorded as (410, 415 and 420) kN respectively. It can be noticed from the tests that the appearance of vertical cracks in the concrete cover was always the first sign of failure of the tested control columns, these cracks spread rapidly after spalling of concrete cover.

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At this stage the core of concrete carried the applied axial load because it is confined by the arching effect between the ties and longitudinal steel bars. At the end of this stage the ties will slip as the expansion of concrete occurs. Figure (3) shows bar graph for ultimate load-carrying capacity of the control columns, while Figure (4) shows the failure pattern of one of control columns.

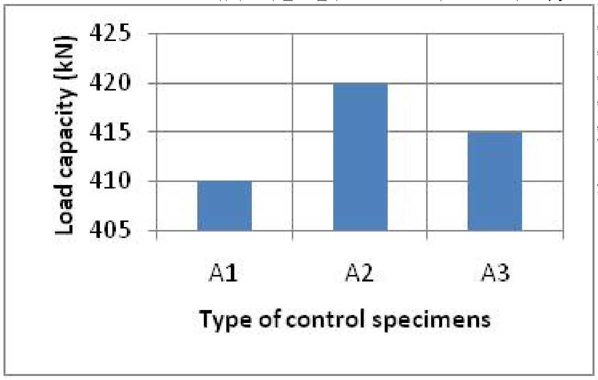

Figure (3) Ultimate load capacity of control columns

Figure (4) Failure pattern of control column

7- Comparison of strengthened and control columns

The effect of strengthening the control columns by using external steel jacket comprising of (4 steel angles with different sizes as [(1"x1"x1/8"), (1.25"x1.25"x3/16") and (1.5"x1.5"x3/16")] at column corners linked by horizontal battens of dimensions (1") with thickness of 3mm is shown in Figure (5). It is observed from the experimental data and the corresponding bar graph that strengthening leads to increase in the ultimate load carrying capacity from (415kN) for the mean of control columns (Am), to (760kN), (885kN) and (920kN) for first group of strengthened columns (B1), (B2) and (B3) respectively.

Thus there is an increase in ultimate loads as (83.1%) for (B1), (113.3%) for (B2) and (121.7%) for (B3) comparing with control column respectively.

Also the effect of strengthening the control columns by using external steel jacket comprising of (4) steel angles with constant sizes as (1"x1"x1/8") at column corners besides use of different sizes of steel plates (100, 200, 300)mm with thickness of 3mm as height from top and bottom of specimen is shown in Figure (6). It is observed from the experimental data and the corresponding bar graph that strengthening leads to increase in the ultimate load carrying capacity from (415kN) for the mean of control columns (Am), to (590kN), (635kN) and (740kN) for second group of strengthened columns (C1), (C2) and (C3) respectively.

Thus there is an increase in ultimate loads as (42.2%) for (C1), (53.1%) for (C2) and (78.3%) for (C3) comparing with control column respectively.

By similar the effect of strengthening the control columns by using external steel jacket comprising of (4) steel angles with constant sizes as (1"x1"x1/8") at column corners besides use of different sizes of steel plates (100, 200, 300)mm with thickness of 3mm as height from top and bottom of specimen linked by horizontal battens of dimensions (1") with thickness of 3mm is shown in Figure (7).

It is observed from the experimental data and the corresponding bar graph that strengthening leads to increase in the ultimate load carrying capacity from (415kN) for the mean of control columns (Am), to (700kN), (730kN) and (820kN) for third group of strengthened columns (D1), (D2) and (D3) respectively. Thus there is an increase in ultimate loads as (68.7%) for (D1), (75.9%) for (D2) and (97.6%) for (D3) comparing with control column respectively.

Enhancement in the load carrying capacity of strengthened columns is mainly due to improvement in the strength of the confined concrete as shown in Figure (8), while Figures (9) to (12) explained that the increase in ultimate load capacity of strengthened columns comparing with control specimen.

It is also conducted that using the steel-casing, the effective moment of inertia is increased and thus ductility demand will also be increased. The stiffening action of steel strip and angles enhanced the confined concrete strength. In this case, delay in the sudden compression failure of the strength columns occurs.

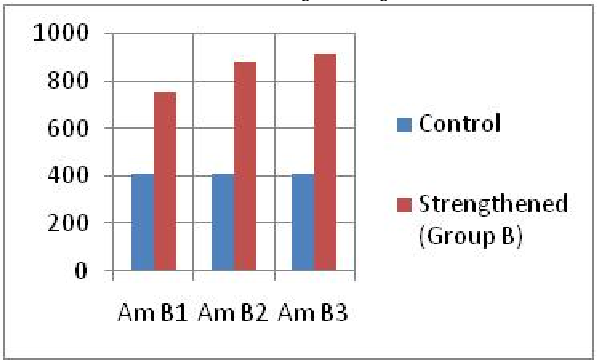

Figure (5) Ultimate load capacity of control and strengthened (group B) columns

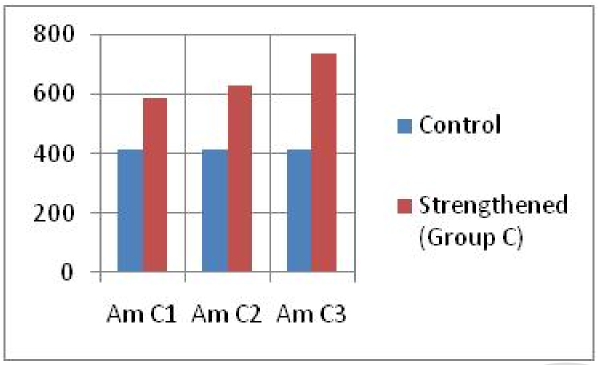

Figure (6) Ultimate load capacity of control and strengthened (group C) columns

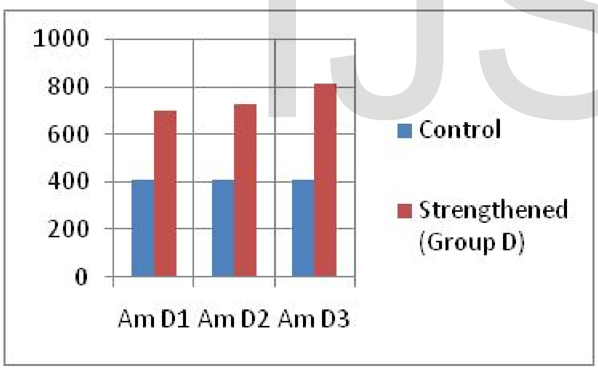

Figure (7) Ultimate load capacity of control and strengthened (group D) columns

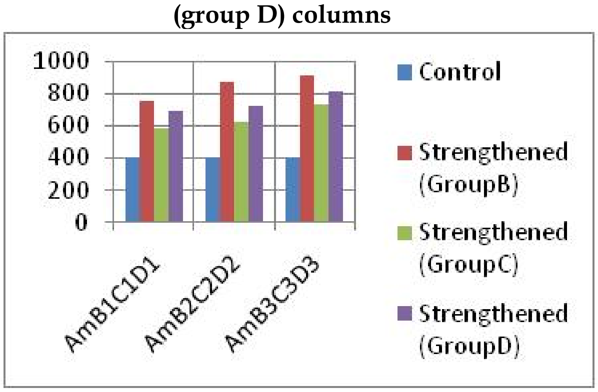

Figure (8) Ultimate load capacity of control and all groups of strengthened columns

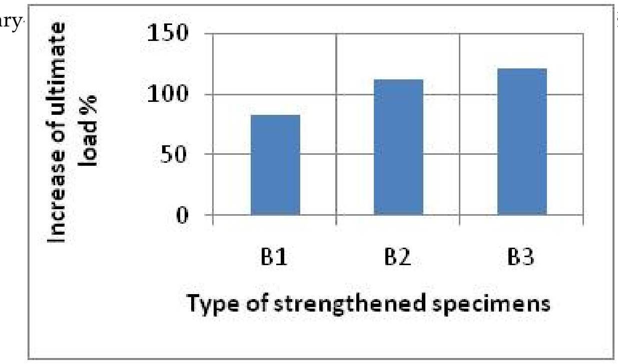

Figure (9) Increase of ultimate load capacity for strengthened columns (group B)

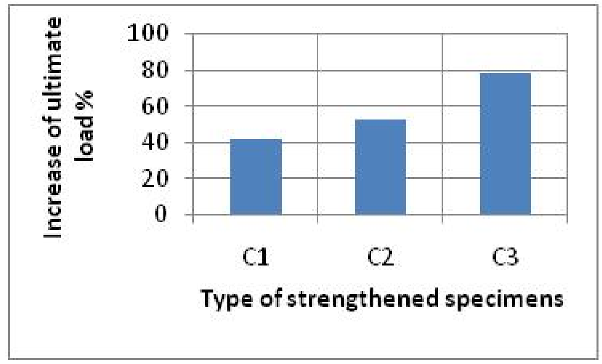

Figure (10) Increase of ultimate load capacity for strengthened columns (group C)

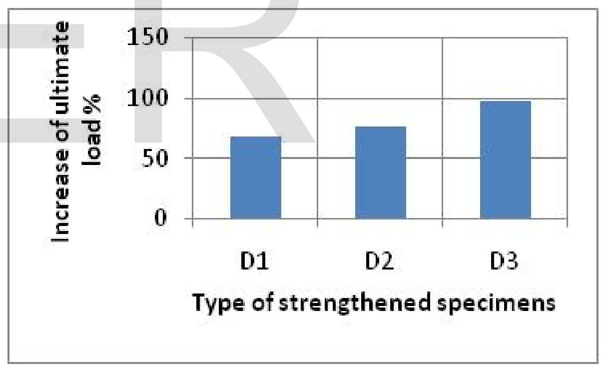

Figure (11) Increase of ultimate load capacity for strengthened columns (group D)

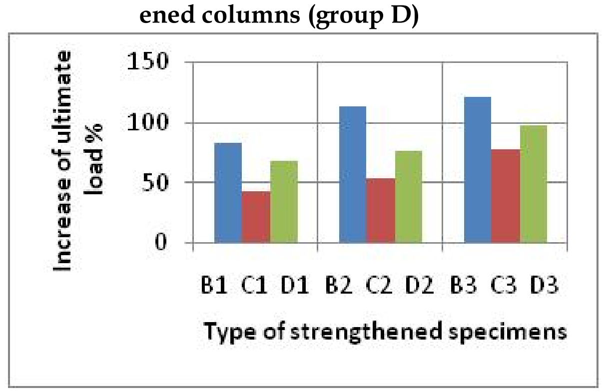

Figure (12) Increase of ultimate load capacity for all strengthened columns

The failure modes of the columns, which are of considerable importance, are primarily associated with steel yielding, steel local buckling and concrete crushing, monitored for a selection

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of test specimens.
The concrete crushing that occurs at failure load causes a significant redistribution if a stress acts on the steel casing, this redistribution then promotes local buckling of steel after the peak load is reached.
The control specimen failure mode is a typical compression failure of the reinforced concrete column. It has to be observed that for strengthening reinforced concrete columns using steel angles besides using or not steel plates and horizontal battens, the column failure occurs when the steel cage is no longer to confine the concrete (the steel cage yields) and the concrete between the battens is splitting out. The failure patterns of arbitrary strengthened specimens are shown in Figures (13) to (15).

Figure (13) The failure pattern of strengthened column

Figure (14) The failure pattern of strengthened column

Figure (15) The failure pattern of strengthened column

8. Conclusion

The most important conclusions that can be drawn from the present paper are:

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1- The rehabilitation technique (strengthening) of RC columns by using external steel jacket comprising of steel angles and steel plates besides the horizontal battens is applicable and can increase the ultimate load for all cases of strengthening from (42.2-121.7%) compared with the unstrengthened (control) columns.

2- For the first case of strengthening (group B) which is performed by using external steel jacket comprising of (4 steel angles with different sizes as [(1"x1"x1/8"), (1.25"x1.25"x3/16") and (1.5"x1.5"x3/16")] at column corners linked by horizontal battens of dimensions (1") with thickness of 3mm leads to increase in the ultimate load carrying capacity from (415kN) for the mean of control columns (Am), to (760kN), (885kN) and (920kN) respectively. Thus there is an increase in ultimate loads as (83.1%) for (B1), (113.3%) for (B2) and (121.7%) for (B3) comparing with control column respectively.

3- For the second case of strengthening (group C) which is performed by using external steel jacket comprising of (4) steel angles with constant sizes as (1"x1"x1/8") at column corners besides use of different sizes of steel plates (100, 200, 300)mm with thickness of 3mm as height from top and bottom of specimen leads to increase in the ultimate load carrying capacity from (415kN) for the mean of control columns (Am), to (590kN), (635kN) and (740kN) respectively. Thus there is an increase in ultimate loads as (42.2%) for (C1), (53.1%) for (C2) and (78.3%) for (C3) comparing with control column respectively.

4- For the third case of strengthening (group D) which is performed by using external steel jacket comprising of (4) steel angles with constant sizes as (1"x1"x1/8") at column corners besides use of different sizes of steel plates (100, 200, 300)mm with thickness of 3mm as height from top and bottom of specimen linked by horizontal battens of dimensions (1") with thickness of 3mm leads to increase in the ultimate load carrying capacity from (415kN) for the mean of control columns (Am), to (700kN), (730kN) and (820kN) respectively. Thus there is an increase in ultimate loads as (68.7%) for (D1), (75.9%) for (D2) and (97.6%) for (D3) comparing with control column respectively.

5- The observed control specimen failure mode is a standard compression failure (crushing of concrete) of the reinforced concrete column, while for strengthening reinforced concrete columns using steel angles besides using or not steel plates and horizontal battens, the column failure occurs when the steel cage is no longer to confine the concrete (the steel cage yields) and the concrete between the battens is splitting out.

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