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Retrofitting of Reinforced Concrete Square Columns using Ferrocement Jacketing

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Abstract - Retrofitting is solution provided when the existing structure is incapable to carry more loads. Ferrocement jacketing is a form retrofitting technique to strengthen the structure, by maintaining its function, as the original geometry of the structure is not rendered with. This experimental study focuses on the effectiveness of ferrocement jacketing for strengthening of existing RC column preloaded with a fraction of its ultimate load carrying capacity. The jacketing technique used is square jacketing with single layer (SLTL) wire mesh with two extra layers mesh at each corner (SLTL) for reducing stress concentration problem of square jacketing in columns and to strengthen all corners. The primary variables considered are number of layers of ferrocement mesh, amount of preloading and effectiveness of SLTL type wire mesh wrapping. Square columns are prepared of similar cross sectional area and reinforcement and are axially loaded. The square columns are preloaded with 70% and 100% of the ultimate load carrying capacity and are wrapped with one and two layers of wire mesh. A cement mortar of 1:2 ratio is applied around the wire mesh uniformly and kept for curing. The strengthened columns were again axially loaded and the results were compared with the results of conventional columns. The test results showed that the confinement effectiveness is high with SLTL type wrapping and that load carrying capacity increases with number of layers of wire mesh.

Index terms - Square columns, Preload, Ferrocement jacketing, Retrofitting, Ultimate load, Strengthening

1. INTRODUCTION

Retrofitting of RCC structural members is carried out to regain the strength of deteriorated structural concrete elements and to prevent further distress in concrete. Strength deficiency of concrete structural members can be due to poor workmanship, design errors, and deterioration due to the aggression of harmful agents. Common problems include, Structural cracks, Damage to structural members, Excessive loading, Errors in design or construction, Modification of structural system, Seismic damage, Corrosion due to penetration- honey combs etc. The strengthening of damaged and deteriorated concrete structures has become a challenge and a necessity. It is far more economic than constructing new structures but it also involves complications. The vital role of transferring the loads of the structure is carried out by the structural element, reinforced concrete columns. The deficiencies in concrete columns are the lack of lateral confinement and low energy absorption capacity. These could be enhanced by constructing additional external confinement around columns. There are several techniques which are used to retrofit structural members such as section enlargement, external plate bonding, external post-tensioning, grouting, fibre reinforced polymer composites and jacketing.

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Based on the severity of the damage and required capacity to be regained, a proper retrofitting technique is specified and implemented. Retrofitting improves the capacity of the buildings which are subjected to higher loads than they are designed for. Retrofitting of an existing building is upgrading of certain building systems to make them more resistant to future increase in loads. Retrofitting proves to be a better economic consideration and immediate shelter to problems rather than replacement of buildings. When deciding on a retrofit, it is important to consider upgrading for accessibility, safety and security at the same time. Designing major renovations and retrofits for existing buildings to include sustainability initiatives will reduce operation costs and environmental impacts, and can increase building adaptability, durability, and resiliency.

Jacketing is a type of retrofitting technique used for strengthening of buildings and structural elements. There are different types of Jacketing such as Steel, Reinforced concrete, Fiber reinforced polymer composite, jackets with high tension materials like carbon fiber, glass fibre etc. and ferrocement jacketing. Major strengthening of foundation may be avoided in these cases.

1.1 Ferrocement Jacketing Process

Ferrocement is a construction material consisting of wire meshes and cement mortar. Ferrocement is a composite construction material which has 95% cement mortar and 5% wire mesh. It consists of closely spaced single or multilayered steel mesh. It is a high performing thin element. It is resistant to elongation, ductility and impact loads of reinforced concrete columns and it is fire and corrosion resistant. Applications of ferrocement in construction are vast due to the low self-weight, lack of skilled workers, no need of framework etc.

Ferrocement Jacketing is one of the retrofitting techniques. Deteriorated and failed reinforced concrete columns are repaired using cement mortar and the sides of the column are restored. The surface of the concrete column is roughened and woven with wire mesh and cement grouted. After it is set, cement mortar is applied and cured for 28 days. Full jacketing provided along the column except small distance from top and bottom to avoid direct loading to ferrocement

2. RESEARCH SIGNIFICANCE

Modern day construction activities face challenges in terms of time and resources. One such construction technique to combat these limitations is retrofitting. There has been several studies based on these, but are limited in case of novelty of techniques. Therefore this experimental investigation focuses on retrofitting of columns using one such technique of retrofitting where the structural element has been preloaded.

This is a study on the effectiveness of ferrocement jacketing in SLTL type wire mesh wrapping for retrofitting of square reinforced concrete columns preloaded with a fraction of its ultimate load carrying capacity and for completely failed columns. To strengthen the columns using Ferrocement jacketing method of retrofitting and to use SLTL type of wire mesh wrapping for ferrocement jacketing with one and two layers for preloads of ultimate load carrying capacity. To study the effect on strength, confinement effectiveness, failure pattern and number of layers of mesh wrapping of columns.

3. EXPERIMENTAL PROGRAMME

The experimental work was carried out with 10 square short columns having equal cross sectional area, area of steel reinforcement and load carrying capacity. The cross sectional area of column is 150×150 mm^2 and length of column is 1.2 m. The short columns were designed for an ultimate load of 225kN.

From these specimens, two columns were considered as control columns to find the ultimate load carrying capacity and the rest eight columns were loaded with 70% and 100% of the ultimate load carrying capacity. They were retrofitted using ferrocement jacketing with one and two layers of wire mesh wrapping of SLTL type. The parameters studied are the amount of preloading, type of wire mesh wrapping and number of layers of wire mesh wrapping.

4. MATERIALS

The cement used for this project work was 53 grade PPC which is manufactured by Ultra-tech. Tests on cement were conducted to find its properties as provided in Table 1.

Fine aggregate generally consists of small particles of grain and minerals which passes through a 4.75mm sieve. The size of the coarse should be greater than 4.75mm and a size up to 80mm can be used for construction purposes.

River sand and M-sand are two types of fine aggregates. Due to the unavailability of river sand, locally available M-sand was used for the project. Tests were carried out for finding out properties of the fine aggregates and are given in Table 2.

The coarse aggregate used for this project work is 20mm in size. Tests were conducted to find its properties which are given in Table 3. Potable drinking water having pH value ranging between 6 and 8 can be used for construction. Therefore water used for this project was potable water free from impurities.

TABLE 1: PROPERTIES OF CEMENT

Property	Test Result	Limit as per IS 1489:1991
Specific Gravity	2.95	-
Fineness	8%	Not more than 10%
Consistency	36%	-
Initial setting time	68 Minutes	Not less than 30 minutes
Final setting time	225 Minutes	Not more than 600 minutes

TABLE 2: PROPERTIES OF FINE AGGREGATE.

Item	Test Result
Specific Gravity	2.75
Fineness Modulus	2.64
Water Absorption	1%
Grading zone	II

TABLE 3: PROPERTIES OF COARSE AGGREGATE.

Item	Result
Specific gravity	2.8
Water absorption	1%

5. WIRE MESH WRAPPING

Welded wire mesh is an electric fusion welded prefabricated joined grid consisting of a series of parallel longitudinal wires with accurate spacing welded to cross. The wire mesh used for the experimental investigation has square openings of 15×15mm and the diameter of the wires were found to be 0.65 mm.

Fig 2 : Wire mesh roll

There are different kinds of wire meshes wrappings available for square concrete columns, such as, SL (Square jacketed single layer wire mesh), RSL (Square jacketed single layer with Rounded corners wire mesh) and SLTL(Square jacketed single layer with Two Layers wire mesh).

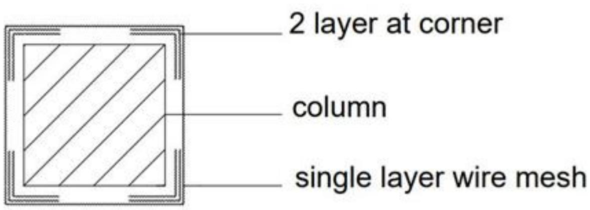

Fig 3 : SLTL type wrapping

SLTL shows highest load carrying capacity than RSL and SL. SLTL shows highest value for both axial and lateral deflection than RSL and SL. [3] Hence SLTL type wrapping was considered for the experiment investigation.

6. REINFORCED CONCRETE SHORT COLUMNS

The columns were designed for an axial compressive load of 225kN as per IS 456:2000. The short columns are of cross section 150mm × 150mm, and length 1.2m. The mix proportion for the design concrete mix was designed as 1 : 1.25 : 2.3 for a water cement ratio of 0.4. The compressive strength of cubes casted were found to be 30N/mm²

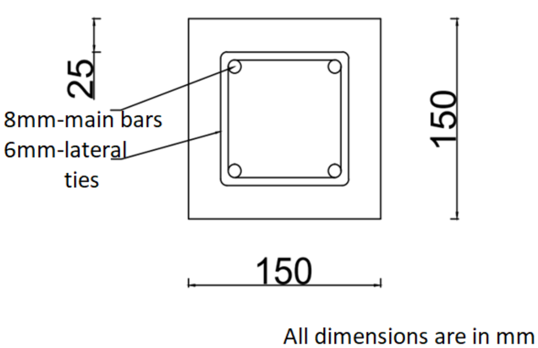

Fig 4: Cross section of short column.

Four 8mm bars were used as longitudinal bars and 6mm diameter bars were used for ties. The ties are kept at 100mm center to center spacing. The reinforcement details are as shown in figure 4 and 5.

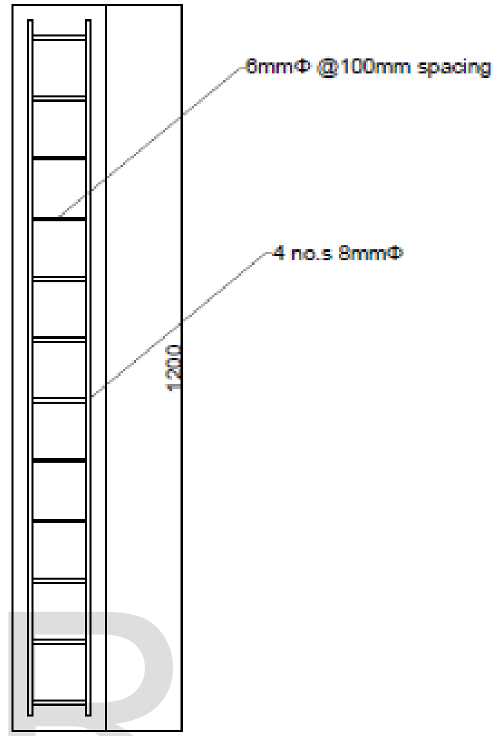

Fig 5: Longitudinal cross section of short column

The short columns were cast with the design mix for M30 grade and required reinforcements at a clear cover of 25mm. The casted columns were demoulded after 24 hours and kept for curing for 28 days using water curing with wet sacks. Details of the casted columns are given in Table 4.

TABLE 4: DETAILS OF SHORT COLUMN SPECIMENS:

Sl no:	Cross section (mm²)	Preload (%)	Number of layers	Identification
1	150×150	0	0	CC1
2	150×150	0	0	CC2
3	150×150	70	1	RC1-70-1
4	150×150	70	1	RC2-70-1
5	150×150	70	2	RC1-70-2
6	150×150	70	2	RC2-70-2
7	150×150	100	1	RC1-100-1
8	150×150	100	1	RC2-100-1
9	150×150	100	2	RC1-100-2
10	150×150	100	2	RC2-100-2

Where, CC1 - Control Column 1, CC2 – Control Column 2, RC1 – Retrofitted Column 1 and RC2 – Retrofitted Column 2 with preloads of 70% and 100% having 1 and 2 layers of wrapping.

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7. PRELOADING AND JACKETING OF COLUMNS

The columns except the control columns were preloaded with their ultimate load carrying capacity obtained from testing of control columns. A 100T hydraulic jack was used in the loading frame with a loading cell of capacity 1500kN and least count of 0.5 kN. LVDTs were used to find the axial deformation with a least count of 0.1mm. The eight reinforced concrete short columns preloaded with 70% and 100% of the ultimate load with 1 and 2 layers of wire mesh wrapping and are then jacketed after 28 days of curing with steel wire mesh of opening size 15mm×15mm and diameter of 0.65mm.

The preloaded columns were checked for cracks and these cracks and corners damaged were restored with cement paste and cement grout. The sides of the specimen were roughened for better bonding between the ferrocement and the columns. The short columns which are preloaded were wrapped with one and two layers of wire mesh of SLTL type and cement grout of mix 1:2 were applied for strong bond along the length of the column. It was kept for curing for 28 days using water curing. Some of these processes are shown in the following figures.

Fig 6 : Casting of short columns

Fig 7: Corners are restored using cement grout and wire mesh cut to required dimension

Fig 8 : Stages of retrofitting of columns

8. TESTING OF SHORT COLUMNS

Control and ferrocement jacketed columns were tested in a loading frame under axial compressive loading with a hydraulic jack of 100T capacity, a load cell and LVDTs. The columns were loaded with compressive load from the bottom of the columns.

The test setup is shown in the figure. It was ensured that the control columns and preloaded column were kept vertical and plates were kept at both ends of the columns for uniform compressive loading throughout the length of the columns and to eliminate any particular displacements. The load was given from one end, that is, the lower end. The ultimate load carrying capacity, axial deformations and failure patterns were observed.

Fig 9: Test setup

9. RESULTS AND DISCUSSIONS

The control columns and preloaded short columns were tested and the following were observed.

9.1 Ultimate Load Carrying Capacity

The short columns were tested under Axial compression and the ultimate load carrying capacity was found as given in the Table 5 and Maximum axial loads obtained from compression testing are also provided in the table 5.

9.2 Number of Wire Mesh Wrappings

The strength gain is highest for Retrofitted concrete columns of 70% preload and 2 layers of SLTL type wire mesh wrapping. It is followed by retrofitted concrete column of 70% preload and single layer of SLTL type wire mesh wrapping. Similarly for 100% preloaded columns strength gain is higher for 2 layers of SLTL type wire mesh wrapping than single layer of wire mesh wrapping.

The Load carrying capacity of 70% preloaded columns retrofitted with one and two layers of wrapping increases by 65% and 86% respectively and that of 100% preloaded columns with one and two layers of wrapping increases by 29% and 43% respectively. Therefore it can be observed that strength gain increases with number of layers of wire mesh wrapping and confinement is more effective with increase in number of layers of wrapping.

9.3 Failure modes

The control columns and retrofitted columns were tested until failure. The cracks developed mainly at top and bottom of the column specimens. The cracks developed for 70% preloaded column are lean cracks at the corners spreading to middle of column whereas for 100% preloaded columns showed wide cracks at corners.

The retrofitted columns that were preloaded with 70% of the ultimate load carrying capacity showed a ductile failure, whereas the 100% preloaded columns showed brittle failure. The Failure patterns of preloaded concrete short columns are as shown in figure 10.

TABLE 5 : ULTIMATE LOAD CARRYING CAPACITY OF COLUMNS

Sl no:	Identification	Ultimate Load (T)	Mean Load(T)	Strength Gain
1	CC1	35	34.75	1
2	CC2	34.5		
3	RC1-70-1	56.5	57.5	1.65
4	RC2-70-1	59		
5	RC1-70-2	65.5	64.75	1.86
6	RC2-70-2	64		
7	RC1-100-1	46	45	1.3
8	RC2-100-1	44		
9	RC1-100-2	49	50	1.44
10	RC2-100-2	51		

Where, CC1 - Control Column 1, CC2 – Control Column 2, RC1 – Retrofitted Column 1 and RC2 – Retrofitted Column 2 with preloads of 70% and 100% having 1 and 2 layers of wrapping.

Fig 10: Crack patterns of tested retrofitted columns

The Load –Displacement curves shows that retrofitted preloaded columns show much higher load carrying capacity than control columns. The failed retrofitted columns outperformed the control columns.

The following curves shows the ultimate load carrying capacity :

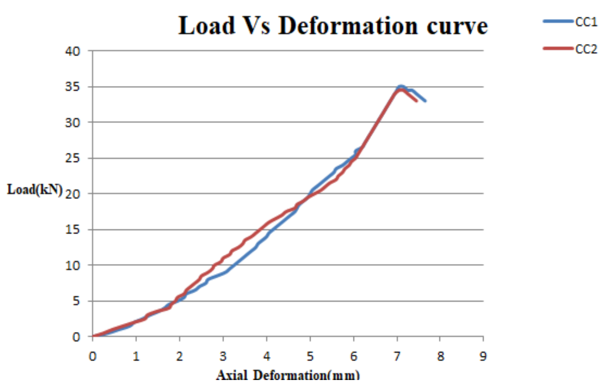

Fig 11: Load – Deformation curve for control columns

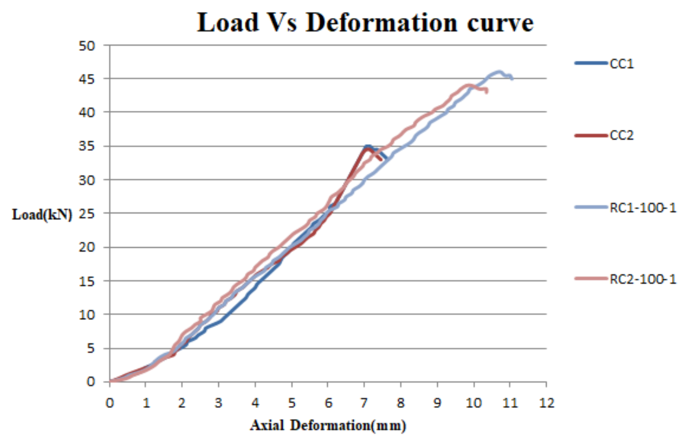

Fig 14 : Load – Deformation curve for 100% preloaded column with single layer of wrapping

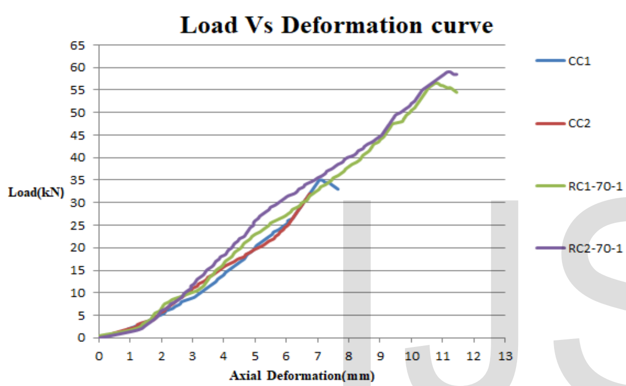

Fig 12: Load – Deformation curve for 70% preloaded column with single layer of wrapping

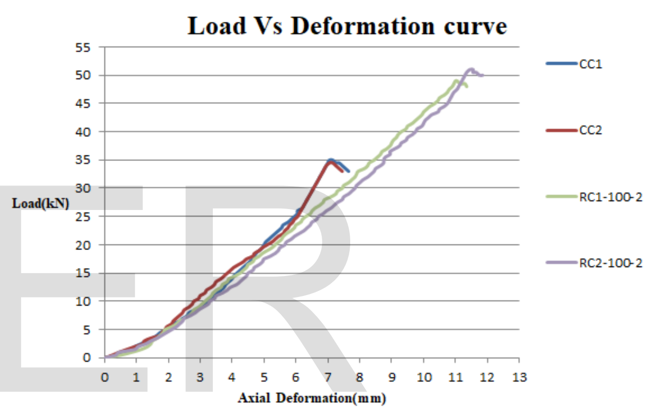

Fig 15 : Load – Deformation curve for 100% preloaded column with two layer of wrapping

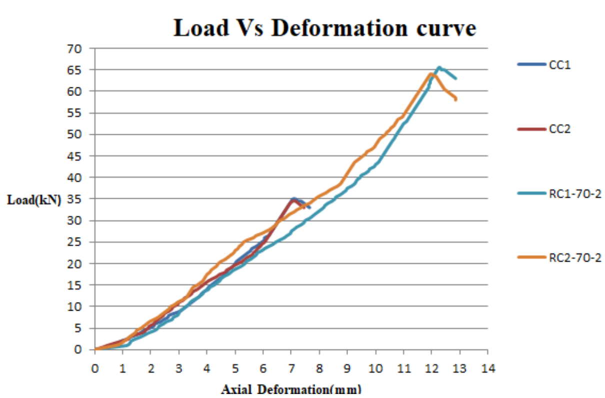

Fig 13: Load – Deformation curve for 70% preloaded column with two layer of wrapping

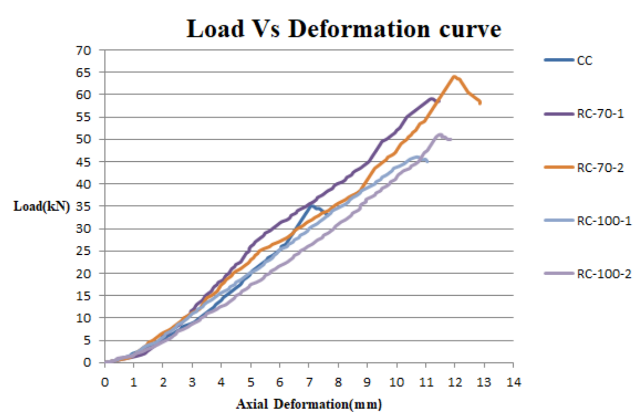

Fig 16: Load – Deformation curve showing the average values

The inference obtained from the experimental tests and result analysis as follows:

- The load carrying capacity of control column is 35 Tonne.
- The Load carrying capacity of 70% preloaded columns retrofitted with one and two layers of wrapping increases by 65% and 86% respectively.
- The load carrying capacity of 100% preloaded columns with one and two layers of wrapping increases by 29% and 43% respectively.
- The confinement is more effective for 70% preloaded columns with 2 layers of wrapping. The strength gain is more for SLTL type of wire mesh wrapping. [1]
- Partially damaged columns shows ductile failure with cracks at top and bottom ends of the columns. Fully damaged columns shows brittle failure, with wide cracks at the corners, spreading to the middle of the columns[1].

From these results , the 70% preloaded columns with two layers of SLTL type wrapping shows higher confinement and higher strength gain.

10. CONCLUSION

The experimental investigation was carried out for short column specimens having equal load carrying capacity and equal cross sectional area was retrofitted with ferrocement jacketing of one and two layers of SLTL type wire mesh wrapping. The specimens were preloaded with a fraction of its ultimate load carrying capacity. Axial compression loads were applied on the specimens and the following were concluded based on the observations the following were inferred;

- Retrofitting using Ferrocement jacketing improves the ultimate load carrying capacity of Reinforced Concrete columns and Square jacketing of SLTL type wire mesh wrappings proved really effective.
- Square concrete columns loaded upto failure with two layers of wrapping showed higher load carrying capacity than the original load carrying capacity.
- The Load carrying capacity of 70% preloaded columns retrofitted with one and two layers of wrapping increases by 65% and 86% respectively. The load carrying capacity of 100% preloaded columns with one and two layers of wrapping increases by 29% and 43% respectively.
- Square concrete columns loaded up to 70% of the ultimate load carrying capacity and up to 100% of ultimate load carrying capacity with 2 layers of wire mesh wrapping showed higher strength gain. The load carrying capacity increases with better ferrocement jacket confinement such as SLTL type wire mesh wrapping than other wrapping methods. [1][3].
- The confinement effectiveness increases with increase in number of layers of wrapping and the Axial deformation behavior increases with increase in number of layers of wire mesh wrapping.
- The Failure pattern of fully damaged column showed brittle failure with wide cracks at the corners spreading to the middle of columns whereas the partially damaged columns showed ductile failure with mild cracks at the corners of both top and bottom of the columns. [3].[1].

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