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STRENGTHENING AND REHABILITATION OF REINFORCEMENT CONCRETE SQUARE COLUMNS CONFINED WITH EXTERNAL STEEL COLLARS

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ABSTRACT

Strengthening and rehabilitation by confinement technique of reinforced concrete columns was investigated. The columns were confined by external steel collars. Behavior and failure load of columns were experimentally investigated. Results show that Confinement in concrete column has improved its strength and ductility. Effect of confined area, size of collar and compressive strength of concrete on strengthening was investigated .Confined area had significant effect on the failure load for strengthened specimens and had more effective on the failure load for repaired specimens. The confinment had clearer effect with low compressive strength of concrete. The result show an increase in ultimate axial load reach to (12.36 – 56.04%) for strengthening columns and (47.5 –96.7%) for reaparing columns.

KEYWORDS: Columns, Confinement, Steel collars, Strengthening, Repairing.

تقوية وترميم الاعمدة الخرسانية المسلحة المربعة بأستخدام الاطواق الحديدية الخارجية

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الخلاصة

في البحث الحالي تم دراسة تقوية وترميم الاعمدة الخرسانية المسلحة مربعة المقطع بأستخدام تقنية الحصر(التطويق)حيث تم حصر الاعمدة خارجيا بأستخدام الاطواق الحديدية. تم دراسة سلوك وحمل الفشل للاعمدة عمليا. الدراسة تناولت تاثير مساحة التطويق , حجم الاطواق , و مقاومة انظغاط خرسانة العمود . بينت النتائج ان تقنية الحصر ادت الى تحسين مقاومة ومطيلية الاعمدة. مساحة التطويق ادت الى تطور في حمل الفشل في حالة تقوية او ترميم الاعمدة. كما بينت النتائج ان تأثير التطويق على تقوية العمود يكون اكثر وضوحا عندما تكون مقاومة انضغاط العمود قليلة. بينت النتائج حدوث زيادة بالتحمل يصل الى (% 56.04 – 12.36) في حالة تقوية الاعمدة و (%96.7– 47.5) عند ترميم الاعمدة.

الكلمات المفتاحية : الاعمدة، التطويق، الاطواق الحديدية، التقوية، الترميم.

1. INTRODUCTION

The need to strength a structure is caused by problems due to wrong design, the degradation of the characteristics of the materials along the time and the amplification of the load capacity caused by a new utilization of the building. Other cause is the publication of new design codes that increases the actions, such as the seismic action (Gomes and Appleton 2002). So there has been an imperative need of improvement in columns in order to ensure safty and durability.
Engineers have used different methods and techniques to consolidation existing structures by providing external confining stresses (Al-Salloum 2007). Confinement of concrete is an efficient technique used to increase the load carrying capacity and ductility of a column because the transverse confining stress. When concrete is subjected to laterally confining pressure, the compressive strength f'_{cc} and the corresponding strain ε_{cc} are much higher than those of unconfined concrete f'_{co} and ε_{co} as shown in Fig. 1 (Mander et al. 1988). In which, f'_t , f'_{co} , f'_{cc} , ε_t , ε_{co}, ε_{cc}, ε_{cu} , ε_{sp} ,E_c , and E_{sec} are the tensile strength of concrete, the compressive strength of unconfined concrete, the compressive strength of confined concrete, the tensile rupture strain of concrete, the concrete strains corresponding to peak strength of unconfined concrete, the concrete strains corresponding to peak strength of confined concrete, the ultimate compressive strain of confined concrete, the strain at which the concrete cover is considered completely spalled, the modulus of elasticity of concrete, and the secant modulus of confined concrete at peak stress, respectively.

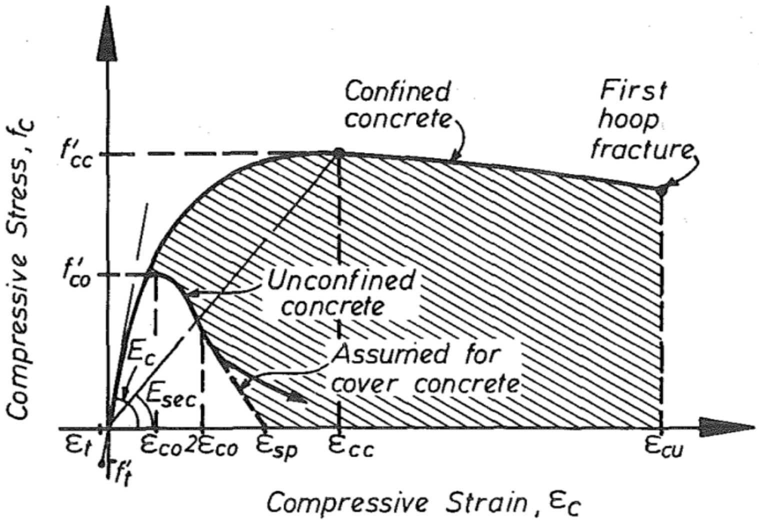


Fig. 1. Typical Improved Stress-strain Curve of Confined Concrete (Mander et al.1988)

Several researchers have investigated strengthening of reinforced concrete columns using steel jacket as Priestley et al. 1994, Xiao et al. 2003 and Julio et al. 2003, Experimental investigations showed that strength and ductility was greatly improved by strengthening using steel jacket technique. This technique has been proven successfully in retrofitting columns.
Hussain and driver (2003, 2005) and Chapman and driver 2006 studied the behavior of collared reinforced concrete columns under axial load or combined lateral and axial loads with different end condition, collared columns did not have internal reinforcement ties in the test region, collared columns had improved performance compared to conventionally reinforced columns. The use of steel collars is investigated rehabilitation and strengthening for short reinforced concrete columns subjected to combined axial and cyclic lateral loading by Liu et al. 2008. No internal transverse reinforcement was provided in the test regions of columns. The experimental results show excellent improvements in ductility, strength, and energy dissipation capacity of the columns due to the presence of the collars.

Wei and Wu 2014 investigated the effect of high strength wire confined concrete columns, The studies have proven that it is an effective and efficient method of column jacketing that can significantly increase column strength and ductility. Andrews and Sharma 1988, Singh 1996, and Malhotra 2013, have investigated on ferrocement as a strengthening material for columns and indicated that ferrocement jacket can be an effective alternative material to strengthen reinforced concrete column. Pantazopoulou et al. 2009 proved in their investigation the explored the performance and efficiency of jacketing with FRP wraps as an alternative to conventional repair methods for corrosion-damaged reinforced concrete columns.
In this study, confinement technique using external steel collars for strengthening and repairing of conventionally reinforced concrete columns was investigated.

2. EXPERIMENTAL WORK

A total of thirteen reinforced concrete columns were constructed. All columns had same internal steel reinforcement. The cross sections of columns were 150 mm×150 mm and had a height of 1200 mm, as depicted in Fig. 2. These columns were divided into two groups, first group was strengthening columns by external steel collars, and second group was repairing damaged columns by external steel collars. All columns were cured for 28 days under field conditions and tested vertically under concentric axial loading by a hydraulic jack.

3. MATERIALS USED

3.1. Concrete

Ordinary Portland cement type I was used and it confirmed the Iraqi standard specifications No.5/1984. Crushed limestone with a maximum size of 20 mm and specific gravity of 2.60 was used as a coarse aggregate and it complying with IQS NO. 45 / 1984. The used fine aggregate was natural river sand, zone 2 according to IQS: 45 1984 with 2.71 fineness modulus.
Three volumetric mixing ratio of (1:2:4), (1:1.5:3), and (1:1.25:2.5) (cement: sand: gravel) were used, with water/cement ratio (w/c) = 0.5. The concrete cylinder strength f'_c and modulus of rupture f_r from the concrete mix are given in Table 1.

Table 1. Test results of concrete cylinders (at 28 days)

Mixing ratio	$f\acute{c}$, MPa	fr, MPa
1:2:4	22.2	2.89
1:1.5:3	26.5	3.15
1:1.25:2.5	29.4	3.30

3.2. Internal steel reinforcement detail

All columns had 4 deformed bars of size Ø10 mm as longitudinal reinforcement, and tie bars (Ø 10 mm) spaced at 150 mm as shown in Fig. 2. Sample of bar was tested by tensile testing machein (as shown in Fig. 4) to product some properties of the bar, results of test were listed in Table 2.

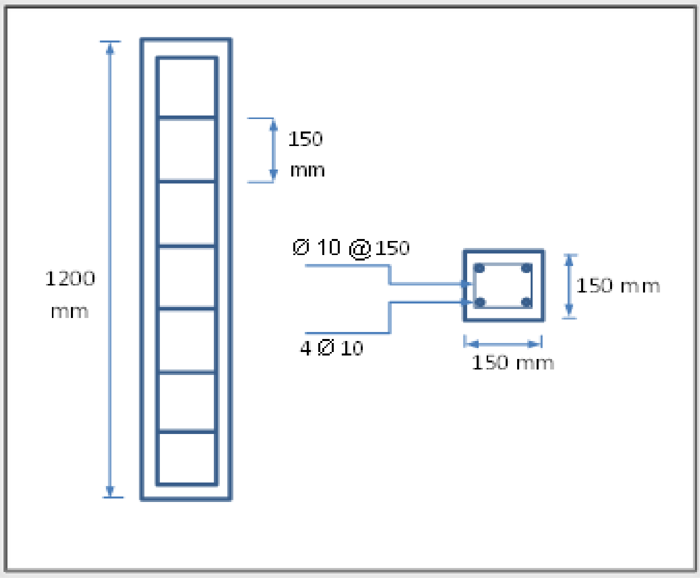


Fig. 2 Geometrical and reinforcement details of columns

3.3. External steel collars details

An external steel angle (L33×33×2) mm, (L40×40×3) mm, and (L40×40×4) mm was selected to made collars, the interior cross section of collars was 150×150 mm (as the same dimensions of column). Sample of each type of steel angle was tested by tensile testing machein (as shown in Fig. 4), results of test was listed in Table 2. All the collars had welded in two corner configuration and bolted in the other corners connection to provide an assessment of limits of fixity, as shown in Fig. 3. The use of two different connections in collars was to make it easier in used in the laboratory work.

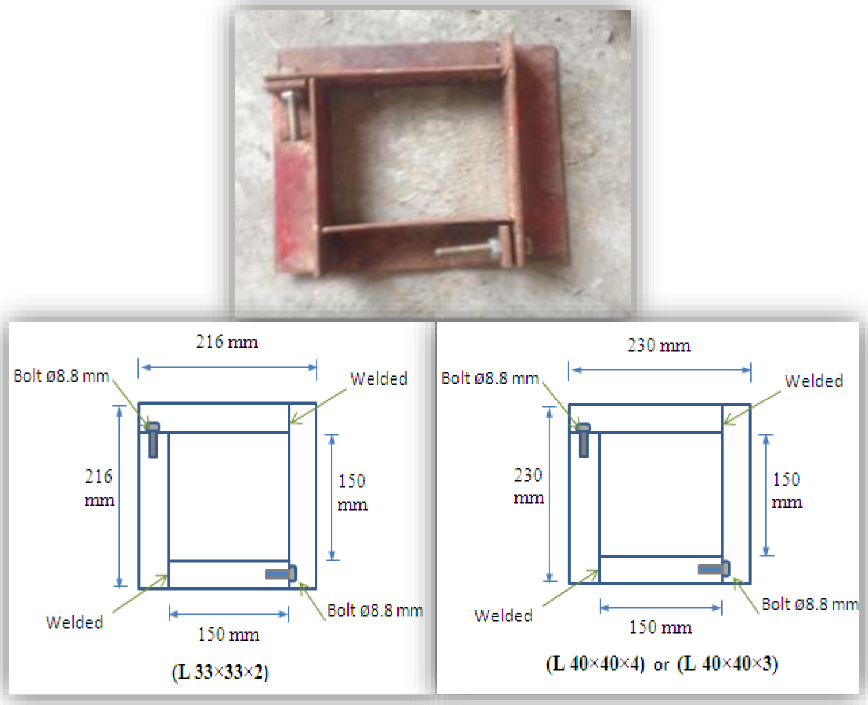


Fig. 3. Typical steel collar

Table 2. Test results of steel (MPa)

Material type	f_y	f_u
Ø 10	437	690
L33×33×2	440	663
L40×40×3	435	674
L40×40×4	422	636

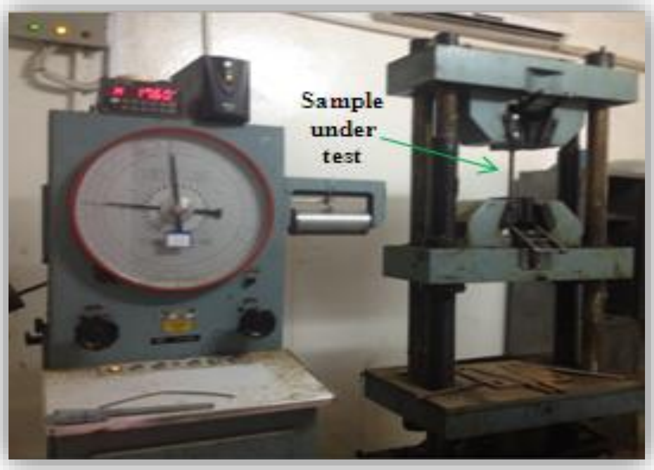


Fig. 4. Tensile testing machine

4. TESTING PROCEDURE

All thirteen reinforced columns were tested for concentric axial loads in a universal testing machine with a compressive capacity of (200) ton. The load was applied through a bearing plate in small increments until failure occurs. For each increment, the load was kept constant until the required measurements were recorded. The axial deformation of the columns was recorded using dial-gage placed vertically at the top face of column while the lateral deflection was measured using dial-gages plased horizontally at the mid height of column in each side.

There are two important steps that must be controlled before testing to achieve full contact between the collar and column surfaces. First, the angles of collar corner must match the angle of column corner. Second, the inside face of collar should be vertical as column face. In cases where gaps between collar and column occur, shimming by piece of thin plate was used to ensure the good confinement.

4.1. Strengthening Group

A group of eleven columns was used to study the effect of strengthening with external steel collars. Three of columns (C, C_e, and C_f) were tested without strengthening and used as refrences columns for comparison to evaluate the performance benefits achieved using external steel collars. The other columns were strengthened before tested with external steel collars then it's tested up to failure.

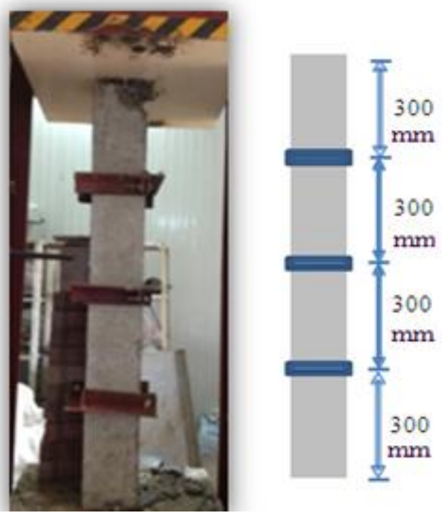
The strengthening study involved the following points:

1. To study the effect of quantity of confined area on strengthening and ductility of column, three of columns (C3, C5, and C7) were strengthening before tested by three,

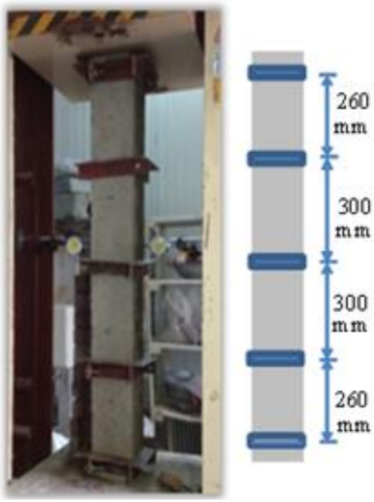
five, and seven same external steel collars respectively as indicted in Table 3 and Fig. 5, and have a comparison with non-collar column C. These columns have cylinder compressive strength 26.5 MPa.

2. To study the effect of size of collar, three of columns ($C3_a$, $C3_b$, and $C3_c$) were strengthening with three different sizes of collars as indicted in Table 3 and Fig. 5, and have comparison with non-collar column C. These columns have cylinder compressive strength 26.5 MPa.
3. To study the effect of collar with different compressive strength of column, three of columns ($C3_e$, C3, and $C3_f$) with compressive strength (22.2, 26.5, and 29.4) MPa respectively, were strengthening before tested by same external steel collars as indicted in Table 3 and Fig. 5. Three non-collar columns (C_e, C, and C_f) with compressive strength (22.2, 26.5, and 29.4) MPa respectively, were used as references columns for comparison.

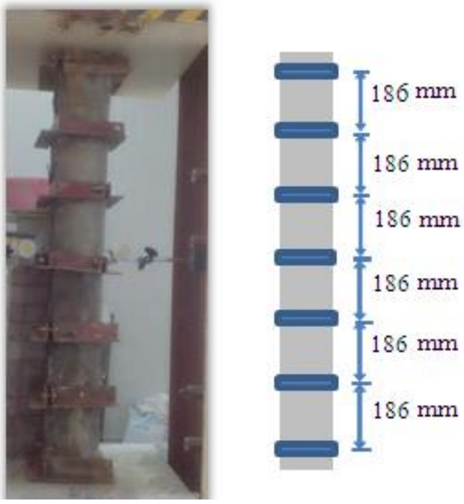
Column C



Column C_3



Column C5



Column C7

Fig. 5. Reinforced concrete columns in strengthening group and arrangement of collars on columns

Column C3c **Column C3b** **Column C3a**

Column Ce **Column Cf** **Column C3e** **Column C3f**

Fig. 5. continued

4.2. Repairing Group

To investigate the feasibility of repairing damaged column using external steel collars, three control columns (C,CA,CB) were tested up to failure without strengthening, these columns were retested to failure after repaired by three, five, and seven external steel collars respectively, as shown in Fig. 6, where all collars used are same size and properties.

The repair process involved the following steps:

1- Removing loose concrete

2-Placing repair mortar

3- Preparing the column surface

4- Installing external collars

5- Retesting repaired columns

The repair mortar was used to replace the removed damaged concrete made from cement and sand with proportion (1 cement: 3 sand) and water/cement ratio equal to 0.4. The mortar was allowed to set approximately seven day on column before the retest. The compressive strength of mortar was monitored by casting six (5*5*5 cm) cubes and measured at seven days after casting, where the aveage result of tests is 15.5 MPa.

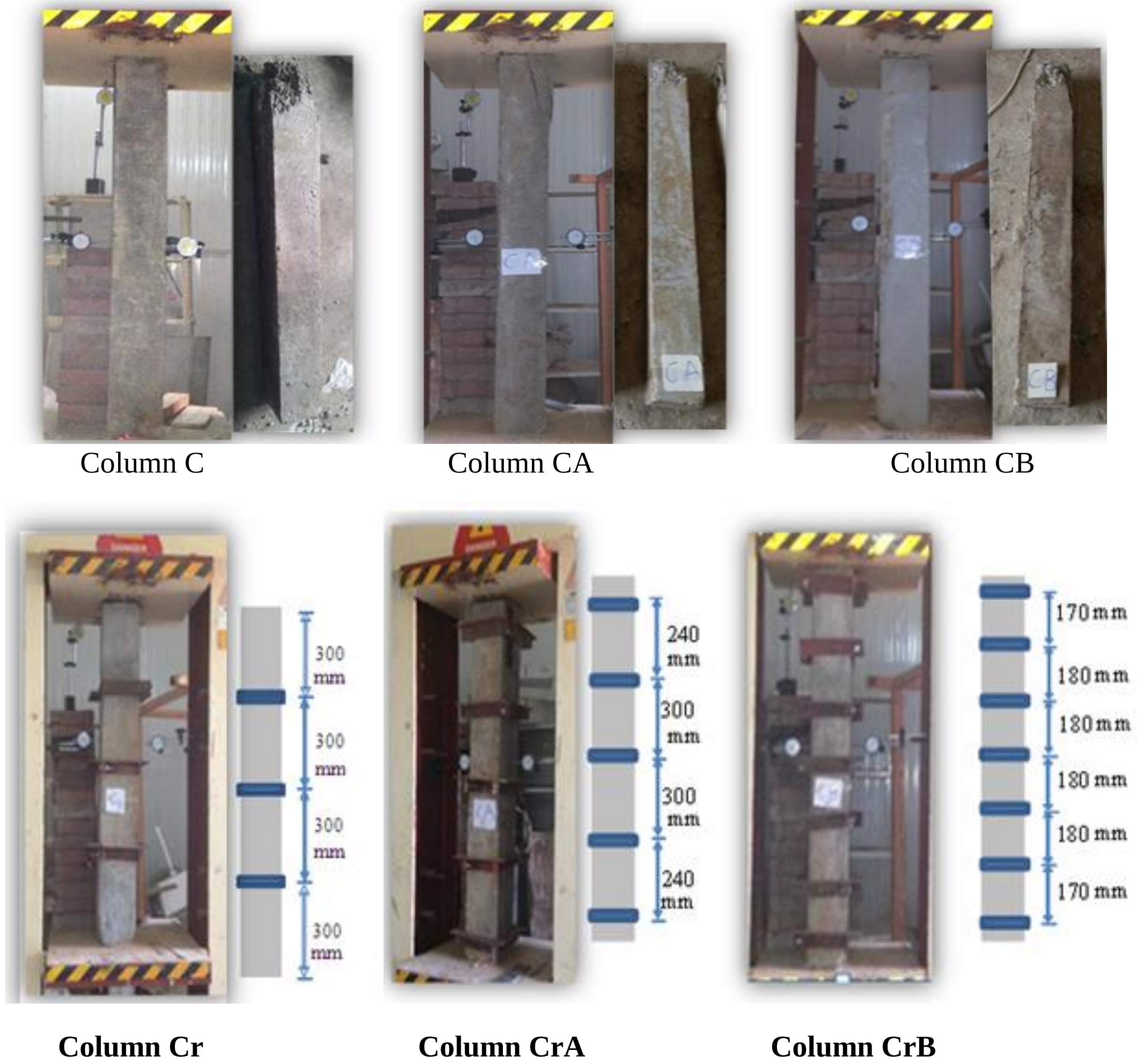


Fig. 6. Reinforced concrete columns in repairing group with collers arrangement

5. RESULTS AND DISCUSSION

The results obtained from the tests carried out on columns are discussed in the subsequent sections.

5.1. Strengthening group

1- The experimental results clearly exhibit that strengthening by confinement with external steel collars techniques enhances the structural performance of reinforced concrete columns under axial loading. Duo to confinement, significant increases in axial strength were achieved in all strengthening columns compared with non-collared columns, but results varied widely with varying number of collars in each columns, where the columns (C3, C5, and C7) have increase in ultimate axial load by (12.36%, 28.29%, and 56.04%) respectively from control non-collar column C because the increasing of area confined on column as shown in Figs. 7–9 and Table 3.

2- Duo to confinement, considerable decrease in lateral deformation of strengthening columns (C3,C5, and C7) by (11.5%, 33.6%, and 82.5%) respectively from control column C, while the total axial deformation increase by amount (18.3%, 28.2%, and 60%) for columns (C3,C5, and C7) respectively from control non-collar column C as shown in Figs. 7 and 8.
3- The columns ($C3_a$, $C3_b$, and $C3_c$) have increase in ultimate axial load by (12.60%, 15.93 %, and 18.68%) respectively from control non-collar column C because the increasing of stiffness of collar as shown in Fig. 10 and 11 and Table 3.
4- From Fig. 12 noted that for the same confined area and stiffnes of collar, the axial strength increase as collar far away from mid high of column.
5- Noted from Figs. 13–15 and Table 3 that effect of confinement on axial strength of column was increase as compressive strength of column decrease, where the columns (C3f, C3, and C3e) with compressive strength (29.4, 26.5, and 22.2) MPa respectively, have increase in ultimate axial load by (7.2%, 12.36%, and 13%) respectively from there control column (Cf, C, and Ce) respectively.
6- During the experimental program was noticed that in all tested columns the failure occurred due to crushing concrete at the ends of column and no failure occurred in bolted or welded collar connections.

Table 3. Test results of columns strengthening with collars

Ref. non-collar column symbol	**Column symbol**	**Steel angle dimension (mm) $b_c \times h_c \times t$**	**f_c' (MPa)**	**No. of collar in column**	**ρ_{collar} ***	**ultimate axial load for Ref. columns (P) kN**	**ultimate axial load for strengthening olumns (P_S) kN**	**Increasing rate in axial strength for strengthening columns $\frac{P_S-P}{P}$ %**
C	C	-	26.5	0	0	364	-	-
	C3	40×40×4	26.5	3	0.100	-	409	+ 12.36
	C5	40×40×4	26.5	5	0.166	-	467	+ 28.29
	C7	40×40×4	26.5	7	0.233	-	568	+ 56.04
C	C3a	33×33×2	26.5	3	0.0825	-	410	+ 12.60
	C3b	40×40×3	26.5	3	0.100	-	422	+ 15.93
	C3c	40×40×4	26.5	3	0.100	-	432	+ 18.68
Ce	Ce	-	22.2	0	0	321		-
	C3e	40×40×4	22.2	3	0.100	-	363	+ 13.0
Cf	Cf	-	29.4	0	0	402		-
	C3f	40×40×4	29.4	3	0.100	-	431	+7.20

$$* \ \rho_{collars} = \frac{\mathbf{At}_{confined}}{\mathbf{Ac}_{side}}$$

$At_{confined}$ = Total side area of collars that confined column directly ($\sum hc \times bcolumn$)

Ac_{side} = side area of column ($h_{column} \times b_{column}$) = 1200 × 150

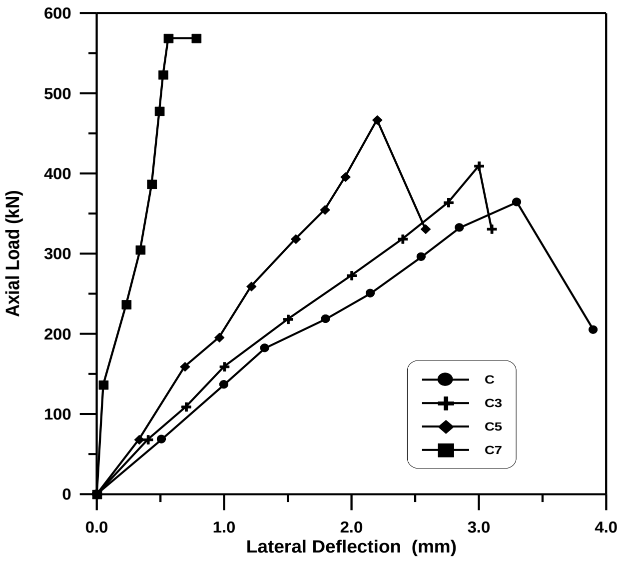


Fig. 7. Load – Lateral deflection curve for columns C, C3,C5,and C7

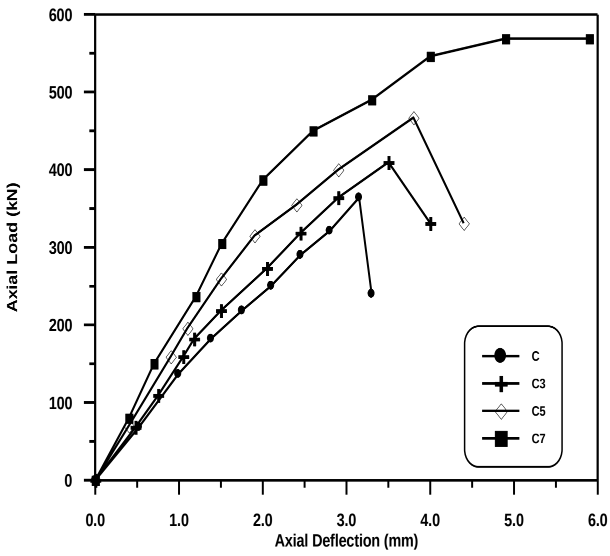


Fig. 8. Load – Axial deflection curve for columns C, C3,C5,and C7

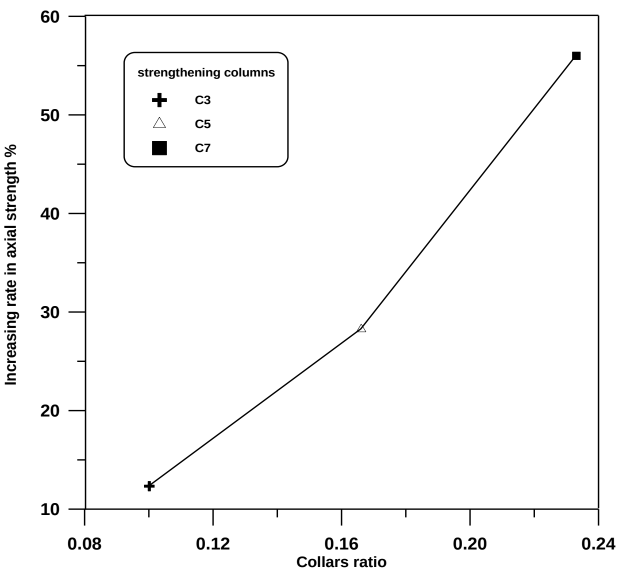


Fig. 9. Relation between collars ratio (ρ_{collar}) and Increasing rate in axial strength

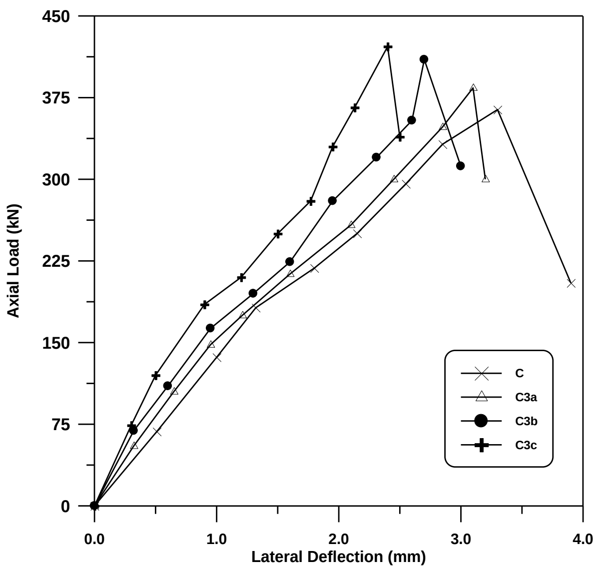


Fig. 10. Load – Lateral deflection curve for columns C, C3a,C3b,and C3c

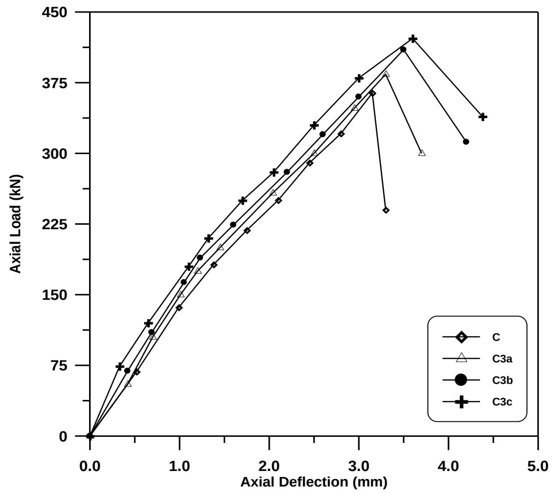


Fig. 11 Load – Axial deflection curve for columns C, C3a,C3b,and C3c

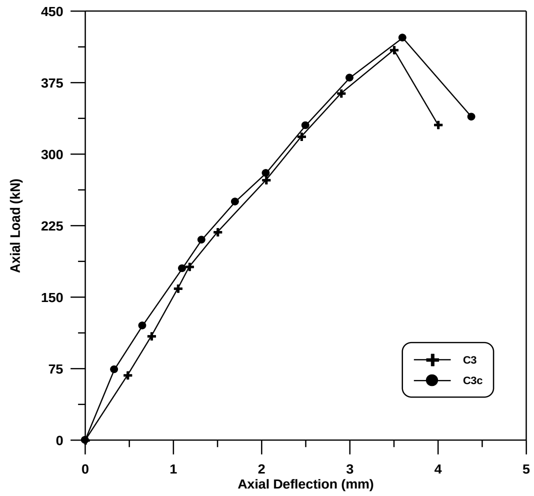


Fig. 12. Load – Axial deflection curve for columns C3,and C3c

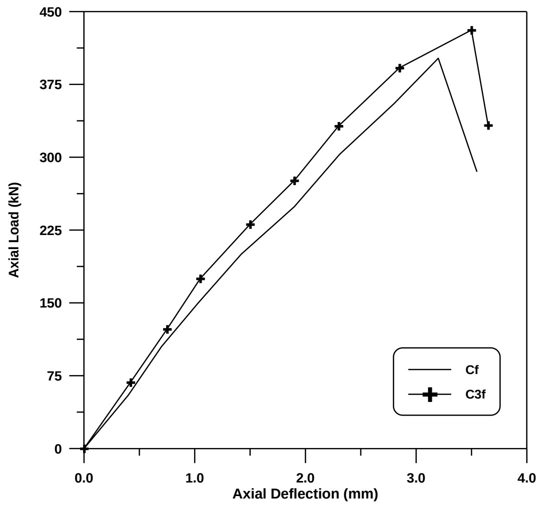


Fig. 13. Load – Axial deflection curve for columns Cf and C3f

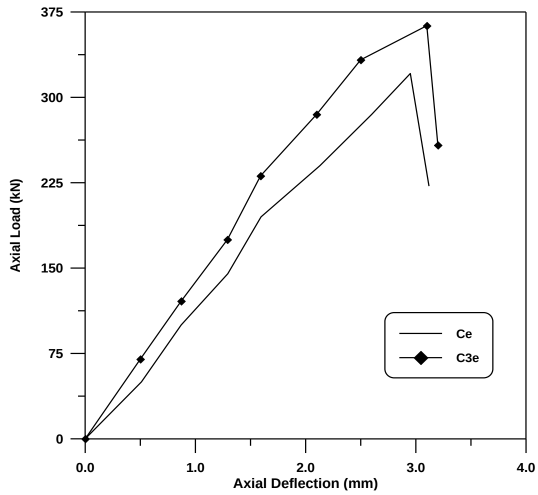


Fig. 14. Load – Axial deflection curve for columns Ce and C3e

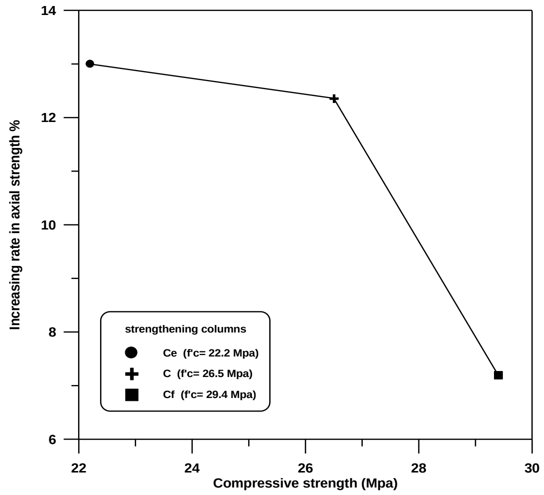


Fig. 15. Relation between compressive strength and Increasing rate in axial strength

5.1 Repairing group

1. Noted from comparison between non-collared Columns (C,CA,CB) that is good convergence in behavior and failure mode (crushing in concrete) due to no difference in material properties of the concrete and reinforcing steel used, and the test condition as shown in Fig. 16 and 17.
2. External confinement by collars has good potential for rehabilitation damage reinforced concrete column in axial strength. The repair columns (Cr, CrA, and CrB) have increase in ultimate load by (47.5%, 62.0%, and 96.7%) of ultimate load before repairing columns by (3, 5, and 7) collars respectively as shown in Fig. 18 and 19 and Table 4.
3. During the experimental program was noticed that in all tested columns the failure occurred due to crushing at the ends and no failure occurred in collars.

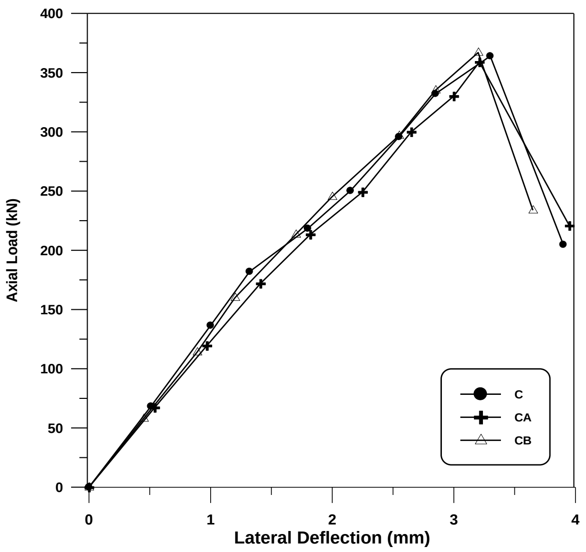


Fig. 16. Load – Lateral deflection curve for columns C, CA, and CB

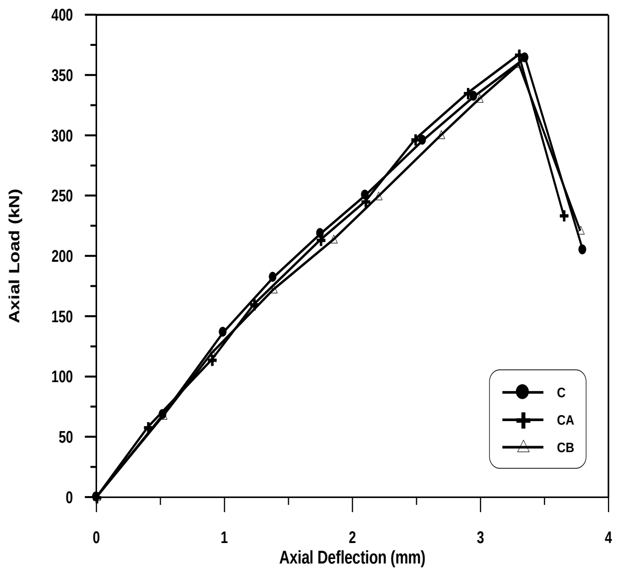


Fig. 17. Load – Axial deflection curve for columns C, CA, and CB

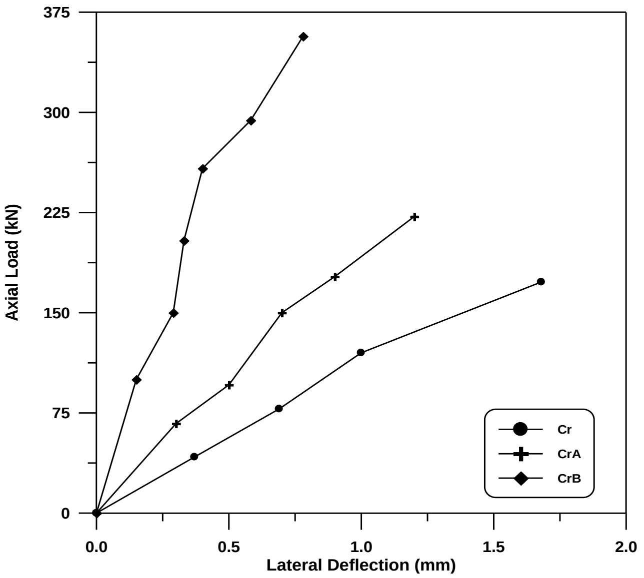


Fig. 18. Load – Lateral deflection curve for repairing columns Cr, CrA, and CrB

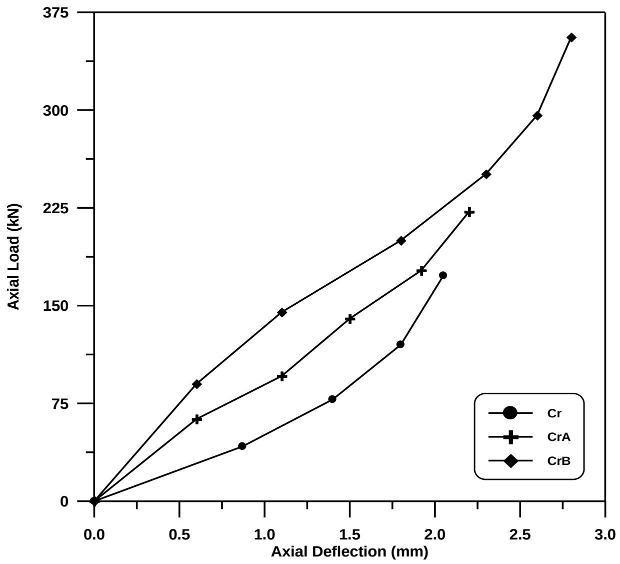


Fig. 19. Load – Axial deflection curve for repairing columns Cr, CrA, and CrB

Table 4. Test results of repairing columns with collars

Column symbol	Ultimate Axial load (P) kN	f_c' (MPa)	Column symbol after repairing	Steel angle dimension (mm) $b_c \times h_c \times t$	No. of collar in repairing column	ρ_{collar}	Ultimate Axial load after repairing (P_R) kN	Inceasing rate in axial load after repairing $\frac{P_R}{P}$ %
C	364	26.5	Cr	40×40×4	3	0.100	173	+ 47.5
CA	358	26.5	CrA	40×40×4	5	0.166	222	+ 62.0
CB	367	26.5	CrB	40×40×4	7	0.233	355	+ 96.7

6. CONCLUSIONS

From above observations and discussions, some points can be concluded.

1- The confinement with external steel collars techniques in reinforced concrete columns can improve strength and ductility of strengthening and repairing columns and enhancing concrete capacity duo to increases the lateral pressure on the member.
2- The increase confied area of collars made the efficiency of confinement increases, where the increasing in ultimate load reach to (12.36 – 56.04%).
3- Confinement with external steel collars increaseing the axial deflection by about (18.3 – 60%) of reference column, and decrease the lateral deflection of reinforced concrete column by about (11.5 – 82.5%) of reference column.
4- The increasing thickness of collars caused increasing in columns capacity by about (12.60 – 18.68%).
5- The effect of confinement is clearer in column with low compressive strength.
6- The confinement techniques provide increaseing in ultimate axial load reach to (47.5 – 96.7%) for repairing column.

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