

Strengthening of Loaded Reinforced Concrete Columns Using Ferrocement Jackets

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ABSTRACT: Columns are very important structural elements. They must be safe to carry the applied loads. Sometimes, reinforced concrete (RC) columns suffer from deterioration and consequently need strengthening. The famous method of strengthening is applying jackets from reinforced concrete, steel, or fiber reinforced polymer composites. Extensive research have studied the strengthening of columns with full load release contrary to the practical cases. In this paper, fourteen RC columns were tested under concentric load to investigate the possibility of strengthening partially loaded RC columns using ferrocement jacket as a new method. The variables considered in this study are the slenderness ratio of column, the pre-loading level of the original column, and the orientation of ferrocement mesh. Initial cracking load, ultimate capacity, and mode of failure were recorded and discussed for different models. It was observed that the ferrocement jacket increases the load capacity and ductility of the columns depending on the parameters.

KEYWORDS: Column, Strengthening, Ferrocement, Concentric loading.

I. INTRODUCTION

Strength and ductility are two important factors to be considered in the design of reinforced concrete (RC) columns, where they may be subjected to large deformation. In the case of RC columns, the behavior depends largely on the amount of the confinement provided to the concrete core or the original column at the repair or strengthening case. Strengthening using RC jackets around the defective columns are the most widely used method. It improves the defective columns performance by increasing their confinement and bearing capacity [1 to 4]. As the designers look for increasing the ultimate capacity of columns by applying RC jackets, they must consider the effect of increasing the stiffness of columns before deciding the type of the applied jacket especially in case of seismic loading. Where, RC jackets increase the stiffness of the columns, which is dangerous at seismic period.

Ferrocement jackets can be safely used without a large change in the strengthened column stiffness. Also, ferrocement jackets are easy in application and have low cost compared to the RC jackets. In the last two decades, some attempts have been made to study the behavior of column reinforced or strengthened by ferrocement [5 to 19].

II. RELATED WORK

It is not practical to release all the loads on columns before or during the strengthening. Therefore, the objectives of this study are to investigate experimentally the behavior of the RC columns when they are strengthened by ferrocement jacket during loading state.

The primary variables considered in this study are:

1. Slenderness ratio of the column (short or long).
2. Orientation of the ferrocement meshes (17° or 73°).
3. Pre-loading level of the original column before strengthening.

III. EXPERIMENTAL PROGRAM

Test columns and preparation

To achieve the main purpose of this study, fourteen reinforced concrete (RC) columns were casted, strengthened and tested under concentric loading. The experimental program includes twelve strengthened RC columns in addition to two RC columns without strengthening as controls. The original RC columns have rectangular cross-section of 60×130 mm and RC slab of 230×160×60 mm thickness at the ends to overcome the excessive tensile stresses in the lateral direction. Seven columns have 600 mm clear height between the RC slabs to represent the short columns, while the others have 950 mm to represent long columns. The full details of the tested columns are given in Fig. 1. All original columns were provided with 6 Φ 6 mm as vertical steel reinforcement and Φ 2.5 mm / 50 mm as stirrups. In all tested columns, the characteristic concrete compressive strength (f_{cu}) was 26 MPa, while the yield stresses for vertical reinforcement and stirrups were 256 and 265 MPa, respectively.

The parameters of the study are:

- (1) Slenderness ratio of the column (short or long),
- (2) Orientation of the ferrocement meshes (17° or 73°), and
- (3) Pre-loading level of the original column before strengthening.

The tested columns were classified into seven groups in order to study the above mentioned parameters. The full description of the classified groups is given in Table 1. The first group (G1) includes two RC columns without jackets to study the effect of the slenderness ratio on the column load capacity and to represent as control columns for the columns in the second and third group (G2 and G3). Both the second and third group (G2 and G3) include two columns with ferrocement jackets to investigate the effectiveness of the strengthening jacket and were tested without pre-loading to serve as control columns to the pre-loaded columns in the next groups. The fourth and fifth groups (G4, and G5) represent short columns under different pre-loading level and have different ferrocement mesh orientation. The sixth and seventh groups (G6, and G7) represent long columns under different pre-loading level and have different ferrocement mesh orientation.

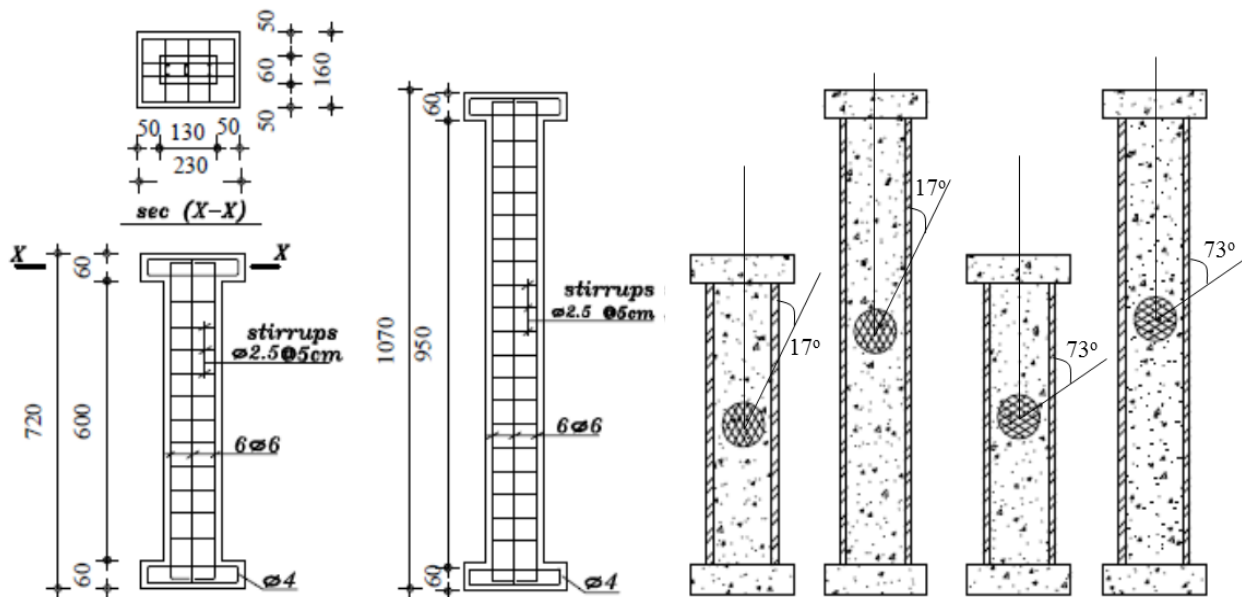


Fig. 1. Test columns details

International Journal of Innovative Research in Science, Engineering and Technology

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Table 1: Test program

Group	Column	Column type	Pre-loading level (kN)	Orientation (degrees)	Remarks
G1	C1	Short	--	--	--
	C2	Long	--	--	--
G2	C1	short	--	--	--
	C3	Short	--	17°	With jacket
	C4	Short	--	73°	With jacket
G3	C2	Long	--	--	--
	C5	Long	--	17°	With jacket
	C6	Long	--	73°	With jacket
G4	C3	Short	--	17°	With jacket
	C7	Short	80	17°	With jacket
	C8	Short	120	17°	With jacket
G5	C4	Short	--	73°	With jacket
	C9	Short	80	73°	With jacket
	C10	Short	120	73°	With jacket
G6	C5	Long	--	17°	With jacket
	C11	Long	70	17°	With jacket
	C12	Long	105	17°	With jacket
G7	C6	Long	--	73°	With jacket
	C13	Long	70	73°	With jacket
	C14	Long	105	73°	With jacket

Strengthening Procedure

After 28 days of casting, the columns C3 to C6 were wrapped with ferrocement jackets to obtain strengthened columns. All the jackets had the same thickness of 20 mm and height equal to the clear length between the two slabs. The jackets were made according to the following steps:

1. The side surface of original column was roughened with a chisel.
2. The corners were curved by sawing machine to a radius of 10mm.
3. The side surface of the column was carefully cleaned.
4. The ferrocement mesh, which had the properties given in Table 2, was cut to a dimension equal to the side surface area of the column with addition to 40 mm to represent the overlap.
5. The ferrocement mesh was wrapped around the column and fixed by steel bent nails on the side surface of the column between the two slabs. The mesh was put on the column to fulfill the orientation required (17° or 73°), as shown in Fig. 1.
6. The old concrete surface of the column was coated with thin layer of commercial epoxy resin to increase the bond between the old concrete and new matrix of ferrocement.
7. The ferrocement matrix, which had the properties given in Table 3, was hand-applied by trowel on the ferrocement mesh to thickness of 20 mm all around the column.
8. The columns were cured under wet burlap for 28 days.

After 28 days of casting, the columns C7 to C14 were loaded to the pre-loading level according to the test program. The pre-loading level represents about 50 % and 75 % of the maximum load of the control columns according to the column type (short or long). The pre-loading was applied by compression machine and four threaded rods were used to maintain the load constant as shown in Fig.2. Then, the columns were kept out the machine. After the pre-loading process had been finished, the ferrocement jackets were made on the columns with the same steps described before. The column heads for all columns were leveled using commercially available free flowing and non-shrink cement mortar.

International Journal of Innovative Research in Science, Engineering and Technology

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Ferrocement Mesh

Ferrocement mesh used in this study was expanded steel mesh, which was fabricated from mild steel. It was obtained from local manufacturer and commercially known as EX-1562. Its properties are given in Table 2 based on the manufacturer data.

Ferrocement Matrix

Ferrocement matrix is a mix, which contains sand, workability agent, a high ratio of cement content, and silica fume to increase the compressive strength. The mix proportion of the matrix is shown in Table 3. The maximum nominal size of sand is 2.5 mm. The compressive strength of matrix was 42 MPa at 28 days for the standard cube of 70×70×70 mm.

Table 2: Properties of the used expanded metal mesh

Property	Value
Weight, kg/m ²	4.70
Diamond size, (LWD x SWD), mm	62 x 19
Strand size, (width x thickness), mm	4.5 x 1.5
Volume fraction for 2.0 cm matrix thickness	3.0 %
Yield stress, MPA [8]	98

Table 3: Mix proportions of ferrocement matrix

Type of material	Mix proportion by weight
Cement + silica fume	1.00
Sand	1.60
Water/cement + silica fume ratio	0.35
Workability agent	0.02
Silica fume replacement of cement	0.15

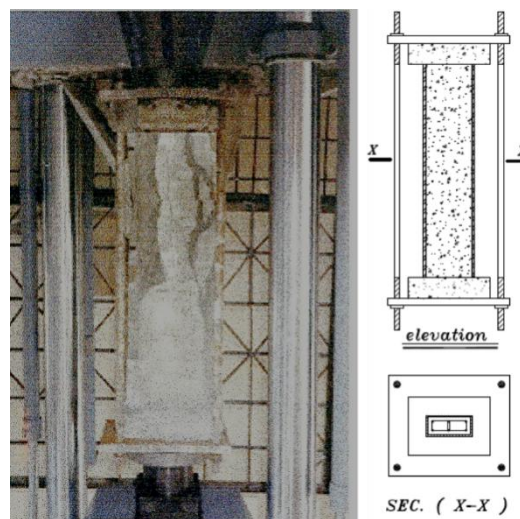


Fig. 2. Method to maintain the load constant

Test Setup

All the columns were tested under concentric axial compression under a hydraulic universal testing machine with a sphere loading heads. The machine has a vertical load capacity of 1000 KN and a load control system. The columns were placed vertically into the testing machine as shown in Fig. 2. The centerline of columns was aligned with the

International Journal of Innovative Research in Science, Engineering and Technology

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vertical centerline of bottom and top heads of the testing machine. The applied load was gradually increased from zero to a certain load level. Then, the machine jack which controls the load increment was stopped and kept constant to observe the cracks. The load was kept constant (about 2 minutes) during measurement and observations. After that, the load increment was provided and new set of measurements were recorded. All these steps were done automatically by using a computer software program in which the load increment was stored. These steps were conducted for all columns until the tested columns attained its ultimate capacity. The relationship between the vertical compression load and vertical deformation was recorded through the computer accompanied-testing machine. The ultimate loads and mode of failure were recorded until cover failure. In all cases, tests were terminated when the load was decreased and resulted in complete destruction of the column. The control columns (C1 and C2) were tested at 28 days age, while the strengthened columns (C3 to C14) were tested after 28 days from applying theferrocement jackets.

IV. TEST RESULTS AND DISCUSSION

The applied vertical compression force versus vertical concrete deformations was plotted for all columns as shown in Fig. 3(a to h). To examine the effect of the various parameters on the behavior of the tested columns, three measures are used: (1) the ultimate load capacity, (2) ductility ratio and (3) energy absorption as shown in Table 4. The ductility ratio, denoted by D.R, is defined as the ratio between the deformations at the ultimate load (Δ_u) to that at the onset yielding (Δ_y). The energy absorption, denoted by E.A, is defined as the area under the load–deformation curve up to the maximum load (P_u), because the portion after the maximum load is not perfectly accurate.

Table 4: Experimental results of the tested columns

Group	Model	P_u (kN)	% Increase of P_u	Δ_u (mm)	Δ_y (mm)	D.R= Δ_u/Δ_y	E.A (kN.mm)	% Increase of E.A
G1	C1	165.0	--	4.45	3.70	1.28	405.8	--
	C2	141.4	--	3.72	3.12	1.19	284.2	--
G2	C1	165.0	--	4.45	3.70	1.28	405.8	--
	C3	430.0	161	5.02	3.69	1.36	1160.6	186
	C4	409.0	148	5.07	3.75	1.35	1136.4	180
G3	C2	141.4	--	3.72	3.12	1.19	284.2	--
	C5	416.0	194	5.80	4.41	1.32	1417.8	399
	C6	380.0	161	5.50	4.28	1.28	1089.0	283
G4	C3	430.0	161	5.02	3.69	1.36	1160.6	186
	C7	384.5	133	7.07	5.66	1.25	1454.3	258
	C8	356.8	116	7.30	5.90	1.24	1328.2	228
G5	C4	409.0	148	5.07	3.75	1.35	1136.4	180
	C9	351.5	130	7.60	6.00	1.26	1439.5	255
	C10	338.8	105	7.56	6.20	1.22	1313.4	224
G6	C5	416.0	194	5.80	4.41	1.32	1417.8	399
	C11	373.0	164	7.72	5.69	1.36	1585.2	458
	C12	329.7	133	8.00	6.28	1.27	1382.3	386
G7	C6	380.0	161	5.50	4.28	1.28	1089.0	283
	C13	324.0	129	8.32	6.41	1.30	1475.2	419
	C14	314.7	123	8.00	6.55	1.22	1317.6	364

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

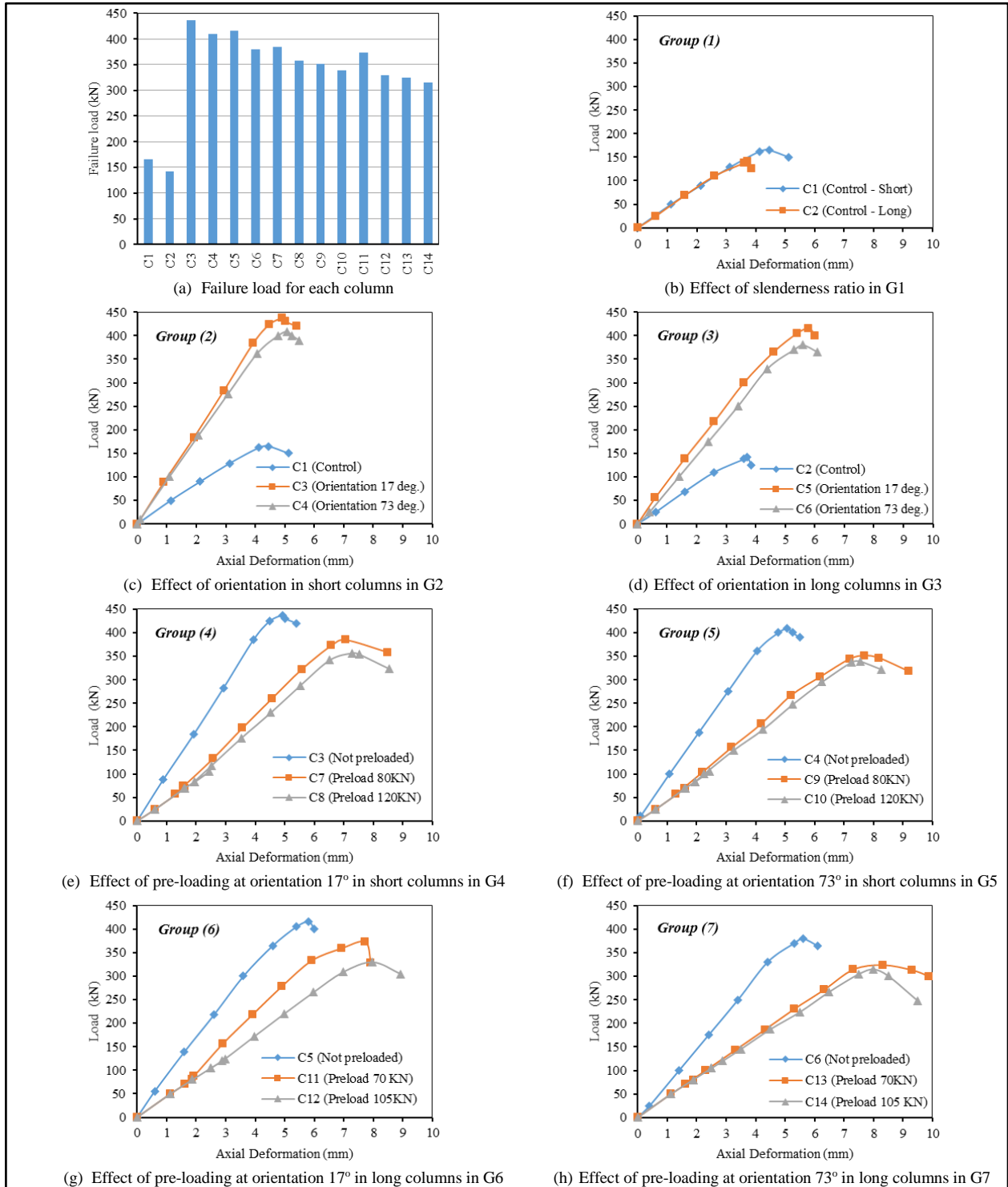


Fig. 3. Test results

International Journal of Innovative Research in Science, Engineering and Technology

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Behavior of columns under load

The relationship between the applied compression load and the vertical deformation of C1 to C6, increases almost linearly until the yielding load. Then the load decreases by high rates until failure. While in C7 to C14, this relationship is plotted in three phases; the first phase is plotted from zero load up to the pre-loading level. The second phase; the release load due to the four bars elongation is calculated and plotted. The third phase; the load versus vertical deformation is built from the last point of phase two. This relationship, for strengthened C7 to C14, increases almost linearly until the pre-loading level. After pre-loading, the relationship increases almost linearly with slope greater than that before pre-loading until the maximum load level. This means, the stiffness increased by strengthening. It is clear from Fig.3(e to h) that the stiffness of the columns without pre-loading is more than that of 50 % pre-loading level, whereas the latter is more than that of 75 % pre-loading level. Wherever, the stiffness decreases with increasing the pre-loading level. Based on the test results, there is an increase in P_u , D.R and E.A after strengthening with ferrocement jacket, as shown in Table 4. This increase is directly attributed to the bearing capacity of ferrocement jacket which also provides some confinement to the original column.

Effect of Slenderness ratio of columns

Fig. 3(b) and Table 4 show that the ultimate load, D.R and E.A of short column are more by 17 %, 7.6%, and 43 % than that of the long column, respectively. Also, there are some ratio of increase in P_u , D.R and E.A of short columns than that of long columns with the same parameters in the other groups, but with smaller values than that in G1.

Effect of Orientation of Ferrocement Mesh

The test results of G2 and G3 in Table 4, Fig. 3(c and d) shows that the orientation of mesh opening has significant effect on the increase in P_u . The increase in P_u for C3 with orientation of 17° and for C4 with orientation of 73° is 161 % and 148 % compared to C1, respectively. Also, the increase in P_u for C5 with orientation of 17° and for C6 with orientation of 73° is 194 % and 161 % compared to C2, respectively. Because of the great area of steel, using of expanded steel mesh in the longitudinal direction is more effective than that in transverse direction. Because of the large aspect ratio of column cross-section, the confinement has not significant effect on the increase in P_u . The increase in E.A for C3 with orientation of 17° and for C4 with orientation of 73° is 186 % and 180 % compared to C1, respectively. Also, the increase in E.A for C5 with orientation of 17° and for C6 with orientation of 73° is 399 % and 283% compared to C2, respectively. The bigger ratio of increase of P_u and E.A for column in G3 than that in G2 may be attributed to the decrease of slenderness ratio. The orientation of expanded steel mesh has a little effect on ductility ratio. The same results can be concluded for columns in G4 to G7.

Effect of Pre-loading Level during Strengthening

For the columns in G4 where the orientation equals 17° , raising the pre-loading level of the original column from 80 kN to 120 kN resulted in lower gain in P_u from 133 % to 116 % for C7 and C8, respectively. While the column C3 without pre-loading has gain in P_u of 161 % (see Fig. 3(e)). In G5 where the orientation equals 73° , raising the pre-loading level of the original column from 80 kN to 120 kN resulted in lower gain in P_u from 130 % to 105 % for C9 and C10, respectively. While the column C4 without pre-loading has gain in P_u of 148 % (see Fig. 3(f)). Also, the same effect can be noticed for columns in G6, and G7 (see Fig. 3(g and h)). The main reason for this behavior is increasing of the pre-loading level increases the damage and cracking level for the columns before strengthening. When the E.A is considered as the total area under the load-deflection curve, the E.A of the preloaded columns was greater than the column without pre-loading. But, when the E.A is considered as the area under load-deformation curve for the part after strengthening, the E.A the columns were pre-loaded is smaller than the column without pre-loading. The gain in E.A decreases with the increase of pre-loading level. The increase of pre-loading level has a small effect on the ductility ratio as indicated in Table 4.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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V. CONCLUSION

Based on the results and observations of the experimental investigation presented in this paper about the effectiveness of ferrocement jackets in strengthening the reinforced concrete(RC)columns the following conclusions can be drawn:

1. Under concentric loading conditions, RC columns can be strengthened significantly with enhanced strength and performance using ferrocement jacket.
2. After strengthening, all test columns showed higher deformation at ultimate load, increase in ductility ratio, and considerable increase in energy absorption as well. High ductility and energy absorption are very important characteristics, especially for dynamic loading applications.
3. High pre-loading levels resulted in lower gain in the load carrying capacity and energy absorption, yet increase in gain in the ductility ratio. Columns pre-loaded to 50% of the ultimate load of control column showed higher gain in the ultimate load and energy absorption than those pre-loaded to 75% however the increase in the ductility ratio was the least.
4. Based on the comparison between the theoretical gains in the load carrying capacity with the experimental ones, it is obvious that ferrocement jackets provided the strengthened columns with strong confinement effect.

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