WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2023.145273
ARCHIVES OF CIVIL ENGINEERING
Vol. LXIX ISSUE 2 2023

pp. 367 –379

Research paper

Behavior of RC columns strengthened with steel jacket under static axial load

Abd Rahman Mujahid Ahmed Ghoneim[1],
Mohamed Mahmoud Ahmed Mohamed[2], **Kader Haridy**[3],
Hazem Ahmed[4], **Mohmmad Pyram**[5], **Abdu Khalf**[6]

Abstract: The column is one of the most significant structural elements, which is designed to support mainly the compressive load. Strengthening of existing reinforced concrete columns is required to enhance ductility and increase load capacity to sustain the overload as sometimes there may be a change in use. Ten rectangular concrete columns were constructed and tested. H/b ratio was kept constant and equals 6 for all columns The aim of this work is to study the behaviour and efficiency of RC columns strengthened with steel jackets subjected to axial load. An experimental study of the behaviour of ten strengthened concrete columns with slenderness ratio (H/b) equals 6 was carried out. Variables such as aspect ratio (t/b), the volume of steel batten plates, and spacing of steel batten plates at centres (S) were considered. 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.

Keywords: reinforced concrete, column, strengthening, confinement, steel angles, steel strips

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[1] Prof. PhD., Eng., Assiut University, Faculty of Engineering, Civil Engineering Department, Assiut, P.O. Box 71515, Egypt, e-mail: abdelrahman.ghonaim@eng.au.edu.eg, ORCID: 0000-0001-9129-6860

[2] Prof. PhD., Eng., Assiut University, Faculty of Engineering, Civil Engineering Department, Assiut, P.O. Box 71515, e-mail: mohamed.mohamed33@eng.au.edu.eg, ORCID: 0000-0002-3545-2205

[3] PhD., Eng., Al-Azhar University, Faculty of Engineering-Qena, Civil Engineering Department, 83513, Egypt, e-mail: kaderharidy@azhar.edu.eg, ORCID: 0000-0002-0113-337X

[4] Eng., Al-Azhar University, Faculty of Engineering-Qena, Civil Engineering Department, 83513, Egypt, e-mail: hazem tantawy86@yahoo.com, ORCID: 0000-0002-6204-7395

[5] PhD., Eng., Al-Azhar University, Faculty of Engineering-Qena, Civil Engineering Department, 83513, Egypt, e-mail: mohammedyouns2543.el@azhar.edu.eg, ORCID: 0000-0003-2820-8121

[6] Assistance Prof. PhD., Eng., Al-Azhar University, Faculty of Engineering-Qena, Civil Engineering Department, 83513, Egypt, e-mail: abdounagah2067.el@azhar.edu.eg, ORCID: 0000-0002-3754-6395

1. Introduction

There are many methods to increase the axial load capacity and ductility of Reinforced concrete structures. This strengthening may be necessary due to Sometimes it may be change in use causing higher loads, deterioration due to factors like environmental factors, for withstanding lateral loads, design errors [1–7]. These cases may require strengthened, repaired or retrofitted for concrete structure. popular methods for strengthening columns include adding new concrete jacket with additional reinforcement, using external steel angles and horizontal strips, and fiber reinforced polymer (FRP) jacketing [8–11]. It has been proven that all these methods effectively increase the axial load capacity of the columns. Strengthening of reinforced concrete columns using steel corners welded with horizontal bars is one of the easiest technologies available almost [12]. In this technique four steel vertical angles installed at the corners of the column joined by horizontal steel batten plates. This technology has many advantages such as small thickness compared to concrete jackets, very light weight and requires less fire protection compared to wrapping with FRP [11]. Many researchers studied the performance and the ultimate capacity for columns strengthened by steel jacketed.

An experimental behavior of eight rectangular reinforced concrete columns of low compressive strength concrete which were strengthened by steel jackets presented by [4]. All specimens were rectangular concrete column with aspect ratio equal two, 15 × 30 cm cross section. The column was provided at the two ends by two caps 15 × 60 cm cross section and 22.5 cm height. The total length of the column was 165 cm. The steel jacket consisted of vertical four angles in the corners and horizontal batten plates 40 × 6 mm at intervals 10, 15 & 20 cm, which were distributed along the length of column and welded between the corner angles. The experimental behavior of the strengthened concrete column was studied with variable size of corner angles mm and different spacing of the batten plates using either anchor in the middle on the long side of the columns or without anchors. the proposed steel jacket can be successfully used for increasing the ultimate load of the concrete columns by up to 74.8%. Also decreasing the spacing of the horizontal steel batten plates improved the behavior of the strengthened columns. an experimental and finite element investigation for studying the effect of external confinement for damaged (RC) columns by using steel jacketing technique with a various percentage of covered steel surface area to column surface area (36, 42, 50, 57 and 64) studied by Owidaet [13]. A total of twenty reinforced concrete columns specimens having a cross section of 125 × 250 mm and a different slenderness 6, 8, 10 and 12 have been tested. the columns tested until failure to study the external confinement for damaged (RC) columns.

All damaged concrete parts were removed and replaced the loose concrete part with grout mortar and retrofitted by using steel straps jacketing technique. The steel jacket consists of four vertical steel angles placed at each corner of column and connected together with horizontal steel batten plates with a variable width 20, 30, 40, 50 and 60 mm. The results give an increase in the column carrying capacity by increasing percentage of covered steel surface area to column surface area and decrease by increasing slenderness ratio. Faire agreement was found between finite element results and experimental results [13–15]. The objective of this research program is to determine the effect of volume of steel batten plates, spacing of steel batten plates at centres and cross-sectional aspect ratio on the behavior of strengthened RC column using steel jacket technique [16].

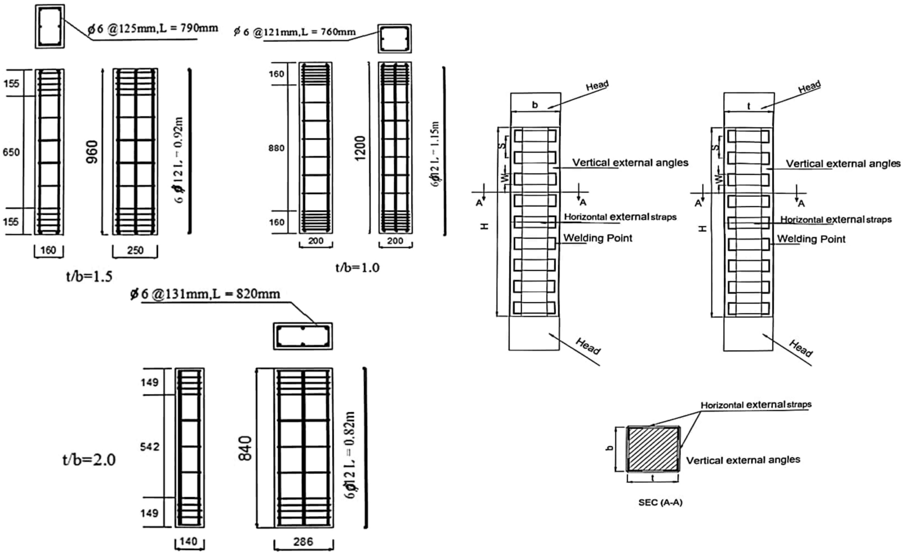
2. Experimental program

2.1. Details of the tested column and materials

Ten rectangular concrete columns were constructed and tested. H/b ratio was kept constant and equals 6 for all columns. The columns reinforced with six bars 12 mm in diameter as vertical reinforcement and 6 mm in diameter as stirrups. See Table 1, as well as Fig. 1(a, b, and c). All columns were made using normal strength concrete of about 35 N/mm^2, which is evaluated by six cubic specimens with a side length of 150 mm after 28 days. The high tensile steel with about 427.5 N/mm^2 proof stress, was used as main reinforcement, while the steel used as stirrups was mild steel of about 242 N/mm^2 yield strength.

Table 1. Details of tested columns

Col.	Cross section (mm)	Aspect ratio t/b	Height of column H (mm)	Internal reinforcement		Vertical steel angles	Width of batten plates W (mm)	Spacing of steel batten plates at centers S (mm)
				Longitudinal steel	Stirrups			
C-1.00	200×200	1.00	1200	6 bars 12 dia.	$\phi 6$ mm @ 100 mm	–	–	–
C-1.50	160×250	1.56	960			–	–	–
C-2.00	140×286	2.04	840			–	–	–
Cs-1-W50-S100	200×200	1.00	1200	6 bars 12 dia.	$\phi 6$ mm @ 100 mm	4L $50 \times 50 \times 3$ mm	50	100
Cs-1.5-W50-S100	160×250	1.56	960					
Cs-2-W50-S100	140×286	2.04	840					
Cs-1-W40-S100	200×200	1.00	1200	6 bars 12 dia.	$\phi 6$ mm @ 100 mm	4L $50 \times 50 \times 3$ mm	40	100
Cs-1-W50-S100	200×200	1.00	1200				50	
Cs-1-W60-S100	200×200	1.00	1200				60	
Cs-1-W50-S70	200×200	1.00	1200	6 bars 12 dia.	$\phi 6$ mm @ 100 mm	4L $50 \times 50 \times 3$ mm	50	70
Cs-1-W50-S100	200×200	1.00	1200					100
Cs-1-W50-S130	200×200	1.00	1200					130



a) Internal strengthening b) External strengthening

Fig. 1. Configuration of the tested columns

2.2. Preparation of test Specimens and test procedure

The specimens were placed in the testing machine between the jack head and the steel frame. The strain gages and linear voltage displacement transducer (LVDT) were placed as shown in Fig. 2. All specimens were tested under centric loads monotonically applied using a compression testing machine of 5000 kN capacity with load-controlled rate of 140 kN/min till failure load. Two steel heads were used to confine the column heads to avoid concentration stress at specimen's ends causing premature failure. In strengthened specimens Prepared the concrete surface using a light hammer and blower to remove the

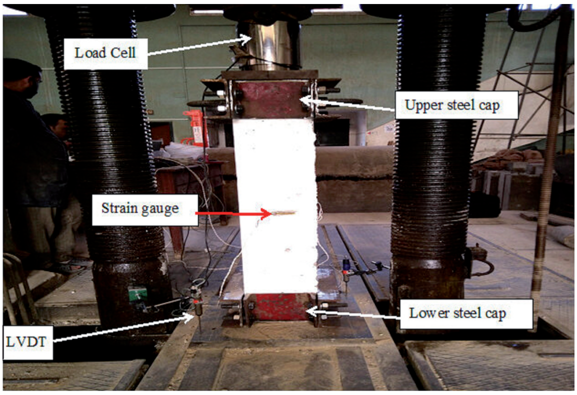


Fig. 2. Details of test setup

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. Then the steel angles are fitted and fixed with metal clamps. Then weld the batten plates with the steel angles.

3. Results and discussion

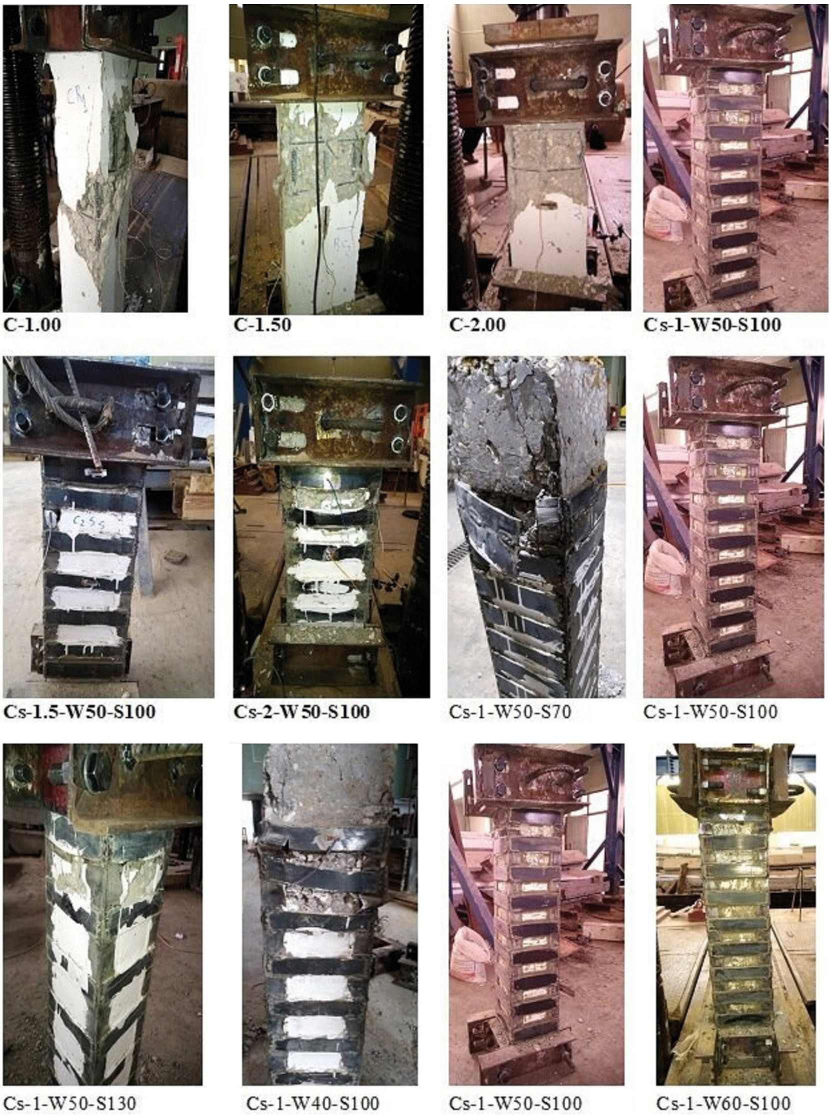
3.1. Compressive strength and Failure modes

Table 2 shows the maximum failure load for control and strengthened columns as well as the increase in column carrying capacity. It can be revealed that confinement with steel jacket increased the compressive strength. The smaller spacing between batten plates the greater the gain in the compressive with respect to the corresponding unconfined column. the increase volume of steel batten plates increased the column capacity. For the steel jacket the increase in aspect ratio resulted in a decrease in load capacity. The maximum increase was achieved in square columns, which showed a 49% increase against the control columns. Two failure modes were observed during the tests. These failure modes are presented as follows:

Table 2. Failure load of control and strengthened column specimens

Groups	Col.	Jacket			Failure load (kN)	Gained strength
		Vertical steel angles	Width of batten plate (mm)	Spacing of steel batten plates at centres (S) (mm)		
Control column	C-1.00	–	–	–	1238.75	–
	C-1.50	–	–	–	1188.75	–
	C-2.00	–	–	–	1085	–
1	Cs-1-W50-S100	4L 50 × 50 × 3 mm	50	100	1850	49.34%
	Cs-1.5-W50-S100				1565	31.65%
	Cs-2-W50-S100				1417.5	30.64%
2	Cs-1-W50-S70	4L 50 × 50 × 3 mm	50	70	2070	67.10%
	Cs-1-W50-S100			100	1850	49.34%
	Cs-1-W50-S130			130	1670	34.81%
3	Cs-1-W40-S100	4L 50 × 50 × 3 mm	40	100	1731.25	39.75%
	Cs-1-W50-S100		50		1850	49.34%
	Cs-1-W60-S100		60		1942.5	56.81%

The first mode was a brittle failure which was observed clearly for the unconfined columns (C-1, C-1.5 and C-2). behavior of reference columns was similar. As the load increases, 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 ultimate load of the column, the concrete cover spalled off and the longitudinal bars appeared to buckle between two stirrups. During failure of column C-1, the lock of one stirrup started to open outside the section during failure stage. When the load reached the maximum load, severe damage was observed and total collapse of specimens occurred Fig. 3.



C-1.00 C-1.50 C-2.00 Cs-1-W50-S100

Cs-1.5-W50-S100 Cs-2-W50-S100 Cs-1-W50-S70 Cs-1-W50-S100

Cs-1-W50-S130 Cs-1-W40-S100 Cs-1-W50-S100 Cs-1-W60-S100

Fig. 3. Failure mechanism of specimens

The second mode in the case of the strengthened columns, 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 mode is local buckling of one or more of the vertical angles followed by the buckling of the reinforcement steel bars and eventually a crushing of concrete section near these bars. In some specimens, it was noted that the weld between the horizontal batten plates and vertical angle was broken, because of the lateral expansion of concrete. most probably after the occurrence of buckling of the vertical angles as it is obvious from the buckling shape of the angles.

3.2. Stress- VL Strain response

The ultimate load of each column to that of the reference column of the same group is shown in Table 2. The typical relationship between the applied axial stress and the corresponding axial strain of tested specimen are shown in Figs. 4, 5, 6 and 7. The axial

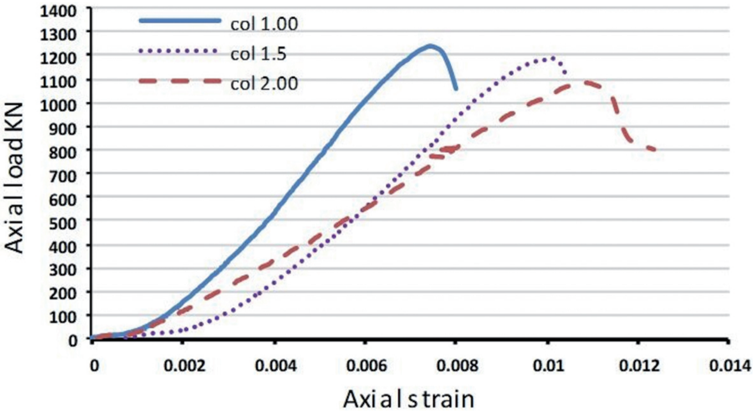


Fig. 4. Load-strain response for control column

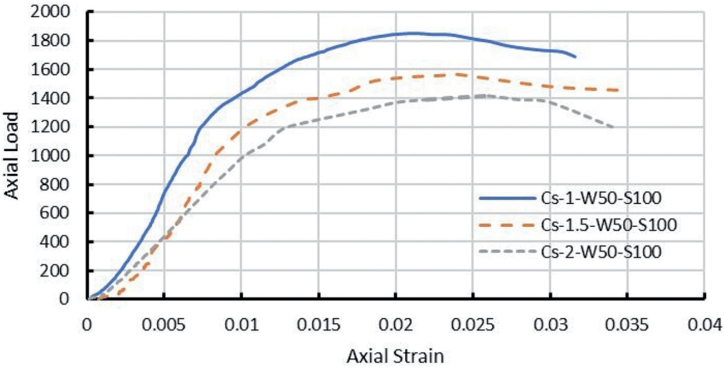


Fig. 5. Load-strain response for the strengthened specimens of group 1

vertical strains are calculated from the average readings of the two vertical LVDTs divided by the length of the specimens.

By analyzing Fig. 4 it is confirmed that the behavior of RC square control column was different than 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 may be attributed to the more uniform stress from transvers steel hoop than the case of; ($t/b = 1.00$). the initial stiffness decreased by increasing (t/b) but the influence was minor. For the ($t/b = 1.56$) and ($t/b = 2.04$) specimens the initial stiffness almost has the same slope because of the passive pressure by transverse steel was smaller. Fig. 5 verified that the stiffening action of steel jacket can enhanced the confined concrete strength. It is obvious from the figure that sufficiently confined square and rectangular columns confined with steel jacket can exhibit highly ductile compressive behavior. Additionally, the steel jacket is more effective in square section than rectangular. Also, as the aspect ratio increases the ultimate confined strength decreases. On the contrary the aspect ratio increases the ultimate strain increases. By analyzing the Figs. 6 and 7 in general, all the strengthened columns achieved higher maximum axial strain than those of the reference columns without steel jacket. This indicates more ductility when a steel jacket is added.as well as in the initial elastic zone, the confined and unconfined specimens behave in the same manner. the maximum axial strains increased with decreasing the batten plates spacing. When volume of steel batten plates increases the maximum axial strains increase.

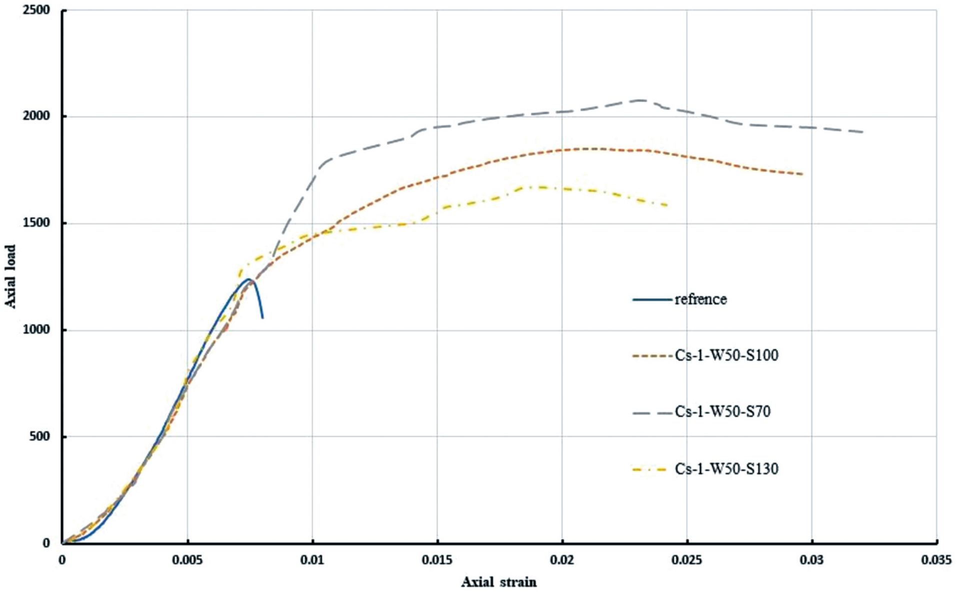


Fig. 6. Load-strain response for the strengthened specimens of group 2

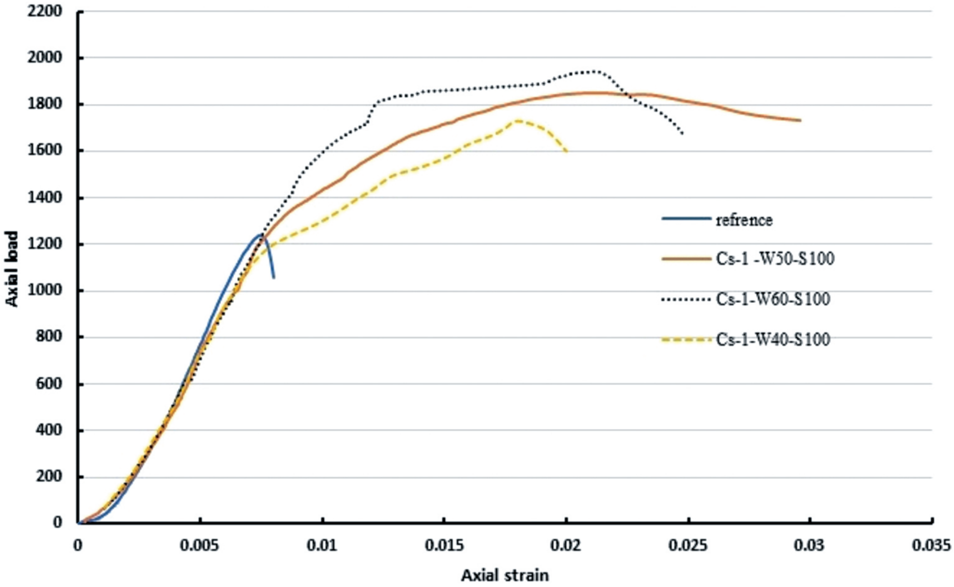


Fig. 7. Load-strain response for the strengthened specimens of group 3

3.3. Horizontal strip strains

The main role of the steel batten plates is to prevent the earlier buckling of the vertical angles and to reduce the horizontal expansion of the concrete section, which leads to confining the concrete section. Figs. 8, 9, 10, and 11 show the relationship between the applied axial load versus the strains of the horizontal batten plates. The circumferential strains were measured at top at long and short directions of specimens. By analyzing

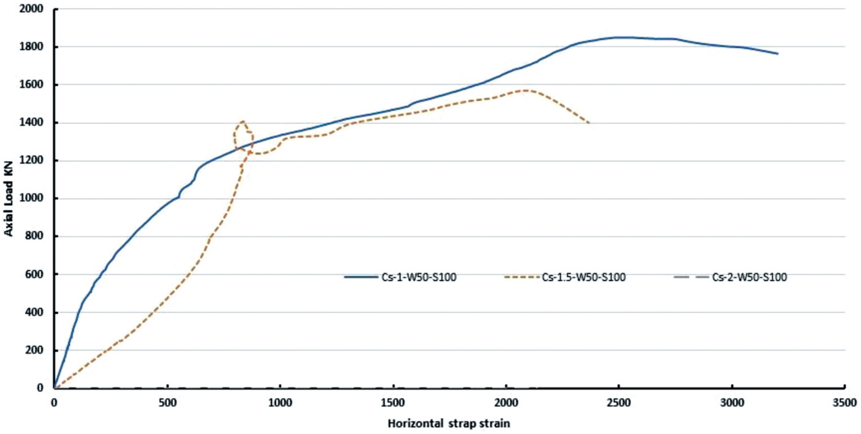


Fig. 8. Axial load versus axial strain of horizontal steel batten plate for the short side of Group 1

the Figs. 8 and 9 it is verified that the ultimate lateral strains values on the shorter side are greater those on the longer side. generally. For the same strengthening technique, the ultimate lateral strains on both longer and shorter sides decreases as the aspect ratio increases. By analyzing the Fig. 10 it is confirmed that the strain increases in batten plates

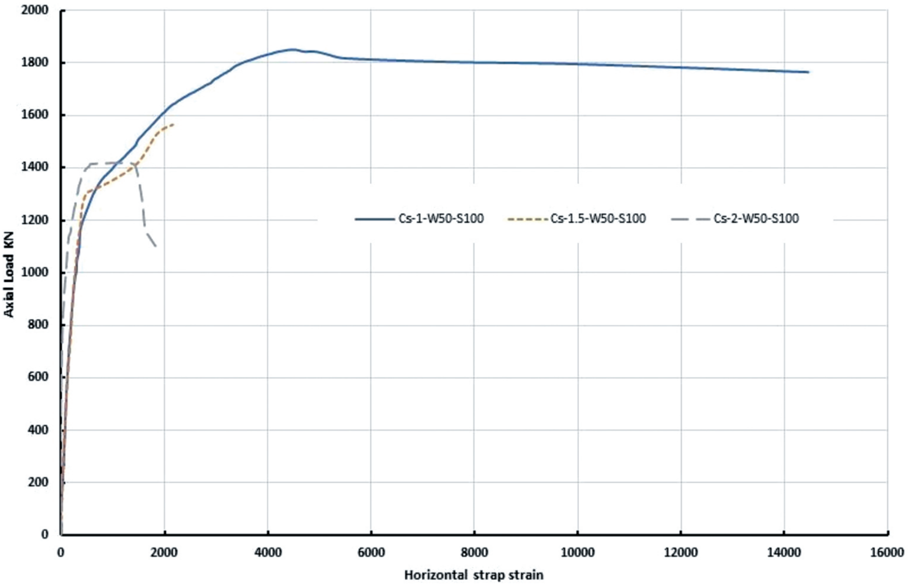


Fig. 9. Axial load versus axial strain of horizontal steel batten plate for long side of Group 1

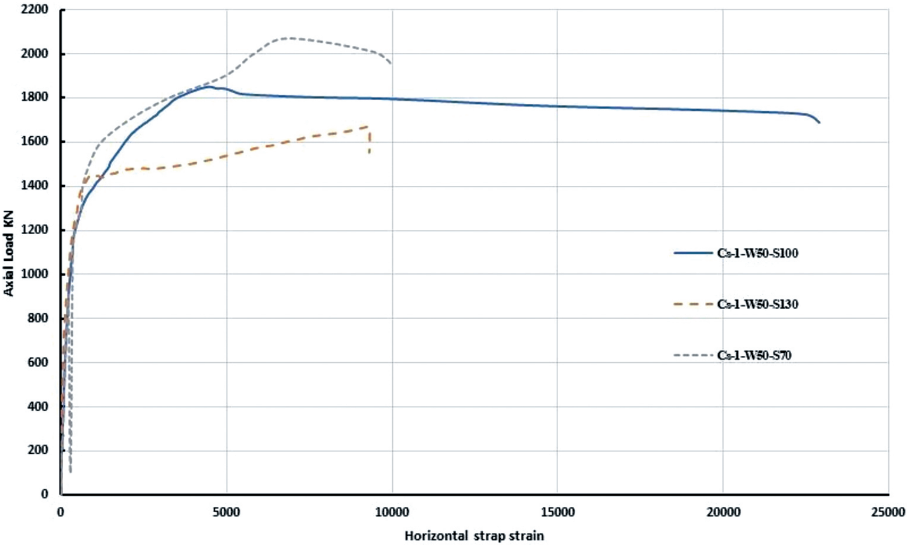


Fig. 10. Axial load versus axial strain of horizontal steel batten plate of Group 2

by decreasing space of steel batten plates at centers (S). this indicates that the confining effect is higher as space of steel batten plates decreases. It can be shown from Fig. 11 that the strain values increase in batten plates by increasing volume of steel batten plates.

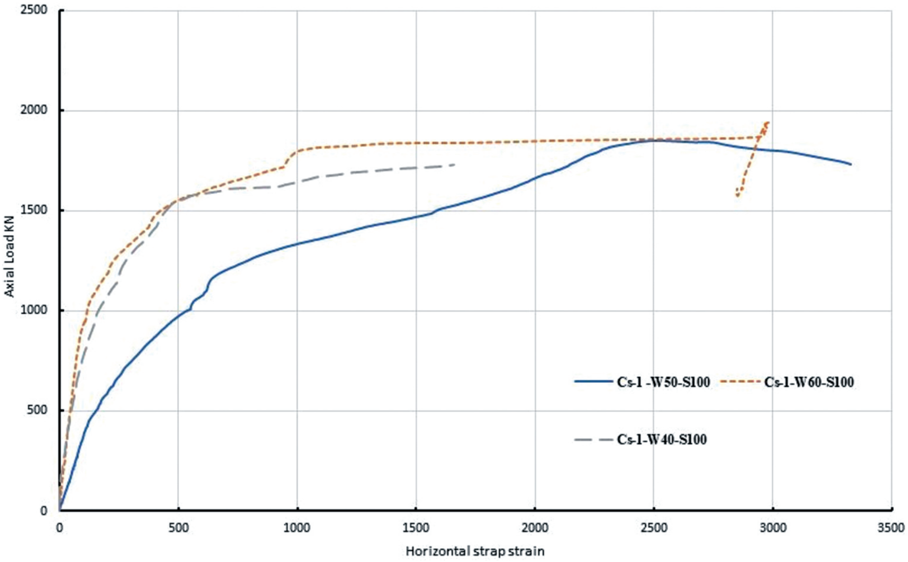


Fig. 11. Axial load versus axial strain of horizontal steel batten plates of Group 3

3.4. Rectangularity of the cross section

All strengthened specimens showed improved in load carrying capacity compared to the control specimens. There is a significant improvement in compressive strength of the confined columns with steel jacket whereas the ratio of improvement reaches 1.49 for square columns while the specimens with aspect ratio of 1.54, 2.04 the ratio of improvement reaches 1.31, 1.30. This means that the steel jacket is more effective in square sections than in rectangular sections. It can be concluded that by increases the aspect ratio t/b, the ultimate strength confined columns decrease.

3.5. Effect of spacing of horizontal steel batten plates at centres

When spacing between horizontal steel batten plates is relatively major the ultimate axial load as well as the maximum axial shortenings were less than those corresponding to columns having smaller spacing between batten plates. It can be observed that the increased spacing between horizontal batten plate, quickened the action of buckling of the vertical angles and this led to the relatively quick failure of these columns. It was found that for column strengthened by 4 steel angles connected with batten plates 50 × 3 mm at spacing 70mm the maximum failure load increased from 1238.75 kN for control column to a maximum value of 2070 kN which represent 67.10% increase compared to reference specimen. while the load increased from 1238.75 kN for control column to 1670 kN for column strengthened by batten plates 50 × 3 mm at spacing 130 mm which was 34.81% increase compared to the reference specimen.

3.6. Effect of volume of steel batten plates

The parameter of volume of steel batten plates has a significant effect on the ultimate axial load of the strengthened concrete column. For the columns strengthened with steel jacket Increasing Volume of steel batten plates makes more confinement of concrete. Also, the yielding of the batten plate occurred at higher load values. This leads to a delay of the concrete splitting out, As a result, the bearing capacity of the strengthened concrete column is increased. It was found that for column strengthened by 4 steel angles connected with batten plates at spacing 100 mm, the failure load increased from 1238.75 kN for control column to 1942.5 kN for column strengthened by batten plates 60 × 3 mm which represent 56.81% increase compared to reference specimen. While the failure load increased from 1238.75 kN for control column to 1731.25 kN for column strengthened by batten plates 40 × 3 mm, this is a 39.75% increase compared to the reference specimen.

4. Conclusions

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

1. Using steel jacket for strengthening reinforced concrete columns is an effective technique.
2. The failure mode of the control reinforced concrete column was brittle while strengthening with steel jacket changed failure mode to be more ductile.
3. The effect of batten plates spacing for column strengthened by corner angle 50 × 50 × 3 mm with batten plate 50 × 3 mm at intervals 70, 100 and 130 mm increase the columns ultimate load by 67.10%, 49.34% and 34.81% respectively.
4. The effect of volume of steel batten plates for column strengthened by corner angle 50 × 50 × 3 mm with the spacing of horizontal steel batten plates at centres 100 mm at different width 40, 50 and 60 mm increase the columns ultimate load by 39.75%, 49.34% and 56.81% respectively.
5. for the same strengthening technique, the increase in aspect ratio resulted in a decrease in load capacity. The maximum increase in compressive strength were achieved in the square RC columns which reached 1.49 for steel jacket confined columns.
6. Rectangularity, spacing of horizontal steel batten plates and volume of steel batten plates parameters are considered very important parameters which significantly affect the strength, the ductility, and the failure mode of the strengthened column.

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2022-10-09, Revised: 2023-02-21