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Strengthening of RC short square columns subjected to concentric axial loading by Ferrocement Jacketing

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Abstract – *This paper represents an experimental study on strengthening the RC short square columns with ferrocement jacketing. Extensive research in the past have studied the strengthening of both partially and fully loaded columns. In this study, a total of six RC short square columns were casted and three of them are taken as control specimens and were tested to failure after 28 days under pure axial concentric loading in order to investigate the effect of strengthening with ferrocement jacket as an alternative technique to classical RC Jacketing. Thus, the observed experimental ultimate axial load carrying capacity of retrofitted columns is compared with the calculated theoretical values as per IS code approach. Moreover, the effect of jacketing on the slenderness ratio of column is also studied and initial cracking load, and ultimate load carrying capacity were recorded and discussed for future scope.*

From the result analysis, it was observed that the retrofitted column shows an increase of 62% in the ultimate load carrying capacity, when compared to the control specimen C.

Key Words: *Reinforced Concrete, Strengthening, Short Columns, Ferrocement Jacketing and Wire mesh*

1. INTRODUCTION

The need for rehabilitation i.e. strengthening and repair of existing reinforced concrete columns has significantly increased over the past few decades. Infact, the continuous use of land for construction has created the demand for adding extra stories to existing buildings. As the columns are one of the most important structural member which transfers the entire loads to the foundation. Therefore, for such cases, it is usually required to strengthen a number of columns of an existing building to increase their loading capacity to meet the extra load requirements. Replacement of the damaged structural members is very difficult and cost intensive process which in fact creates a high risk to the integrity of other connecting members of the structure, such as beams and slab. Thus, in order to restore the required strength of the damaged structure, retrofitting technique is the only solution to be used all over the world. The corrosion of steel, poor quality of concrete and the lack of proper maintenance while casting the structural member may led to the partial deterioration of reinforced concrete structures. Infact, corrosion of reinforcement is probably the major cause of such partial deterioration and this is the reason why in most of the cases, the repair work or the strengthening of structural member requires the use of an additional reinforcement in order to compensate for the corroded original bars.

In practice, the use of reinforced concrete jackets also called as classical RC jacketing is one of the most commonly available techniques for strengthening or repairing the deteriorated reinforced concrete columns .It is typically done by enlarging the original cross section of column by adding an extra layer of concrete with additional bars provided as both longitudinal and lateral reinforcement. As the most of the structural designers look for an increase in the ultimate load carrying capacity of columns strengthened with RC jackets, but in the case of seismic loading they must consider the effect of increasing the overall stiffness of the deteriorated columns by RC jacketing before deciding the type of jacketing to be used. Thus, in order to slow down the increase of overall stiffness in the repaired column, ferrocement jacketing can be used as the best alternative to classical RC jacketing. Ferrocement is a special type of reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh which provides ductility to the otherwise brittle concrete. (Ferrocement matrix + Wire mesh). Infact, application of this jacketing to the deteriorated Reinforced concrete column is very easy and needs no skilled labour. Moreover, due to the uniform distribution of reinforcement in the form of wire mesh, it offers an increase in the various engineering properties such as improved tensile and flexural strength, fracture, toughness, and crack control and impact resistance. Moreover, Ferrocement jackets are easy in application and have very low cost as compared to the classical RC jackets. In the last two decades, various attempts have been made to study the behavior of deteriorated columns repaired or retrofitted with ferrocement jacketing.

2. RESEARCH SIGNIFICANCE

Muhammed Salih D.S et.al conducted a research on strengthening of RC column using polypropylene fibre in ferrocement jacketing. The experimental ultimate load carrying capacity of the column with different percentages of polypropylene fibres were compared and it was found that the strengthening of column using ferrocement with the application of polypropylene fibre was found to be an effective and practical technique for strengthening of damaged columns. Mohamed A. Tarkhan et al. investigated the possibility of strengthening partially loaded reinforced concrete columns using ferrocement jacketing.It was observed that under concentric loading conditions, RC columns can be strengthened significantly with enhanced strength and performance using ferrocement jacketing which increases the load carrying capacity and ductility of the columns depending on the various parameters. Bishnu Gupt Gautam. et al. conducted research on wire mesh mortar jacketing (WMM) and steel cage mortar jacketing (SCM). The experimental load carrying capacity of the column with concrete of control specimen CS, WMM and SCM were compared with theoretical values determined from Strength of Materials approach and by using IS: 456-2000 design method. The observed ultimate load for various columns were compared and it was found that the column with steel cage mortar jacketing attains maximum ultimate load. Veena M et al. conducted research on strengthening of RC short square columns using improved ferrocement jacketing and the ultimate load carrying capacities were experimentally determined and hence the efficiency of confinement offered by square conventional and advanced jacketing schemes were compared. It was observed ultimate load carrying capacity for advanced jacketed square columns improved by 1.45 times compared to that of control specimens whereas the improvement was only 1.30 times for conventionally jacketed specimens.

From the above mentioned literature review, various parameters and methods were adopted for strengthening reinforced concrete column. Still there is a need for further investigation on RC columns retrofitted with ferrocement jacketing at an affordable cost. In this experimental study, the behaviour of Reinforced Concrete Columns retrofitted with ferrocement jacketing is investigated and tested to failure to find out the ultimate load carrying capacity.

3. EXPERIMENTAL PROGRAMME

Following are the different sections involved in experimental programme used in this study.

3.1 General

In this experimental study, a total of six columns were casted using M 25 grade of concrete after mix design and trial mixes in the optimum ratio 1: 1.27:2.58 with a water-cement ratio of 0.43 and steel grade of Fe-500 are then tested in the structural engineering lab under pure axial concentric loading conditions. The size of the columns are taken 120 mm x 120 mm x 720 mm with 4 bars of 8 mm diameter as longitudinal reinforcement and 5.5 mm diameter lateral ties at a spacing of 120 mm c/c as shown in Fig 1 Moreover, of the six RC short square columns three of them are taken as control specimens (denoted as C) and were tested to failure after 28 days while the other three column specimens (denoted as C_f) are retrofitted with ferrocement jacketing after the preparation of surface.

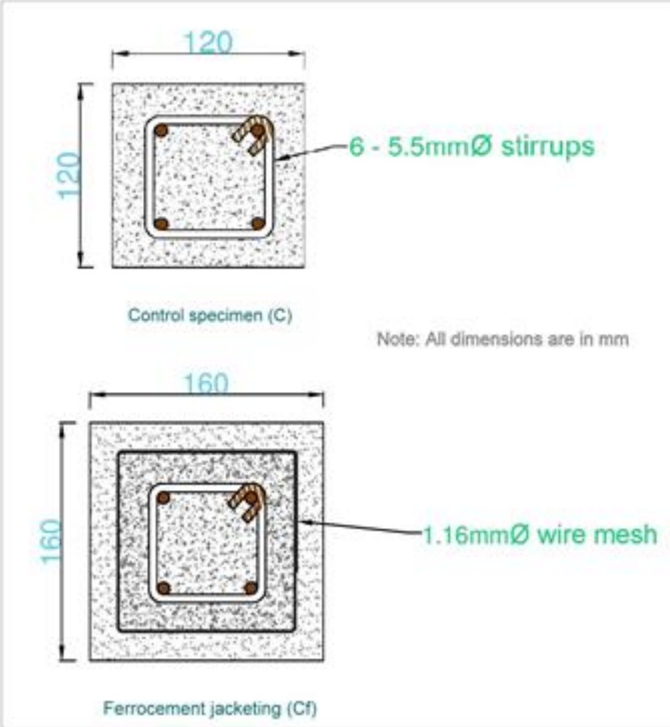

Figure 1 Reinforcement detailing of column specimens

3.2 Material Properties

Basic tests were conducted on different materials used and the results are given below:

a) Cement:
Portland Pozzolana Cement conforming to IS 1489 (1991) specification was used. The different properties of cement obtained from various basic tests are given in Table1.

b) Fine aggregate:
The fine aggregate used in this investigation was commercially available clean river sand, whose maximum size is 4.75 mm, conforming to grading zone II. The sand was air dried, sieved and stored.

c) Coarse aggregate:
Both 10 mm and 20 mm size aggregates in the ratio of 1:1.5 were used in this experimental study. The shape of the coarse aggregates chosen was as per IS 2386 Part 1 (1963). The surface texture characteristics are as per IS 383:1970.

d) Wire mesh:
GI steel wire mesh of 1.16 mm diameter wires welded in square pattern was used for confinement in ferrocement. The grid size of mesh was 15 mm x 15 mm.

Table 1 Material Properties

S.No.	Description of Test	Test Results	Standard Value	Reference Code
1	Normal Consistency of Cement	28.6 %	Not less than 30%	IS:4031-1988

2	Initial Setting Time of Cement	48 mins	Greater than 30 mins	IS:4031-1988
3	Fineness of Cement	4.65%	-	-
4	Specific Gravity of Cement	3.13	3-3.15	IS:2386-1963
5	Specific Gravity of Fine Aggregate	2.64	2.6-2.9	IS:383-1970
6	Specific Gravity of Coarse Aggregate	2.70	2.6-2.9	IS:383-1970
7	Fineness Modulus	6.88	-	-

3.3 Strengthening of specimens

The surfaces of the column specimens to be strengthened were roughened by hand chisel with hammer and corners are made rounded to about radius of 15mm, then cleaned using wire brush. All the specimens were thoroughly washed and dried before the wrapping of wire mesh as shown in the Fig 2.

Fig - 2 Preparation of surface of columns

The required width of 720mm and length of 450mm for one layer of wire mesh was cut and properly wrapped in single layer by two people around the entire prepared column. Moreover, 80 mm overlapping of wire mesh was provided in lateral direction and were tied together with the same diameter of steel wire and kept at the middle of jacket layer with a cover of 10mm in both exterior and interface surfaces. Similarly, this process was repeated for the other two columns as well as shown in Fig 3.

Fig - 3 Wrapping of wire mesh

In this experimental study, the mix proportion of matrix for ferrocement was made with water-cement ratio of 0.4 and cement - sand ratio of 1:2 as shown in Table 2.

Table 2 Mix proportions of ferrocement matrix

Type of material	Mix proportion by weight
Cement	1.00
Sand	2.00
Water/cement ratio	0.40
Workability agent	0.01

Moreover, in order to improve the workability of matrix, 1 % of cement weight of superplasticizer were added. Once the matrix is ready, using trowels it is applied thoroughly on wire mesh wrapped columns for a thickness of 20mm on each side, as shown in Fig 4. Thus, making the overall size of ferrocement jacketed column to 160mm x 160mm x 720mm. All the retrofitted columns were cured in the water for 28 days before testing.

Figure 4 Application of ferrocement matrix

3.4 Testing of specimens

After curing for 28 days, all the retrofitted specimens were air dried before the testing. Load analysis of all the retrofitted columns denoted by C_f under pure axial loading is done on compression testing machine of capacity 3000KN and tested until failure, after proper curing of 28 days. Moreover, two ply caps were used at the ends of the small cross section columns to protect them from slipping off the lower and upper platens. Test setup for column specimens subjected to pure concentric axial loading is shown in Fig 5.

Figure 5 Axial loading Test Setup

3.5 Analysis of Test Results and Discussion

The experimental load carrying capacity of control and retrofitted columns were noted till failure of the specimens and the analysis of test results was done on the basis of ultimate load, slenderness ratio and failure pattern.

a) Ultimate load:

The observed experimental ultimate load carrying capacity of the control specimen (C) and retrofitted column (C_f) were compared with the theoretical values of ultimate load determined from IS: 456-2000 design approach.
Mathematically, the theoretical ultimate axial load is determined by the following equation:

$$\boxed{P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}}$$

where;
P_u = axial load on member,
f_{ck} = characteristic compressive strength of concrete,
f_y = characteristic compressive strength of steel,
A_c = area of concrete; and
A_{sc} = area of longitudinal reinforcement for columns.
Table 3 and Chart 1 shows the comparison of observed experimental ultimate loads for control specimen (C) and retrofitted column (C_f) with the theoretical values of ultimate load determined from IS Code approach.

Table 3 Comparison of ultimate loads

Columns	Description	Dimensions	Observed experimental ultimate load (kN) $P_{u(exp)}$	Ultimate load by IS code approach (kN) $P_{u(IS)}$
C	Control Specimen 1	120mm x 120mm x 720mm	**335.66**	**209.34**
C_f	Ferrocement Jacketing (wired mesh)	160mm x 160mm x 720mm	**544.35**	**321.34**

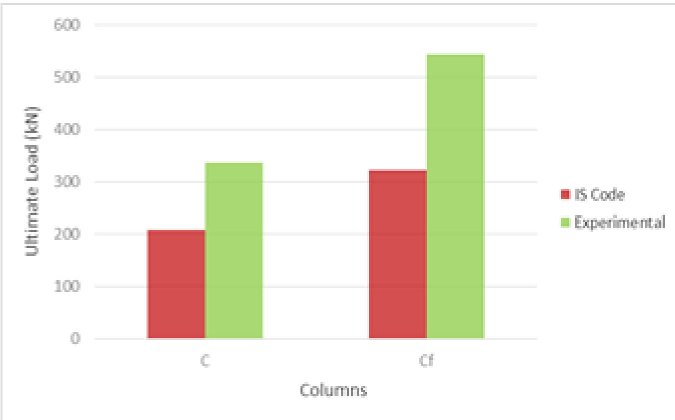

Chart 1 Comparison of ultimate loads

From the above chart, it is clear that all the ferrocement jacketed specimens (C_f) shows significant improvement in the ultimate load carrying capacity than control specimen (C). The average ultimate load carrying capacity of control specimen (C) was observed to be the lowest and equals to 335.66 kN whereas for the jacketed column (C_f) the observed average ultimate load is 544.35 kN which is 1.62 times greater than the control specimen C. Infact, all the jacketed specimens are more ductile than control specimens which is caused by the confinement provided with ferrocement jacketing.

b) Slenderness ratio:
The effect of increase in the size of cross section of jacketed column on the slenderness ratio is compared with the already set slenderness ratio of control specimen.
Chart 2 shows the comparison of slenderness ratio for control specimen (C) and the retrofitted column (C_f).

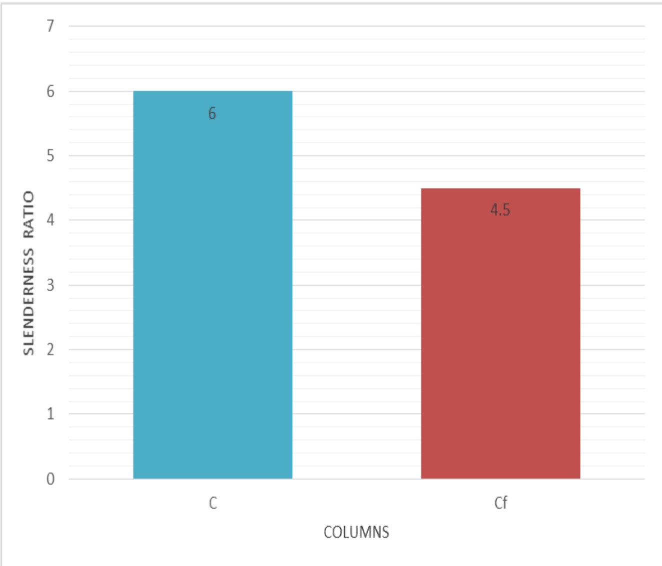

Chart 2 Comparison of Slenderness ratio

From the above chart, it is clear that slenderness ratio of ferrocement jacketed column follows a decreasing trend but not to the extent as in case of classical RC Jacketing.

c) Failure pattern:
In addition to the above analysis, the failure modes of the column specimens were also observed where in the control specimen starts to fail by the crushing of concrete and buckling of steel at the point of application of load whereas retrofitted column starts to fail by the spalling of jacketed mortar at the corners, thus signifying the large stress concentration at the corners.

Fig 6 shows the typical failure pattern of the tested column specimens.

Figure 6 Failure Pattern

Therefore, from this experimental investigation it is clear that column strengthened using ferrocement jackets is more effective and economical than other types of jacketing.

4. CONCLUSIONS

The main objective of this experimental study is to find the increase in the axial load carrying capacity of short reinforced concrete columns after strengthening with ferrocement jackets. Also, the effect of slenderness ratio and the failure pattern are studied. To achieve these objectives, a total of 6 columns of size 120mm x 120mm x 720mm were cast and three of them are taken as control specimens (C) and were tested to failure after 28 days under pure axial concentric loading just to set an exact benchmark for comparison with ferrocement jacketed columns (C_f). Based on the test results of control specimens and strengthened columns, the following conclusions are drawn:

- The average ultimate load carrying capacity of control specimen (C) was observed to be the lowest and equals to 335.66 kN whereas for the jacketed column (C_f) the observed average ultimate load is 544.35 kN which is 1.62 times greater than the control specimen C.
- The Indian Standard code (IS) is conservative to some extent and it gives much lower value with respect to retrofitted columns (C_f).
- Strengthening of square columns using ferrocement jacketing was found to be an effective and practical technique for repairing the damaged columns.
- The failure of ferrocement jacketed specimens caused due to spalling of concrete from the corners, thus signifying the large stress concentration at the corners.

- RC columns can be strengthened significantly with enhanced strength and better performance using ferrocement jackets, subjected to the concentric loading conditions.
- Slenderness ratio of ferrocement jacketed column follows a decreasing trend but not to the extent as in case of classical RC Jacketing.

5. FUTURE RESEARCH

The following recommendations are proposed for future research:

- It is recommended to remove the concrete from the deteriorated zone with hammer and chisel, followed by sand blasting to make the rough interface.
- It is essential to find out a specific position in the damaged portion of concrete rather than confining the whole structural member, so that the overall cost for confinement will be economical.
- Increasing the no. of layers of wire mesh should be such that a minimum cover is provided on inner and outer faces.
- For better results, different layers of wire meshes should be interconnected by providing a rebar, such that confinement may not fail early.
- It is recommended to take orientation into consideration as Proper orientation of wire mesh can make a big difference to withstand heavy axial loads.
- Modifying the corners of columns from pointed to round will eliminate the corner stress concentration and improve ferrocement confinement effectiveness.

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