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Behavior of RC Columns Strengthened with Steel Jacket Under Static Axial Load

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Reinforced concrete column, Strengthening, confinement, Steel angles, Steel strips.

Abstract

One of the most important structural elements, the column is primarily intended to support compressive loads. The strengthening is carried out for existing reinforced concrete columns to increase the ductility of the column and to increase load capacity to sustain the applied load as sometimes there may be a use change, which leads to increased loads. This work aims to study the behavior and efficiency of RC columns strengthened with steel jackets and subjected to axial load. An experimental program was performed on columns specimen till failure. Aspect ratio (t is the long side of the cross-section /b is the short side of the cross-section), the volume of steel straps, and the spacing of steel straps at centers(S) were the primary research variables in this work. Ten specimens were rectangular concrete columns with aspect ratios equal to 1, 1.56, and 2.04. the cross sections of the column were (200*200mm), (160*250 mm) and (140*286 mm) respectively. the total height of the specimens was 1200 mm,960mm, and 840mm respectively. Under an axial load, three control columns and seven strengthened columns were tested. The results showed that using this method of strengthening is very effective and an increase in the axial load capacity of the strengthened columns is obtained. This increase was due to the confining effect of the steel jacket, and the ability of the steel angle to withstand a large part of the applied axial load. The failure mode in most of the strengthened specimens was due to the buckling of the steel angles.

1. **Introduction**

The axial load capacity and ductility of reinforced concrete structures can be increased using a variety of techniques. This strengthening may be necessary because sometimes a change in use causes higher loads, deterioration due to factors like environmental factors, withstanding lateral

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loads, and design errors. These cases may require strengthening, repairing, or retrofitting for concrete structures. popular methods for strengthening columns include adding new concrete jackets with additional reinforcement, using external steel angles and horizontal strips, and fiber-reinforced polymer (FRP) jacketing. It has been proven that all these methods effectively increase the axial load capacity of the columns. Strengthening reinforced concrete columns using steel corners welded with horizontal bars is one of the easiest technologies available almost. In this technique, four steel vertical angles were installed at the corners of the column joined by horizontal steel straps. This method has various advantages, including being much lighter than concrete jackets and requiring less fire protection than FRP wrapping. Many researchers studied the performance and the ultimate capacity of columns strengthened by steel jackets.

Badr [1] demonstrated the experimental behavior of eight rectangular reinforced concrete columns reinforced with a steel jacket. All specimens were rectangular concrete columns with an aspect ratio equal 2. The size of corner angles, different spacing of the strap plates, and the usage of anchor bolts in the middle of the long side of the columns were the research variables in this study. The author found that the proposed steel jacket can be successfully used for increasing the ultimate load of the concrete columns by up to 74.8 %. Strengthened column behavior has also been improved by narrowing the spacing of the horizontal steel strips. Bsisu [2] conducted an experimental and theoretical study on 20 square reinforced concrete columns modified with steel jacket technology tested under concentric axial loads. The specimens were divided into four groups. The authors found that reinforcing a square reinforced concrete column with a full steel jacket increases the compressive strength by more than two times that of the original column without reinforcement, and the confined strength of the concrete is about 1.5 times the unconfined strength. Also, the confinement of reinforced concrete columns with steel jackets enhanced the ductility of the column.

Ezz-Eldeen et al. [3] tested eleven columns of specimens that have a rectangular cross-section. The experimental behavior of the strengthened concrete column was studied with variable sizes of corner angles and connected with 3, 5, and 7 straps. The test results obtained proved that the increased cross-sectional area of the steel jacket increased the load-carrying capacity of the strengthened columns. While increasing the straps number had a small effect in increasing column carrying capacity.

Elsamny, Mohamed K et al. [4] conducted experimental tests to investigate the behavior of steel jackets used in strengthening twenty-seven square columns subjected to eccentric loading. The columns were strengthened with steel angle connected with a varying number of horizontal straps and tested under different eccentricities. The test results obtained showed that the steel jacket technology used to strengthen the column increased the maximum capacity of the column to values ranging from 21% to 87%. The number of horizontal straps had no noticeable effect on the ultimate load-bearing capacity of the columns. Additionally, the width of the vertical corners had a significant impact on the ultimate capacity of the strengthened columns. Tarabia and Albakry [5] presented the experimental behavior of square columns strengthened by a steel jacket. The variable concrete strength, type of grout injected between column and steel jacket, horizontal stripe spacing, vertical angle size, and presence or absence of connection between steel jacket and two heads of the specimen were the parameters of this study. The test results show that using vertical angles welded to horizontally spaced strips to strengthen concrete columns is very efficient and greatly enhances the axial load capacity of the strengthened columns Also, the ductility of the strengthened columns increased by 50% compared to the ductility of the un-strengthened columns in most cases. Abd-ELhamed and Ezz-Eldeen [6] Investigate the proposed techniques for Strengthening Damaged Reinforced Concrete Columns Using Steel Angles Wrapped with Ferrocement. Six reinforced concrete columns having a rectangular section were tested until failure under different eccentricities. All specimens have been retrofitted and strengthened. Test results show that columns strengthened with four vertical steel angles and covered with three layers of Ferrocement have higher failure load than that strengthened with three layers of Ferrocement only. Column carrying capacity was increased by 102.5% to 112%. Belal et al. [7] presented an experimental and analytical study to investigate the behavior of concrete columns strengthened by a steel jacket. Seven specimens with a square cross-section were tested. The parameters of the study were the shape of the main strengthening system (using angles, C-channels, and plates), size, and the number of batten plates.

The study has shown that different strengthening schemes have a significant impact on column capacity. The size of the batten plates had a major effect on the ultimate load for specimens strengthened with angles, whereas the number of batten plates was more effective for specimens strengthened with C-channels. The test results showed good agreement between the experimental test and the F.E model. Campione [8] shows the results of an original experimental campaign on RC column specimens with and without steel jacketing subjected to compressive axial and eccentric tests. Next, a new approach is proposed to define a plane fiber-section model of the reinforced cross-section considering the frictional action occurring along the column-angle interfaces. The specimens consisted of a rectangular column with a height of 820 mm. Steel jacket reinforcements were placed by placing an intermediate layer of cement grout between the steel and concrete surfaces. Obtained results show the Frictional interaction occurring along the steel–mortar interface is not negligible, and the mechanical response of steel angles can be described by an elastic perfectly plastic equivalent stress-strain model depending on the cohesive strength (Co) and the friction coefficient (μ). Ali et al. [9] Presented an experimental and analytical study to investigate the effect of strengthening using steel jacketing subjected to eccentricity. three specimens with a square cross-section were tested under vertical load up to failure. The parameter of the study was the shape of the strengthening system. Test results showed that the steel jacketing technique used in the strengthening of columns increased the maximum ultimate capacity of the columns to values ranging from 27.4% to 28.8% concerning the big eccentricity of the load. It has been observed that the number of horizontal straps has negligible effects on the ultimate load of the columns. Results of the F.E. analysis showed good agreement with the experimental results with a difference in the range of 8 %. Owida et al. [10] presented an experimental (EXP) and finite element (FEA) study of the effect of external confinement for damaged (RC) columns by using a steel jacketing technique with various percentages of covered steel surface area to column surface area. Twenty rectangular concrete columns with an aspect ratio equal 2 have been tested until failure. All specimens have been retrofitted and strengthened. The results show that by increasing the percentage of covered steel surface area relative to column surface area and decreasing the slenderness ratio, the column carrying capacity increases. There was good agreement between the results of the experimental work and the finite element results. Shehab Eldeen et al. [11] presented a review of both experimental and analytical investigations conducted by previous researchers on the strengthening techniques of Reinforced Concrete (RC) columns using steel jackets. The author found that most of the investigations were focused to know the effect of strengthening configurations on load-carrying capacity, lateral strength, ductility, and flexural strength by changing parameters like strip thickness, concrete strength, size and spacing, angle size, and thickness. The literature has revealed that the aforementioned factors affect load-carrying capacity. According to numerous researchers' experimental studies, the overall increase in axial strength is between 18.65% and 109%, while the increase in lateral strength is between 63% and 68%.

In the above discussion opinion, it was found that very few limited studies, were carried out on a higher percentage of transverse volume straps. Also, the effect of using different aspect ratios has not been addressed. The main objectives of the presented study are as follows:

1- determine the effect of increasing the transverse straps on the efficiency of the strengthening where narrower closed strip spacing was used to throw the light on this effect.
2- Moreover, the effect of an aspect ratio up to 2 was also included.
3- To study the efficiency of this strengthening technique on the concrete column in the case of a higher percentage of transverse volume straps.

2. Experimental Program

2.1. Materials

All columns were made using normal-strength concrete having a concrete compressive strength of about 25N/mm^2, which is evaluated by six cubic specimens with a side length of 150 mm after 28 days. The mixing proportions of concrete materials by weight/m^3 is 350kg (Portland cement): 618.5 kg (fine aggregate): 1148.7kg (coarse aggregate: 182 litters (water content). The water-cement ratio w/c was 52% for all batches. The used concrete was made from Ordinary Portland Cement. angular crushed coarse aggregates were used in experimental work with a maximum nominal size of 20 mm. The used fine aggregate was River sand. The properties of the used aggregate are shown in Table 1. The high tensile was used as the main reinforcement, while the steel used as stirrups was mild steel. Table (2) presented the mechanical properties of steel reinforcement, steel angles, and straps.

Table 1: Properties of fine and coarse aggregates.

Property	Gravel	Sand
Specific gravity	2.54	2.5
Volume weight (t/m^3)	1.5	1.58
fineness modules	6.52	2.45

Table 2: Mechanical properties of steel reinforcement, steel angles, and straps.

Item	Type	Fy (N/mm^2)	Fu(N/mm^2)
6 mm	Reinforcement	242	398
12 mm	Reinforcement	427.5	610
L 50*50*3 mm	Corner angle	347.8	434.8

Fy : Yield stress Fu : Maximum stress

2.2. Details of the tested columns

Ten rectangular concrete columns were constructed and tested in this work. The specimens with aspect ratio equal 1, 1.56 and 2.04. The cross-section of the columns was (200*200mm), (160*250 mm) and (140*286 mm) respectively. The total height of the specimens was 1200 mm,960 mm and 840mm respectively. The *H/b* ratio was kept constant and equals 6 for all reinforced concrete columns. Where (*H*) is the height of the columns and *b* being the width. This ratio avoids the formation of a significant secondary moment caused by the slenderness effect and satisfies the requirement for short RC columns. All columns had six bars 12 mm diameter as vertical reinforcement (steel area to concrete cross-section area equals approximately 1.7 %). All columns were provided with horizontal stirrups of normal mild steel 6 mm diameter with a volumetric percentage of 0.35%. The left gap between the strap and the concrete column was vertically filled with grout mortar. Three control columns were kept un-strengthened: one in each main group. The other seven columns' specimens were strengthened using four longitudinal steel angles 50*50*3mm and horizontal strips of thickness equal to 3 mm which were welded to the steel angles at a specific spacing. In the specimen's name in table (3) the designation of the control column has two parts. The first part is *C* which refers to the control column. A second part is a number (1.00, 1.50, and 2.00) which refers to the aspect ratio of the cross-section of the column. The designation of other columns has four parts. The first part is *Cs* which refers to the strengthened columns. The second part is a number that refers to the aspect ratio of the cross-section of the column. The third part *W* refers to the width of the steel strap. The four-part *S* refers to the Spacing of steel straps at centers. The test specimens are summarized in Table (3), as well as Fig. (1) shows the cross-section of the test specimens.

2.3. Specimen preparation

The specimens were taken out of the moulds a day after casting and cured in water for 28 days at a constant temperature of 27 c°. After casting and curing all specimens and the concrete had reached an age of 60 days. Three specimens were left un-strengthened and the rest of them were strengthened. In strengthened specimens Prepared the concrete surface using a light hammer and blower to remove the weak elements on the concrete cover and rough places fixing of steel angle. steel angles are installed on the column corner by filleting the column corners and steel angle with non-shrink adhesive epoxy mortar to ensure good contact between the steel angle and column corner. The epoxy mortars an adhesive mortar with medium viscosity and solvent free. It contains two components product based on modified epoxy resin. The two compounds are mixed in according to the manufacturer's specifications before use. The properties of the used epoxy mortars are given in Table (4). Then the steel angles are fitted and fixed with metal clamps. Then weld the batten plates with the steel angles as shown in Fig. (2). The properties of the used epoxy mortars are given in Table (4).

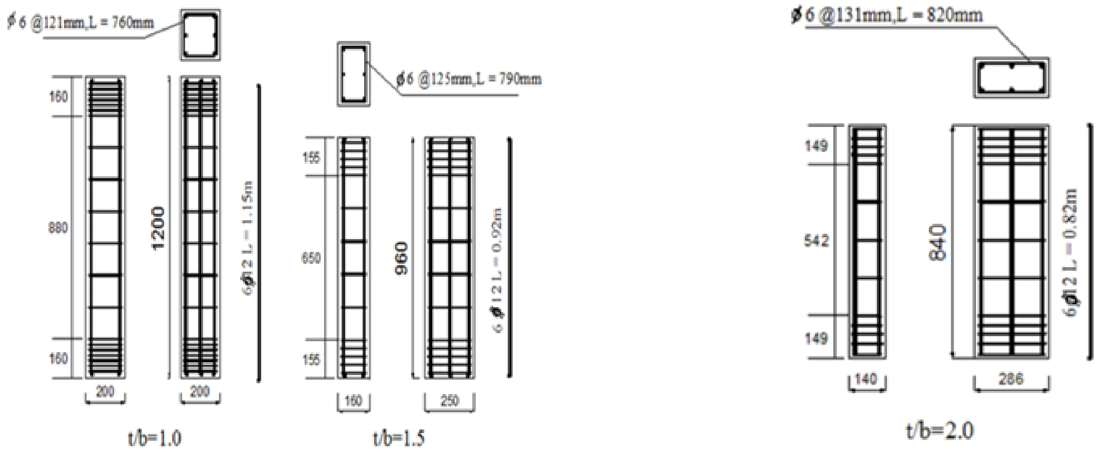
Table 3: Details of tested columns

Series	Col. designation	Cross section dimension (mm)	Aspect Ratio (t/b)	Height Of Column (H) (mm)	Width of strap (W) (mm)	Spacing Of steel straps at centers (S) (mm)
Control column	C-1.00	200 X 200	1.00	1200	-----	-----
	C-1.50	160 X 250	1.56	960	-----	-----
	C-2.00	140 X 286	2.04	840	-----	-----
1	Cs-1.00-W50-S100	200 X 200	1.00	1200	50	100
	Cs-1.50-W50-S100	160 X 250	1.56	960		
	Cs-2.00-W50-S100	140 X 286	2.04	840		
2	Cs-1.00-W40-S100	200 X 200	1.00	1200	40	100
	Cs-1.00 -W50-S100	200 X 200	1.00	1200	50	
	Cs-1.00-W60-S100	200 X 200	1.00	1200	60	
3	Cs-1.00-W50-S70	200 X 200	1.00	1200	50	70
	Cs-1.00-W50-S100	200 X 200	1.00	1200		100

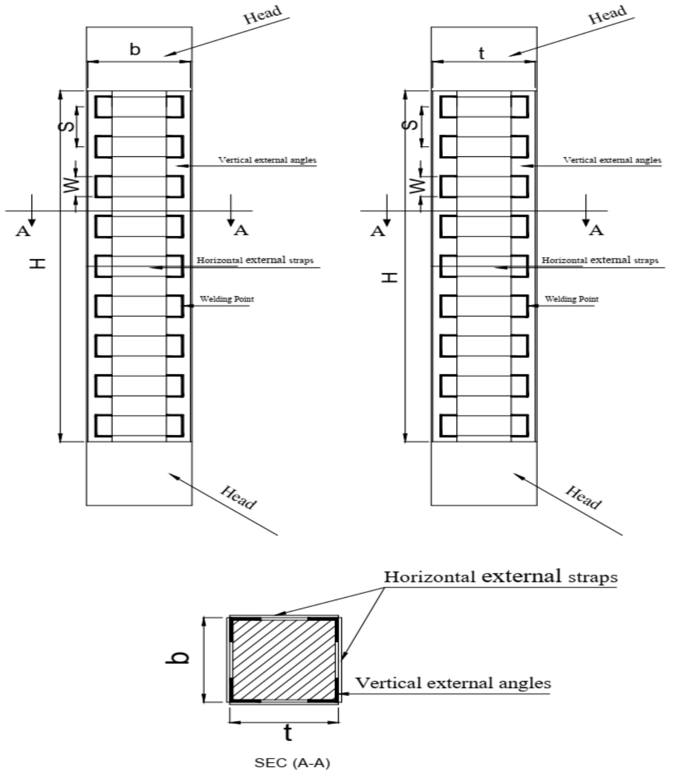
	Cs-1.00-W50-S130	200 X 200	1.00	1200		130

Table 4: Mechanical properties of the used epoxy mortars according to the manufacturer

material	Compressive strength (N/mm^2)	Flexural strength (N/mm^2)
Epoxy mortars	Bigger than 80	Bigger than 40



a) Internal reinforcement



List of symbols

H Height of column

b short side of the cross-section
t long side of the cross-section
S spacing of steel straps at centers

W width of the strap

b) External strengthening
Fig. 1: Configuration of the tested columns.

Fig. 2: Preparing concrete surface and steel jacket application.

2.4. Instrumentation

Between the jack head and the steel frame of the testing machine, the specimens were placed. The data acquisition system, which was connected to a computer and connected to both the strain gauges and the linear voltage displacement transducer (LVDT), was used to regularly record all readings. The load was measured by a load cell of 5000 KN capacity and was connected to a data acquisition system. To measure the average axial deformation of the specimens, two (LVDT) were mounted on two of the opposing faces of each specimen. Two strain gauges were placed on two different vertical angles at the top height of the column in each of the strengthened specimens. Additionally, two strain gauges were positioned in the center of two perpendicular horizontal straps to record strain values at various loading stages to help determine how well these steel elements affected the behavior of the strengthened concrete columns. Fig.3 shows the location/orientation of used strain gauges linked to the tested specimens. To facilitate subsequent data editing and plotting, all test records were automatically stored in a computer file.

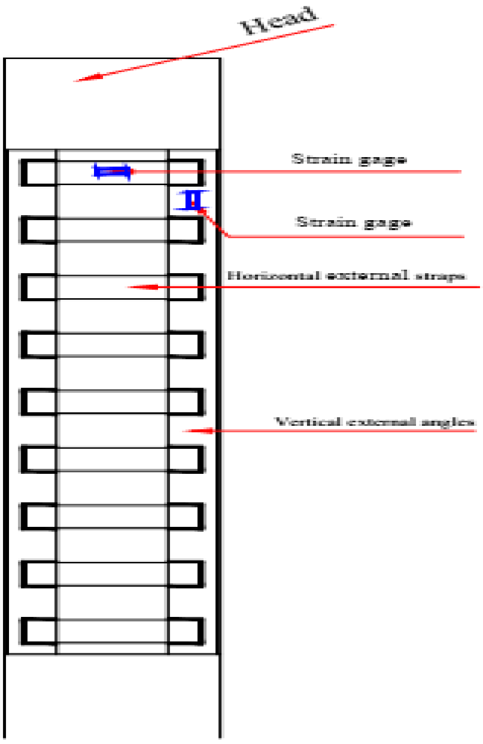


Fig. 3: location of used strain gauges linked to the tested specimens.

2.5. Testing

All specimens were tested under concentric loads monotonically applied using a compression testing machine of 5000 KN capacity and a load-controlled rate of 140 KN/min until the failure load. Two steel heads were used to confine the column heads to prevent early failure due to concentration stress at the ends of the specimen. To ensure a parallel surface and provide uniform bearing surfaces, all columns were capped with steel plates. Fig.4 shows the test setup and measurement devices for the tested columns. All tests were conducted in the strength of material and concrete laboratory of the civil engineering department at Assiut University.

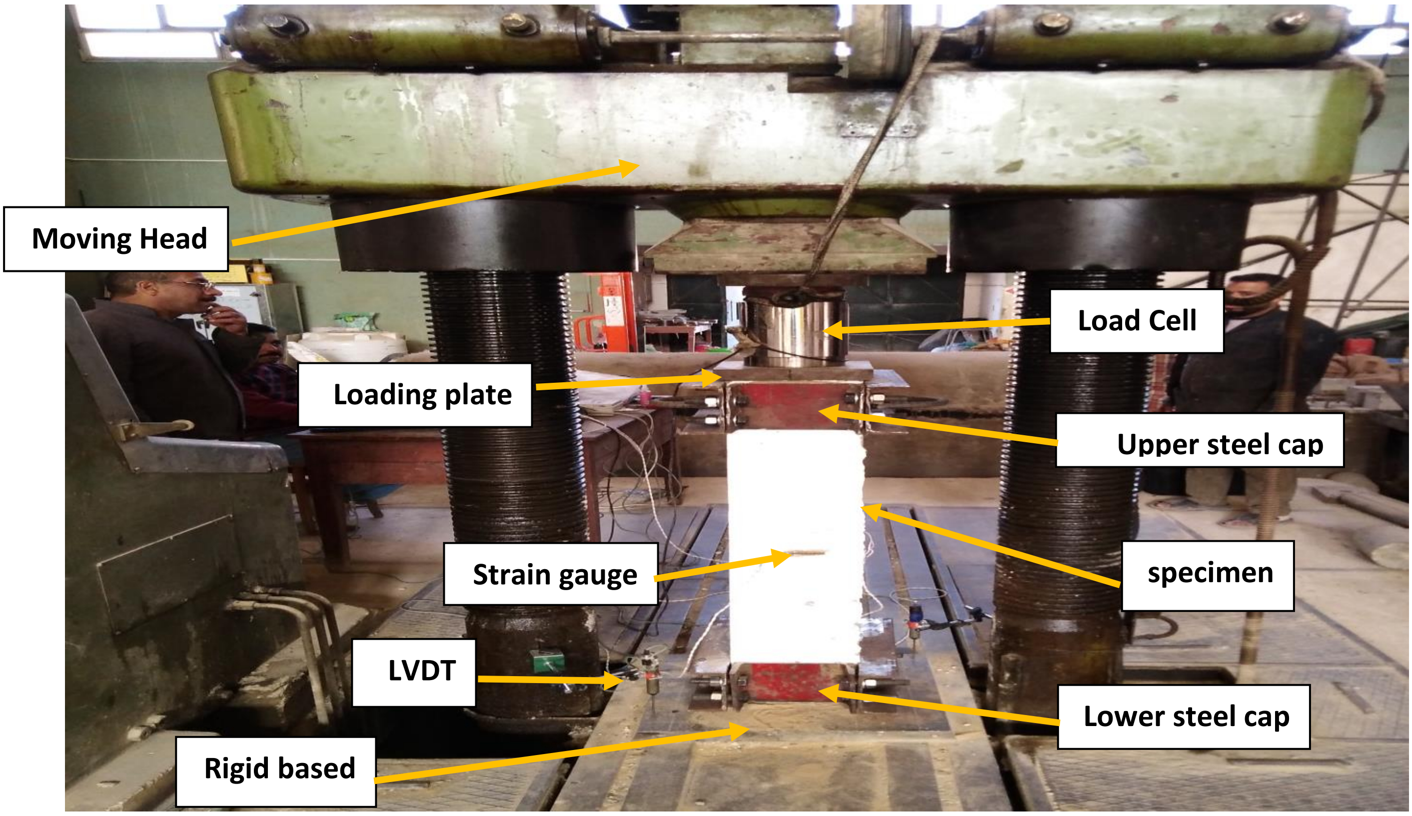


Fig. 4: Details of the test setup and measuring devices.

3. Test Results and Discussion

The obtained results of reinforced concrete specimens with and without strengthening under static loading were classified to include the effect of the following parameters: -
- Effect of aspect ratio.
- Steel straps volume.
- spacing of steel straps at centers.

3.1. Ultimate Failure load and Failure modes.

The maximum ultimate load for control and strengthened columns, the increase in column carrying capacity, and the ratio of each column's ultimate load to the reference column for the same group are all shown in Table (5). The ultimate load was increased by the steel jacket confinement. The gain in the ultimate load relative to the corresponding unconfined column increases with decreasing strap spacing. The column capacity increased as the volume of steel straps increased. The steel jacket's load capacity decreased as the aspect ratio increased. The greatest gain for load capacity was seen in square columns, which increased by 49% when compared to the control column.

During the tests, two failure modes were observed. These failure modes are presented as follows:

The first mode (FM1) was a brittle failure which was observed clearly for the unconfined columns (C-1.00, C-1.50and C-2.00). The behavior of reference columns was similar. As the load increased, inclined cracks began to appear near the top part of the column. Then by increasing the load the wider cracks became. At approximately 95% of the ultimate load of the column, the concrete cover spalled off and the longitudinal bars appeared to buckle between two stirrups. During the failure stage of column C-1, the lock of one stirrup began to open outside the section. When the load reached the maximum load, severe damage was observed, and a total collapse of specimens occurred Fig. 5.

The second mode (FM2) was observed in the case of the strengthened columns where the failure in these specimens started with slight cracks located under the upper steel cap. As the load increased, large cracks began to appear at the bottom of the columns. The failure mechanism is defined by local buckling of one or more vertical angles, followed by a buckling of the reinforcement steel bars and, finally, crushing of the concrete section near these bars. Because of the lateral expansion of concrete, the weld between the horizontal strip and the vertical angle was broken in some specimens. Most likely after the occurrence of buckling of the vertical angles, as evidenced by the buckling shape of the angles in Figs 6,7, and 8.

Table 5: Ultimate load of control and strengthened column specimens

Series	Col. designation	εel	εcu	Ductility= (εcu- εel / εel) x100	ultimate load (kN)	Gained Strength	failure mode
Control column	C-1.00	0.0059	0.0074	25.5%	1238.75	-----	(FM1)
	C-1.50	0.0100	0.0080	25%	1188.75	-----	(FM1)
	C-2.00	0.0101	0.0084	20%	1085	-----	(FM1)
1	Cs-1.00-W50-S100	0.0106	0.0214	101.9%	1850	49.34%	(FM2)
	Cs-1.50-W50-S100	0.0125	0.024	92%	1565	31.65%	(FM2)
	Cs-2.00-W50-S100	0.0138	0.026	88.4%	1417.5	30.64%	(FM2)
2	Cs-1.00-W40-S100	0.0094	0.018	91.4%	1731.25	39.75%	(FM2)
	Cs-100 -W50-S100	0.0106	0.0214	101.9%	1850	49.34%	(FM2)
	Cs-100-W60-S100	0.010	0.0213	113%	1942.5	56.81%	(FM2)
3	Cs-100-W50-S70	0.0105	0.0232	120.9%	2070	67.10%	(FM2)
	Cs-100-W50-S100	0.0106	0.0214	101.9%	1850	49.34%	(FM2)
	Cs-100-W50-S130	0.0097	0.0191	96.9%	1670	34.81%	(FM2)

3.2. The Ductility

Ductility represents the plastic strain of the material, so the ductility was calculated by (εcu- εel / εel) x100, where(εcu) is the maximum strain at the elastic-plastic stage and (εel) is the maximum strain at the elastic stage. Table (5) summarizes the values of ductility of all specimens. It also summarizes the values of (εel) and (εcu). From Table (5) it can be noticed that the ductility of the control column decreases with increasing the aspect ratio. Also, it can be shown that strengthening columns with steel jackets increases ductility. Additionally, the ductility of strengthened columns increases by decreasing both the Spacing Of steel straps at centers and the aspect ratio of the strengthened columns increase. On contrary, it increases as the Volume of steel straps increases.

C-1.00 (b) C-1.50 (c) C-2.00

Fig. 5: Failure mechanism (FM1) for unconfined RC columns

a) Cs-1.00-W50-S100 (b) Cs-1.50-W50-S100 (c) Cs-2.00-W50-S100

Fig. 6: Failure mechanism (FM2) for cross-sectional aspect ratio confined RC columns

(a) Cs-1.00-W40-S100 (b) Cs-100-W50-S100 (c) Cs-1.00-W60-S100

Fig. 7: Failure mechanism (FM2) for the volume of steel straps confined RC columns

(a) Cs-1.00-W50-S70 (b) Cs-1.00-W50-S100 (b) Cs-1-00-W50-S130

Fig. 8: Failure mechanism (FM2) for spacing of steel straps confined RC columns

3.3. Load- Strain response.

Figures. 9, 10, 11, and 12 show the typical relationship between the applied axial stress and the corresponding axial strain of the tested specimen. The axial vertical strains are determined by dividing the average readings of the two vertical LVDTs by the gauge length, which represents the height of the column.

By analyzing Fig (9) it is confirmed that the behavior of the RC square control column was different from any RC rectangular control column in the initial stiffness. The square RC column has a higher initial stiffness, and the control square RC column has the highest value of compressive strength. This is due to the more uniform stress from the transversal steel hoop than in the case of (*t/b* 1.00). The initial stiffness decreased as (*t/b*) increased, but the effect was modest. For the (*t/b* =1.56) and (*t/b* =2.04) specimens the initial stiffness almost has the same slope because the passive pressure by transverse steel was smaller. By analyzing Fig (10) it is verified that the stiffening action of steel jackets can enhance the confined concrete strength. It is obvious from the figure that sufficiently confined square and rectangular columns confined with steel jackets can exhibit highly ductile compressive behavior. Additionally, the steel jacket is more effective in square sections than rectangular ones. Also, as the aspect ratio increases the ultimately confined strength decreases. On the contrary, as the aspect ratio increases the ultimate strain increases. By analyzing Figures. 11 and 12, it was found that all the strengthened columns attained greater maximum axial strain than the reference columns without a steel jacket. This indicates when a steel jacket is added, increased ductility. Both confined and unconfined specimens respond similarly in the initial elastic zone. The maximum axial strains increase as the volume of steel straps increases. The maximum axial strains increased as the strip spacing decreased.

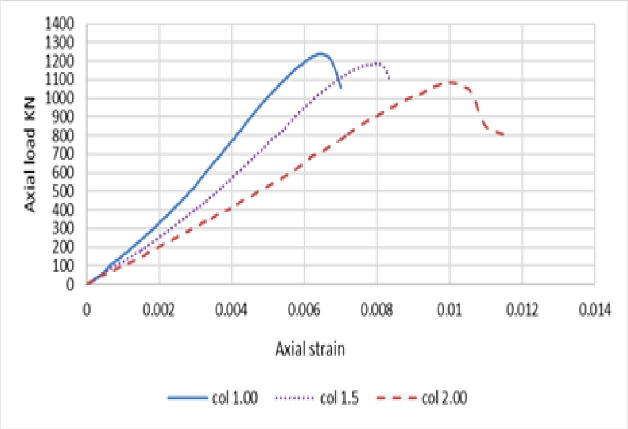


Fig. 9: Load- Strain response for all the control column

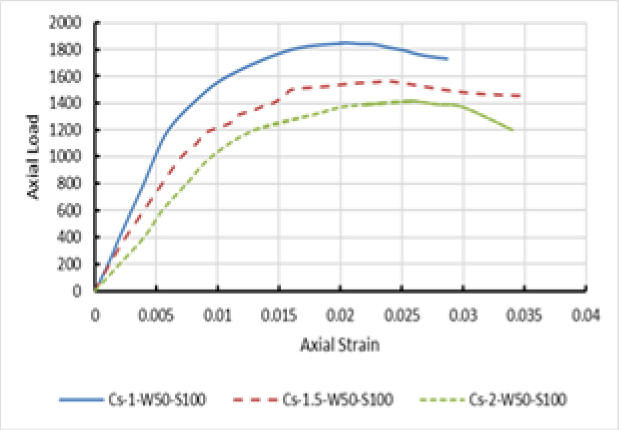


Fig. 10: Load-strain response for the strengthened specimens of the group (1)

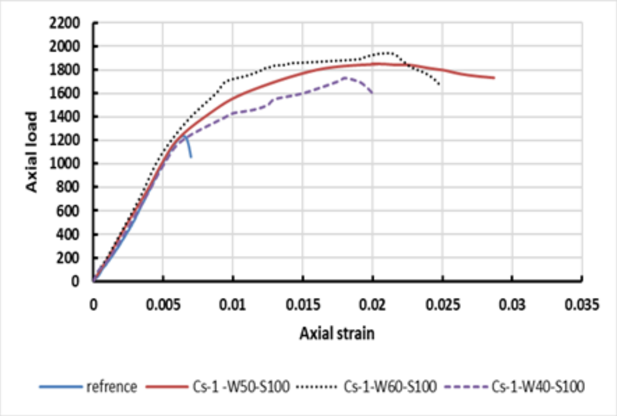


Fig. 11: Load-strain response for the strengthened specimens of the group (2)

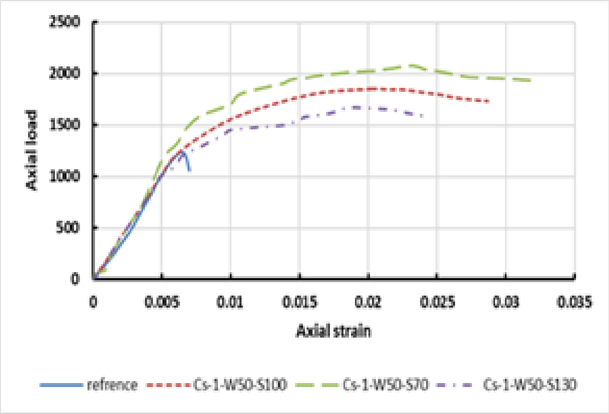


Fig. 12: Load-strain response for the strengthened specimens of the group (3)

3.4. Horizontal strip strains.

The steel strips' primary function is to prevent earlier buckling of the vertical angles and to decrease the horizontal expansion of the concrete section, which leads to restricting the concrete section. Figures 13, 14, 15, and 16 depict the relationship between the applied axial load and the horizontal strip strains. The circumferential strains were measured at the top at long and short directions of specimens. By analyzing Fig (13) and (14) it is verified that the ultimate lateral strain values on the shorter side are greater than those on the longer side. generally, For the same strengthening technique, the ultimate lateral strains on both longer and shorter sides decrease as the aspect ratio increases. It can be shown from fig (15) that the strain values increase in straps by increasing the volume of steel straps**.** By analyzing Fig (16) it is confirmed that the strain increases in straps by decreasing the space of steel straps at centers(*S*). this indicates that the confining effect is higher as the space of steel straps decreases.

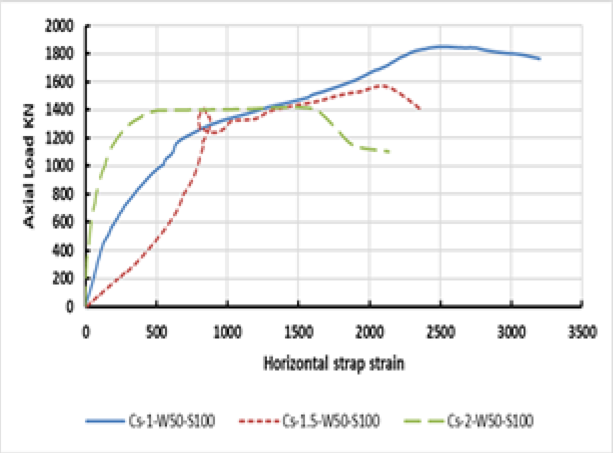


Fig. 13: Axial load versus axial strain of horizontal steel strip for the short side of Group1

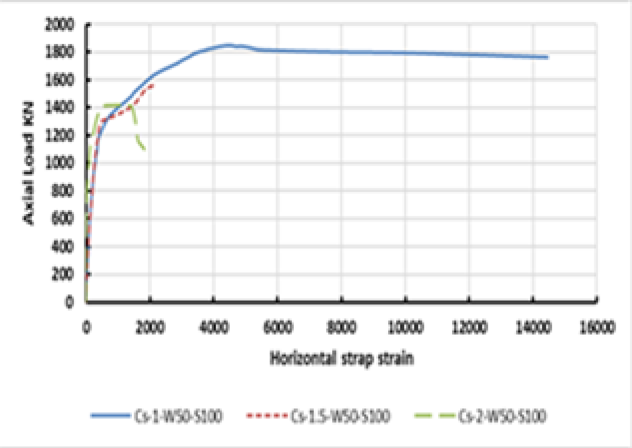


Fig. 14: Axial load versus axial strain of horizontal steel strip for the long side of Group1.

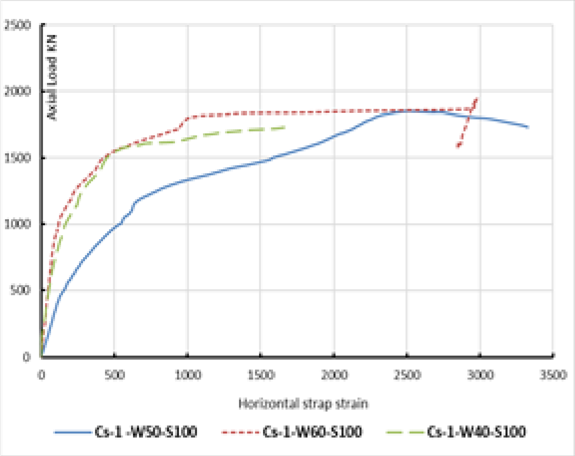


Fig. 15: Axial load versus axial strain of horizontal steel strip of Group 2

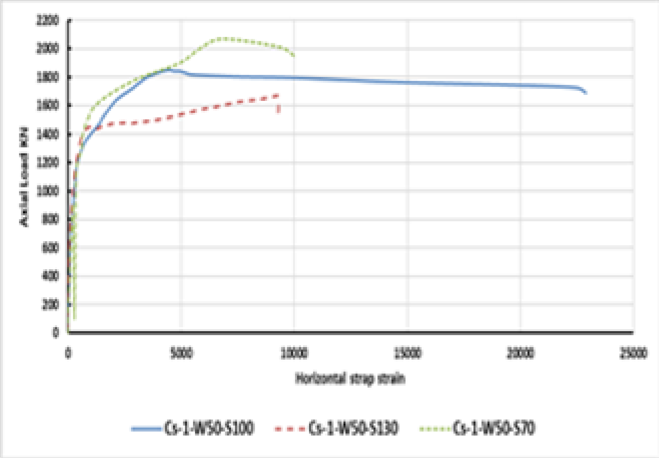


Fig. 16: Axial load versus axial strain of horizontal steel strip of Group 3

3.5. Effect of rectangularity of the cross-section.

All strengthened specimens with the same cross-sectional area had a higher load-carrying capacity than the control specimen. Table (5) shows the ultimate failure load and load increase values for the confined columns for Series 1. The table shows that there is a significant improvement in the ultimate load of the confined columns in the steel jackets, with the ratio of improvement reaching 1.49 for square columns and 1.31 and 1.30 for specimens with aspect ratios of 1.54 and 2.04, respectively. This indicates that square sections of the steel jacket are more effective than rectangular sections, and it also shows that the ultimate confined strength decreases as the aspect ratio increases.

3.6. Effect of spacing of horizontal steel straps at canters on failure load.

The ultimate axial load and the maximum axial shortenings were lower for columns with relatively major spacing between horizontal steel straps than for those with smaller spacing between straps.

The increased horizontal strap spacing sped up the vertical angle buckling action, which contributed to the comparatively speedy failure of these columns. It was found that for a column strengthened by 4 steel angles connected with straps 50 x 3 mm at spacing 70mm the maximum failure load increased from 1238.75 (kN) for the control column to a maximum value of 2070 (kN) which represent 67.10% increase compared with that for the reference specimen, while the load increased from 1238.75 (kN) for control column to 1670 (KN) for column strengthened by straps 50*3 mm at spacing 130mm which represents 34.81% increase compared with that for the reference specimen.

3.7. Effect of Volume of steel straps on failure load.

The volume of steel straps has a good effect on the ultimate axial load of the concrete column. For the columns strengthened with steel jacket Increasing the volume of steel straps makes more confinement of concrete and yielding of the strip occurred at higher load values. This leads to delay in the concrete splitting out, and higher load capacity. It was found that for a column strengthened by 4 steel angles connected with straps at spacing 100mm, the maximum failure load increased from 1238.75 (kN) for the control column to a maximum value of 1942.5 (kN) for a column strengthened by straps 60*3 mm which represent 56.81% increase compared with that of the reference specimen. while the load increased from 1238.75 (kN) for the control column to 1731.25 (KN) for the column strengthened by straps 40*3 mm which represents a 39.75% increase compared with that of the reference specimen

4. Conclusions

The present experimental study showed that strengthening by using steel jackets can be successfully used to enhance and increase the strength, and behavior of RC columns under different technique procedures of steel jacketing. Based on the test results, the following conclusion can be summarized:

- Using a steel jacket for strengthening reinforced concrete columns is an effective technique.
- The failure mode of the control reinforced concrete column was brittle but strengthening with a steel jacket modified the failure mode to be more ductile.
- The effect of strap plate spacing for columns strengthened by corner angle 50*50*3mm with strap plate 50*3mm at intervals 70, 100 and 130 mm increase the column's ultimate load by 67.10%, 49.34%, and 34.81% respectively.
- The effect of the volume of steel straps for column strengthened by corner angle 50*50*3mm with the spacing of horizontal steel straps at centers 100 mm at different widths 40, 50 and 60 mm increase the columns ultimate load by 39.75%, 49.34%, and 56.81% respectively.
- The increase in aspect ratio resulted in a decrease in load capacity for the studied column dimension. Maximum load capacity values were achieved in square RC columns, with a 49% increase for steel jacket confined columns.
- Rectangularity, spacing of horizontal steel straps, and volume of steel straps parameters are considered very important parameters which significantly affect the ultimate load capacity, ductility, and the failure mode of the strengthened column.

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سلوك الأعمدة الخرسانية المسلحة المقواة بإستخدام قميص من القطاعات الحديدية تحت تأثير حمل محوري

الملخص العربى:

تعتبر الأعمدة الخرسانية من اهم العناصر الإنشائية التى يتكون منها المنشأ والتي تلعب دورا مهما. حيث تعتبر الاعمدة هي العنصر الإنشائي الرئيسي المصمم لمقاومة الأحمال الرأسية والجانبية. غالبا ماتتطلب الهياكل الإنشائية التقوية والتدعيم لعدة أسباب لزيادة الممطولية للأعمدة ولزيادة قدرة التحمل لتحمل الأحمال الواقعة حيث في بعض الأحيان قد يكون بسبب التغير في الإستخدام والتي يترتب علية زيادة الأحمال. يهدف هذا البحث الي عمل دراسة معملية لسلوك وكفاءة الأعمدة الخرسانية المسلحة المقواه بقميص من القطاعات الحديدية والمعرضة لحمل محوري. تم اختبار عينات الاعمدة بحمل محوري حتى الانهيار وكان المتغيرات التي تم دراستها بين هذه العينات هي تغيير نسبة الطول الي العرض لقطاع العمود (نسبة المستطيلة) وحجم الخوص الحديدية والمسافة بين الخوص الحديدية. تم اختبار عشر أعمدة خرسانية مسلحة ذات قطاع مستطيل نسبة المستطيلية ١و ١,٥٦و ٢,٠٤ حيث كانت قطاعات الاعمدة (٢٠٠مم×٢٠٠مم) و (١٦٠مم×٢٥٠مم) و (١٤٠مم×٢٨٦مم) على التوالي وكان الارتفاع الكلي للعينات ١٢٠٠مم و٩٦٠مم و٨٤٠مم على التوالي. تم اختبار ثلاث أعمدة بدون تدعيم وسبع أعمدة مقواة بقميص حديدي. أظهرت النتائج أن استخدام طريقة التقوية هذه فعاله للغاية وتم الحصول على زيادة في قدرة التحميل المحورية للأعمدة المقواة. وتعزى هذه الزيادة إلى تأثير الحبس للقميص الحديدي وقدرة زوايا الحديد على تحمل جزء كبير من الحمل المحوري المطبق. كان نمط الإنهيار في معظم العينات المقواة بسبب انبعاج زوايا الحديد.