

Experimental And Analytical Investigations on RC Short Columns Strengthened by Ferrocement Jacketing And Aramid Fibre Sheet Wrapping

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Abstract. Reinforced concrete columns are the main load bearing structural elements in the building. These columns need to be repaired or strengthened due to material deficiencies, design deficiencies, poor construction and quality control. The axial load carrying capacity of RC short columns of Grade M25 and of size 150 mm x 150 mm and height 1 m were determined as per IS 456:2000. Seven RC short columns were cast – three columns were strengthened by ferrocement jacketing, two columns were strengthened by aramid fibre sheet wrapping and the remaining two columns were reference columns. In ferrocement jacketing technique, woven wire mesh of size 12 mm x 12 mm opening and diameter of 0.96 mm were wrapped around the three columns in two layers and mortar of mix ratio 1:3 with a water cement ratio of 0.45 were applied around the columns to cover the wire mesh for a thickness of 20 mm from each face of the columns. In the aramid fibre sheet wrapping technique, the RC columns were wrapped by a single layer of aramid fibresheet using epoxy resin. All the RC short columns hinged at both ends were tested under axial compression in a loading frame of capacity 1200 kN using a hydraulic jack of capacity 1000 kN. Two LVDT's were placed – one perpendicular to the base plate to measure the longitudinal displacement and the other perpendicular to the face of the column to measure the lateral displacement of the columns. The longitudinal and lateral displacements of all RC short columns for each load increment of 10 kN were observed. The ultimate load carrying capacity of RC short columns strengthened using ferrocement jacketing, aramid fibre sheet wrapping and reference columns were compared. Graphs were plotted for axial load vs longitudinal displacement and axial load vs lateral displacement. Finite element analysis of reference columns and strengthened columns were carried out using ABAQUS software. Finally, the experimental results of RC short columns were compared with that obtained from finite element analysis using ABAQUS.

Keywords: longitudinal, lateral displacements, RC short columns.

1 Introduction

A column is generally a compression member supporting beams and slabs in a structural system. A column may be considered to be short when its effective length does not exceed 12 times the least lateral dimension. Short columns fail by crushing of the material. RC columns often require strengthening to increase their capacity to sustain loads. Strengthening may be necessary due to change in use that resulted in additional live loads (like change in use of the

facility from residential to public or storage), deterioration of the load carrying elements, design errors and construction problems during erection. Common methods for strengthening columns include concrete jacketing, fiber reinforced polymer (FRP) jacketing and steel jacketing. All these methods have been shown to effectively increase the axial load capacity of columns.

Many researchers conducted experiments on square columns strengthened by ferrocement jackets and AFRP sheets to study their performance. **Abdullah, Katsuki Takiguchi[1]** investigated a technique by using ferrocement jacket for seismic strengthening of RC columns and compared with different strengthening methods. Three methods of strengthening were studied, including steel jacket, carbon fibre sheet, and ferrocement jacket. The results of this investigation indicated that strengthening of a square reinforced concrete column with ferrocement jacket was considered to be successful than the other two methods.

Robert Ravi. S, Prince Arulraj.G[3] conducted experiments on three RC beam-column joints. The column has an overall length of 1500 mm with a cross section of 200 mm x 200 mm. The beam has a cantilevered portion with a length of 600 mm and has a dimension of 200 mm x 200 mm. The specimen C1 has sheets of GFRP as inner layer and AFRP sheet in outer layer. Likewise the specimen C2 has sheets of AFRP as inner layer and GFRP as outer layer. With the use of hybrid GFRP-AFRP sheet retrofitting technique, the load carrying capacity of the reinforced concrete beam-column joint specimen was found to be 18.3 % more than the control specimens.

Mohammad TaghiKazemi, Reza Morshed [2] investigated a ferrocement jacket reinforced with expanded steel meshes and used to retrofit shear deficient concrete columns. Based on the test results, both circular and square ferrocement jacket enhanced the shear strength and ductility of small-scale square columns.

2. Material Properties And Mix Design

2.1 Cement

In this study, Ordinary Portland Cement (OPC) of 53 Grade was used. Table 1 shows the properties of cement.

Table 1 Properties of Cement

Tests	Results
Specific Gravity	3.15
Consistency	33%
Fineness	1%
Initial Setting Time	190 min
Final Setting Time	440 min

2.2 Fine Aggregates

The fine aggregates passing through 4.75mm IS sieve and retained on 75micron IS Sieve was taken for the study. Table 2 shows The properties of fine aggregates.

Table 2 Properties of Fine Aggregates

Tests	Results
Specific Gravity	2.76
Particle size Distribution	Grading zone II

Free Moisture Content	0.87%
Water Absorption	1.4%

2.3 Coarse Aggregates

The coarse aggregates of maximum size 20mm was taken for the study. The properties of coarse aggregates are given in Table 3.

Table 3 Properties of Coarse Aggregates

Tests	Results
Specific Gravity	2.87
Free Moisture Content	0.3%
Water Absorption	1.32 %
Particle Size Distribution	Well graded

2.4 Reinforcement Steel

High Yield Strength Deformed Bars of Grade Fe 415 are used for the study. Longitudinal bars are of 12mm diameter and ties are of 6mm diameter.

2.5 Mix Design

Concrete mix of Grade M25 was designed as per IS 10262:2009. The obtained mix proportions per m³ of concrete are shown in Table 4. The mix ratio is 1 : 2.14 : 3.78 : 0.5.

Table 4 Quantity of Materials

Materials	Quantity
Cement	350
Fine Aggregates	750.03
Coarse	1325
Water	175

3. Column Details

The cross section of the RC short column was chosen as 150 mm x 150 mm and height 1 m. 12 mm diameter bars are used as longitudinal bars and 6 mm diameter bars are used as ties with a spacing of 100 mm c/c. The description of RC short columns is shown in Table 5. The cross section and reinforcement details of RC column are shown in Figures 1 and 2 respectively.

Table 5 Description of RC Short Columns

S.No.	Symbol	Description
1	REC 1,2	Reference Column
2	SCFJ 1,2,3	Strengthened Column by Ferrocement Jacketing
3	SCAF 1,2	Strengthened Column by Aramid fibre sheet wrapping

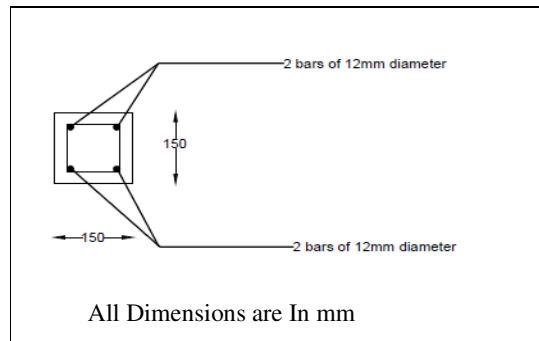


Figure 1: Cross Section Details of RC Short Column

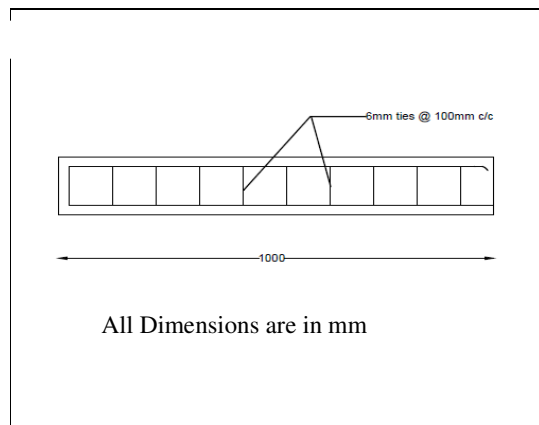


Figure 2: Longitudinal Section of RC Short Column

Axial load carrying capacity of column as per IS 456:2000,

$$P_u = 0.4f_{ck}A_c + 0.67f_yA_{sc}$$

where $A_c = 22047.84 \text{ mm}^2$

$$A_{sc} = 452.16 \text{ mm}^2$$

$$f_{ck} = 25 \text{ N/mm}^2$$

$$f_y = 415 \text{ N/mm}^2$$

$$P_u = (0.4 \times 25 \times 22047.84) + (0.67 \times 415 \times 452.16)$$

$$= 346.2 \text{ kN.}$$

4. Strengthening Of RC Short Columns

4.1 Ferrocement jacketing [1,2,4]

Properties of Materials

The Woven Wire Mesh used in the jackets had square openings of size 12 mm x 12 mm and wire diameter of 0.96 mm. The average yield strength, the average ultimate tensile strength and the average modulus of elasticity of woven wire mesh are 385 MPa, 524 MPa and 106 MPa respectively.

Fabrication

Two layers of woven wire mesh is provided in lateral directions. Mortar is filled for a thickness of 20 mm at all four sides of the short RC columns. Infill mortar is made with water-cement ratio of 0.45 and cement sand ratio of 1: 3. The RC short column strengthened by ferrocement jacketing is shown in Figure 3.



Figure 3: Strengthening of RC Short Columns by Ferrocement Jacketing

4.2 Aramid Fibre Sheet Wrapping

Fabrication

Prior to the application of the epoxy coat to the RC short columns, the concrete surface was cleaned from dust. The aramid fibre sheet which is available in 1000mm width is wrapped directly on the fresh epoxy coat on RC columns. The column is wrapped by single layer of AFRP sheet. The epoxy resin is mixed in the ratio of 1:4 (one part of hardener and four parts of base). Figure 4 shows the RC short column strengthened by AFRP wrapping.



Figure 4: Strengthening of RC Short Columns by Aramid Fibre Sheet Wrapping

5. Experimental Setup

All the RC columns were tested under axial compression in a loading frame of capacity 1200 kN using a hydraulic jack of capacity 1000 kN. The RC columns were placed vertically in the loading frame and are hinged at both ends. Two LVDT's were placed – one perpendicular to the base plate to measure the longitudinal displacement and the other perpendicular to the face of the column to measure the lateral displacement of the columns. The longitudinal and lateral displacements of all RC short columns for each load increment of 10 kN were observed. The experimental setup is shown in Figure 5.



Figure 5: Experimental Setup

6 Results And Discussions

6.1. Ferrocement Jacketing

From the experimental investigations, the load carrying capacities and the deformations of the columns were observed. The columns REC, SCFJ 1, SCFJ 2, and SCFJ 3 fail at 375kN, 670kN, 690 kN and 660kN loads respectively. The above result shows that the column SCFJ 2 carries high axial load of 690 kN. The load carrying capacity of reference column and the columns strengthened by ferrocement jacketing is shown in Table 6.

Table 6 Load Carrying Capacity of RC Short Columns

S.No.	Column	Ultimate Load (kN)
1	REC	375

2	SCFJ 1	670
3	SCFJ 2	690
4	SCFJ 3	660

The load vs longitudinal deflection of the columns REC, SCFJ 1, SCFJ 2, and SCFJ 3 are shown in Figure 6.

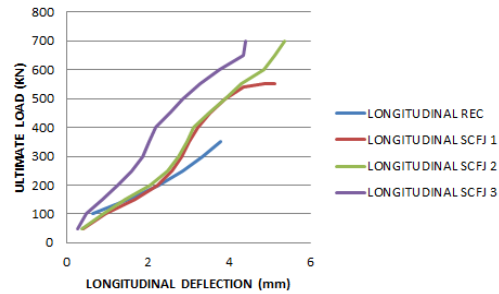


Figure 6:Ultimate Load vs Longitudinal Deflection in REC and SCFJ Columns

The load vs lateral deflection of the columns REC, SCFJ 1, SCFJ 2, and SCFJ 3 are shown are is shown in Figure 7.

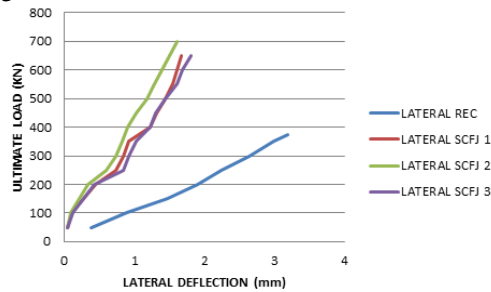


Figure 7:Ultimate Load vs Lateral Deflection in REC and SCFJ Columns

The failure patterns of RC short columns strengthened by ferrocement jacketing and reference columns are shown in Figures 8 and 9 respectively.



Figure 8: Failure Patterns of RC Short Columns Strengthened by Ferrocement Jacketing



Figure 9: Failure Patterns of Reference RC Short Columns

6.2 Aramid Fibre Sheet Wrapping

From the experimental investigations, the load carrying capacities and the deformations of the columns were observed. The columns REC, SCAF 1 and SCAF 2 failed at 390kN, 550kN and 580kN respectively. The load carrying capacity of reference column and the columns strengthened by ferrocement jacketing is shown in Table 7.

Table 7 Load Carrying Capacity of RC Short Columns

S.No.	Column	Ultimate Load (kN)
1	REC	390
2	SCAF 1	550
3	SCAF 2	580

The load vs longitudinal deflection of REC, SCAF 1 and SCAF 2 are shown in Figure 10.

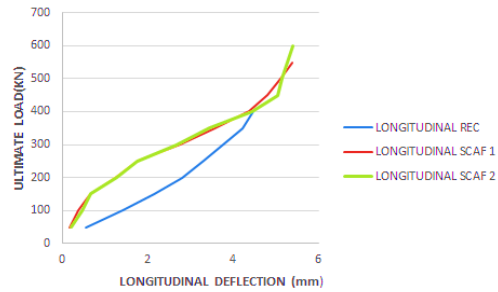


Figure 10: Load vs Longitudinal Deflection in REC and SCAF Columns

The load vs lateral deflection REC, SCAF 1 and SCAF 2 are shown are is shown in Figure 11.

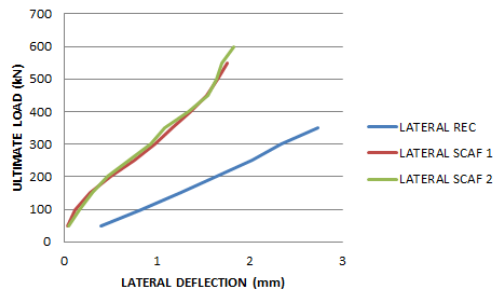


Figure 11: Load Vs Lateral Deflection in REC and SCAF Columns

The failure patterns of RC short columns strengthened by aramid fibre sheet wrapping is shown in Figure 12.



Figure 12: Failure Patterns of RC Short Columns Strengthened by AFRP sheets

7. Comparison Of Experimental Results

The load carrying capacities of RC short reference columns, strengthened columns with ferrocement jacketing and aramid fibre sheet wrapping were compared and are shown in Table 8.

Table 8 Comparison of Load Carrying Capacity

S.No.	Column	Ultimate Load (kN)	Increase in Load (%)
1	REC	382.5	-
2	SCFJ	673.33	76.03
3	SCAF	565	47.7

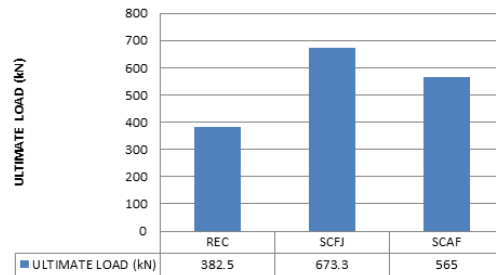


Figure 13: Comparison of Load Carrying Capacity of REC, SCFJ and SCAF Columns

8. ANALYTICAL STUDY

The behaviour of RC reference column and strengthened columns by aramid fibre sheet wrapping were studied analytically using ABAQUS software. Concrete damaged plasticity (CDP) model is used to define the concrete properties. 8 noded brick element is used for concrete element and 3 noded beam element is used for steel element. Table 9 shows the plasticity properties of concrete.

Table 9 CDP Model Properties of Concrete

1	Dilation angle	38
2	Eccentricity	1
3	K	0.6667
4	f_b/f_{c0}	1.12
5	Viscosity parameter	0

Embedded Region

Reinforcement in concrete structures is typically provided by rebar. Normally the rebars are defined as one-dimensional wire truss elements and the reinforcement can be defined in ABAQUS using a single wire.

8.1 Modeling of Short Reference Columns

Boundary conditions

The reference columns were modeled as being vertical, with one side having a fixed-end condition and the other experiencing the applied load. Figure 14 shows the modeling of RC column and reinforcement details

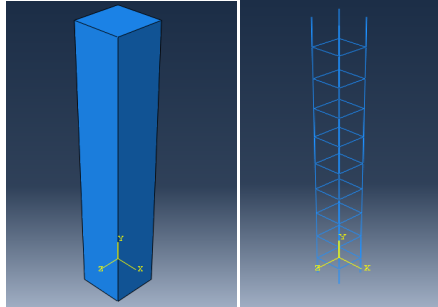


Figure 14: Modeling of RC Short Reference Column and Reinforcement Details
Meshing of Reference Columns

The size of mesh used in Finite Element Method (FEM) can affect the results. The mesh size adopted for this study is 50 mm. Figure 15 shows the meshing and the deflected shape of the reference column.

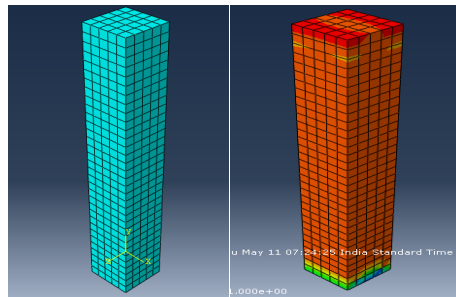


Figure 15: Meshing and Deflected Shape of Short Reference Column

From the analytical study, the ultimate load at which the reference column failed is 354 kN with a maximum longitudinal deflection of 4.17 mm. Figure 16 shows the ultimate load vs longitudinal deflection of the reference column using ABAQUS.

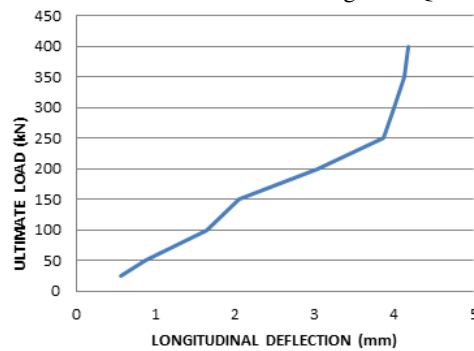


Figure 16: Ultimate Load vs Longitudinal Deflection of Short Reference Column

8.2 Modeling of RC Short Columns Strengthened by Aramid Fibre Sheet Wrapping

The modeling of the strengthened RC short column by aramid fibre sheet wrapping is shown in the Figure 17.

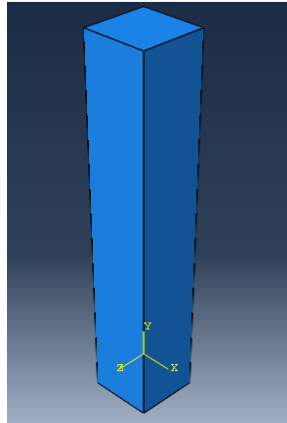


Figure 17: Modeling of RC Short Column Strengthened by AFRP Sheets

Analysis of Strengthened Columns by AFRP Sheets

The mesh size used in Finite Element Method (FEM) can affect the results. The mesh size adopted for this study is 50 mm. Figure 18 shows the meshing and the deflected shape of the strengthened column by AFRP sheets.

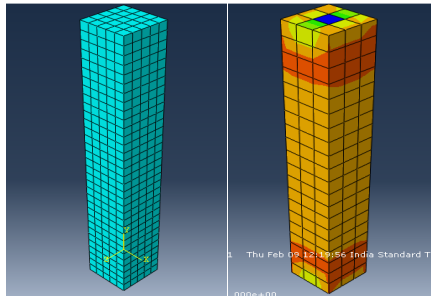


Figure 18: Meshing and Deflected Pattern of RC Short Column Strengthened by AFRP Sheets

From the analytical study, the ultimate load at which the column strengthened by AFRP sheets failed is 537 kN with a maximum longitudinal deflection of 4.41 mm. Figure 19 shows the ultimate load vs longitudinal deflection of the strengthened column using ABAQUS.

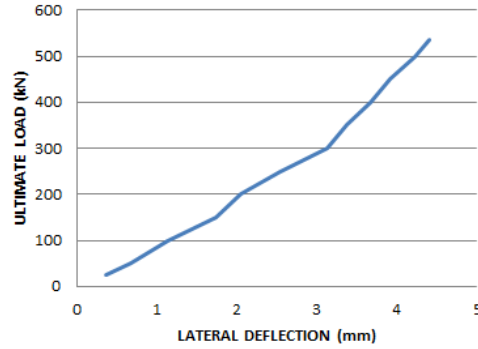


Figure 19: Ultimate Load vs Longitudinal Deflection of RC Short Column Strengthened by AFRP Sheets

8.3 Comparison of Analytical Results

The ultimate load and the longitudinal deflection of the reference column and column strengthened by AFRP sheets are shown in Table 10.

Table 10 Load Carrying Capacity of RC Short Columns Using ABAQUS

S.No.	Column	Ultimate Load (kN)	Longitudinal Deflection (mm)
1	REC	354	4.17
2	SCAF	537	4.41

9 Comparisons Of Experimental And Analytical Results

The comparison of load carrying capacities of reference column and RC short columns strengthened by aramid fibre sheet wrapping by experimental and analytical study are shown in Table 11 and Figure 20 respectively.

Table 11 Comparisons of Experimental and Analytical Results

S.No.	Columns	Experimental Study Ultimate Load(kN)	Analytical Study Ultimate Load (kN)
1	REC	382.5	354
2	SCAF	565	537

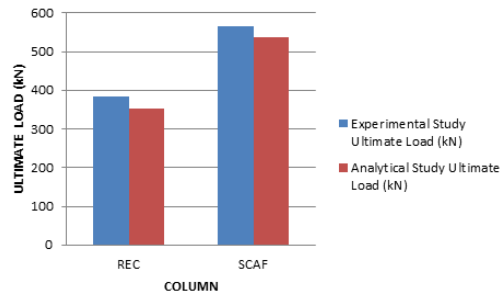


Figure 20: Comparisons of Experimental and Analytical Results of Reference and Strengthened Columns by AFRP Sheets

10 CONCLUSIONS

From the experimental and analytical test results on RC short columns and strengthened columns, the following conclusions were drawn.

- Load carrying capacity of RC short columns increases considerably for the two techniques experimentally.
- The increase in load carrying capacity of RC short columns strengthened by ferrocement jacketing technique is 76.03% higher than the reference column.
- Increase in cross-sectional area is high in RC short column strengthened by ferrocement jacketing when compared with the columns strengthened by AFRP sheets.
- The columns strengthened by ferrocement jacketing and AFRP sheets showed higher resistance in longitudinal deflection when compared with the reference column.
- RC short column strengthened by AFRP sheets showed an increase in ultimate load of 51.69% with respect to the reference column based on the analytical study.

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