BEHAVIOUR OF RCC COLUMNS CONFINED WITH FERROCEMENT

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DECLARATION

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ABSTRACT

Retrofitting of the existing structures has become a large part of the construction activity. Columns are the most authoritative structural element in any structure that transfers the entire loads to the foundation. Slenderness ratio is an important aspect that determines the load carrying capacity of the columns. In general, the load carrying capacity of the concrete columns decreases with increase in slenderness ratio. Therefore, the strengthening of deficient columns is necessary to increase the load carrying capacity, ductility and energy absorption capacity that can be achieved by external confinement of column. External confinement can be done by using different materials such as ferrocement, fibre reinforced polymers (FRP), steel jacketing.

Ferrocement confinement is one of the oldest, efficient and cost effective techniques of re-strengthening of deteriorated and weak columns. Ferrocement is a form of thin wall reinforced concrete using wire mesh and high strength mortar. Small diameter of wires used as reinforcement, leads to a higher specific surface, providing homogeneity to the ferrocement. Closely spaced wires provide more ductility and energy absorption capacity. The structures confined with ferrocement undergo deformation above elastic point, unlike conventional concrete structures that undergo brittle failure. Considering all these points in view, the present study focused on the behaviour of RCC columns with different slenderness ratios on the unconfined columns and ferrocement confined columns.

In the experimental part of this thesis, a total of 27 column specimens with three different slenderness ratios (λ) were casted. Three slenderness ratios were considered (i) λ=3; (ii) λ=7; and (iii) λ=15. These specimens were further divided in to three categories. First category consisted of three unconfined control columns from each size group, second category consisted of three column confined with ferrocement using one layer of wire mesh and third category consisted of three columns confined with ferrocement using two layers of wire mesh. All the columns were tested under monotonic uniaxial compression loading. The results showed that ferrocement confinement increased the load carrying capacity and stability of the column by decreasing the lateral deflection. The increase in slenderness ratio resulted in decrease of strength of the ferrocement confinement. It was also observed that in the ferrocement the wire mesh is more effective up to one or two layers.

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CHAPTER 1

INTRODUCTION

1.1 General

Reinforced concrete is the commonly used material for the construction of structures which are designed in accordance to the specifications given in the standard codes to meet the service life. Based upon these specifications, the loads are taken into account for the design of the various elements of the structure like beams, columns and slabs. During the service life if the loading conditions change due to purpose of use of the structure, this can result in non-performance of the structural elements for which it was designed earlier. The structures are also susceptible to deterioration due to earthquake, flood, cyclone, carbonation, chloride attack, environmental pollution, deficiencies of the material used, inadequate design and faulty construction. The environmental stresses/factors like high humidity, air and water pollutants also cause corrosion and develop cracks leading to the failure of structural elements. Replacement of the damaged structural elements is very difficult and cost intensive process and the replacement of a particular structural element in the existing structure also creates risk to the integrity of other connecting members. To restore the required strength of the deteriorated structure, retrofitting is the solution.

Retrofitting can be done in two ways:

- Global Retrofitting
- Local Retrofitting

In Global Retrofitting, the entire structure is retrofitted to fulfil the serviceability requirements. It involves the analysis and design of the entire structure as per the specifications given in standard codes. Whereas, in Local Retrofitting, only specific member of the structure is either strengthened or replaced. Retrofitting can be done by the following methods.

i. Overlaying: it involves addition of concrete sections

ii. Jacketing construction: addition of concrete sections (or confinement)

iii. Vertical girder addition: addition of members is done

iv. Support method: it involves addition of supports

v. Steel plate bonding: addition of retrofitting members

vi. Fibre-reinforced plastic bonding: addition of retrofitting members

vii. Steel plate jacketing construction: addition of retrofitting members

From all the above techniques, jacketing construction is the most preferred method of retrofitting that can be applied by the following techniques:

1. Confinement with fibre reinforced polymers such as aramid fibres, carbon fibres and glass fibre polymers
2. Confinement with external steel caging techniques
3. Confinement with ferrocement

In comparison to the above, retrofitting with ferrocement confinement is the oldest and cost effective technique used to strengthen the concrete structures. Ferrocement consists of closely-spaced and uniformly-distributed reinforcement which provides ductility to the otherwise brittle concrete. This inherent property makes the ferrocement a distinctive composite construction material. The unique properties of ferrocement such as water proof, fire resistant, durability, low self weight and crack resistant makes it an ideal material for wider applications.

1.2 Ferrocement- a Composite Material

Ferrocement is a type of thin reinforced wall commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh (ACI Committee 549-R97, 1997). In-situ casting of ferrocement structures consists of high cement content, low water cement ratio around 0.4, wire mesh layers, light structural steel, admixtures like silica fume, super plasticizers and non-metallic fibres. This makes ferrocement structures high strength to weight ratio. Therefore, self-weight of ferrocement structure is very less as compared to RCC. In its role as a thin reinforced concrete product and as laminated cement-based composite, ferrocement has found itself in numerous applications both in the construction of new structures and repair/rehabilitation of existing structures. Compared with conventional reinforced concrete, ferrocement is reinforced in two directions; therefore, it has homogenous isotropic properties in two directions. Due to these properties, ferrocement shows a high tensile strength and high modules of rupture. Ferrocement is highly waterproof, crack formation resistant, energy absorbing material. During earthquake, the forces at nodal points of ferrocement structures are less accordingly thereby decreasing the damage and devastation. Structural members confined with ferrocement such as beams, columns develop first crack at high value of force reasonably above the elastic point. In addition, because the specific surface of ferrocement reinforcement is higher than that of reinforced concrete, larger bond forces develops with matrix resulting in average crack spacing and crack width of smaller magnitude than that of conventional reinforced concrete. Other unique features of ferrocement include ease of fabrication and low cost in maintenance and repair. Based on these advantages, ferrocement can be effectively utilized for strengthening or retrofitting such as water tanks, boats, housing wall panels, roofs, form work and.

1.2.1 Constituents of ferrocement

Ferrocement consists of cement mortar and steel wire mesh as the main reinforcing material for confinement of the structural elements (Naaman, 2000; ACI Committee 549R-97; and Nassif and Najm, 2004) and each of these materials are separately described in this section below.

1.2.2 Matrix

Portland cement, water, and aggregate form the main matrix used in ferrocement. This mortar matrix comprises 95% of the ferrocement volume and hence determines the final behavior of the resulting product. The chemical composition of the cement, the nature of the aggregate, the aggregate-cement ratio, and the water cement ratio are the major parameters governing the properties of the matrix.

1) **Portland cement:** Portland cement is generally used in ferrocement. But the type of cement should be selected according to the need or environment in which the structure is built. Mineral admixtures, such as fly ash, silica fume, or blast furnace slag, may be used to maintain a high volume fraction of fine filler material as well as to enhance the properties at wet and hardened state.
2) **Aggregates:** Fine aggregate (sand) is commonly used in ferrocement. It should comply with ASTM C 33 requirements (for fine aggregate) or an equivalent standard. The number of factors should be considered while selecting this constituent such as it should comply with ASTMC 33 requirements, clean, free of organic matter, silt, clay etc. Generally, the maximum particle size passing sieve size i.e. 1.18mm is used for most of the ferrocement applications.

3) **Water:** Potable, clean and fresh water of pH ≥ 7 should be used for mixing the mortar matrix constituents.

4) **Admixtures:** To enhance the strength of ferrocement mortar matrix, polymers can be added to concrete in green stage and after construction, surface coatings like polymer based waterproofing coatings, cement based paint coating can be done.

1.2.3 Wire mesh: Ferrocement uses layers of continuous/ small diameter steel wire/ welded mesh (metallic or non-metallic) as reinforcement with high volume fraction (2 to 8%) and the specific surface of reinforcement is considerably higher for ferrocement than for RCC.

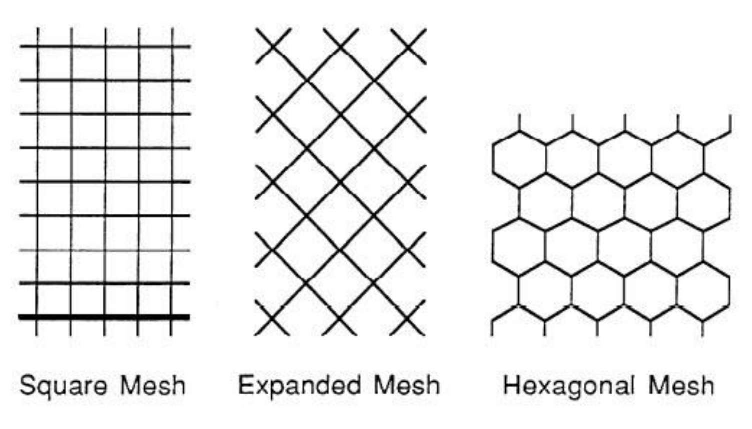


Fig. 1.1 Types of Wire Mesh

Also, the reinforcing steel wire mesh has openings large enough for adequate bonding; the closer distribution and uniform dispersion of reinforcement, transform the otherwise brittle mortar into a high performance material distinct from reinforced concrete. Skeletal of the structure to be built is made first with bars or wires, which are used as spacer material and the mesh layers are later attached to skeletal (Naaman, 2000).

1.3 Advantages of Ferrocement Technology

- **Ferrocement is an isotropic material** up to 40% of the yield and its density is about 2750 kg/m^3. RCC material is a heterogeneous material (density 2500 kg/m^3) consists of voids and capillaries. Therefore, water and other gases easily entrapped in the concrete material which cause crack formation, spalling and corrosion of reinforcement. Moreover, the cracks formed over RCC structures are wide and deep whereas minute and shallow cracks are formed in the ferrocement structures. Structural members of ferrocement remain free of voids and capillaries hence remain corrosion resistant and water proof due to these properties.

- **Ferrocement has high strength to weight ratio**. Ferrocement is thin section high strength structural material highly waterproof, crack formation resistant, energy absorbing material. It is manufactured with high cement content, low water cement ratio around 0.4, wire mesh layers, light structural steel, admixtures mainly silica fume super plasticizers, non-metallic fibres, particularly when ferrocement is cast-in-situ. Therefore self-weight of ferrocement structure is very less as compared to RCC.
- **Ferrocement is highly ductile, resilient, energy absorbing material.** When put under load it develops cracks at a much higher value after the elastic limit. Because of this property a ferrocement structures frame will not collapse like RCC and therefore there will be least loss of life and property. Ferrocement structures do not collapse but get deformed. A large number of such structures as compared to RCC can be easy to repair. The debris formation will also be the less.

1.4 Ferrocement Structural Elements

Ferrocement confined beams and columns are constructed with ferrocement as a skin on the periphery surface. These skins consist of layers of wire mesh, welded wire mesh, high tensile strength wires, mild steel flats, etc. The core consists of high strength concrete. Due to its better crack arresting property and high ductility this arrangement increases the resistance to bending moment, shear, and torsion. The crack formation can be delayed further by addition of fibres on the surface if feasible. Ferrocement confined beams and columns can be further strengthened by welding the mild steel flats, rings in the form of flats angles etc. and round bars at each and every crossing. Therefore there is induced resistance to deflection during fabrication stage itself. This process makes the ferrocement structures highly energy absorbing, resilient and ductile. Ferrocement slab about 20 to 25mm thick consists of grid of Mild Steel flats, wire mesh layers on top and bottom. Welded wire mesh, High Tensile Strength wires can be used in case greater thickness is required.

1.5 Implication of Ferrocement Technology

Ferrocement can be used in various structural members subjected to different type of stresses. As a compression member, hollow columns with horizontal stiffeners can be cast in ferrocement. Columns or walls in concrete, RCC, stone or brickwork can be encased in ferrocement to increase their strength due to confinement. Members subjected to membrane stresses like shells, domes, pyramids can be cast in ferrocement very easily; and being a homogenous material, full section of member is utilized in resisting the membrane stresses. Implication of ferrocement technology in various structures is discussed below.

1.5.1 Horizontal and vertical extension of RCC structures

Vertical extension with ferrocement columns, beams, slabs is much convenient. It is possible to have more additional floors. Since ferrocement has much less self-weight about 50% as compared to RCC. Ferrocement columns, beams are of small sections and ferrocement slabs are thin, say about 40 – 50mm thick. This is because ferrocement is much strong material. In view of small section reinforcement and very high bond strength development, permissible stresses in ferrocement are much high as compared to RCC. Therefore extension of building with ferrocement columns, beams, slabs can have more additional floors than that is possible with RCC. At extra expenditure of removing the existing load of brick work etc. from existing floor, it can be possible to have still more additional floors.

Vertical and horizontal extension by ferrocement Technology is more convenient and feasible since the self-weight of ferrocement element is quite low. Also since the ferrocement element such as beams, slabs are manufactured away from the site cause less inconvenience to the occupants of the building. The time of providing extension work to the building at site is reduced by about 50% since the activity of precast is carried out at other locations.

1.5.2 Ferrocement water storage tanks and water towers

Ferrocement has been used for the construction of water tanks which has shown excellent performance since more than two decades (Moita et. al., 2003). The ferrocement water Tower tanks are most efficient from the point of earthquake and wind. The main reason is that self-weight of the ferrocement water storage tank on the tower is less by more than 50% as compared to RCC.

1.5.3 Resistance to earthquake by ferrocement structures

Ferrocement structures are highly ductile and energy absorbing material that can sustains large deformations without collapsing during earthquakes. Moreover the deformed building structures can be easily repaired at very low cost after deformation. Ferrocement structures resist the earthquake of Richter scale 7.2-7.4 whereas RCC structures collapsed. One such example of strong earthquakes that occurred in Mexico in 1999 twice Richer scale 7.2 & 7.4. These earthquakes destroyed or severely damaged thousands of houses, hundreds of schools and churches and took many lives. The Ferrocement structures such as school, all houses, the class room laboratory, the largest auditorium, all the bridges and small dams that have been designed and constructed were untouched.

Ferrocement structures constructed on small scale in Bhuj, Saurashtra and Ahmedabad have performed very satisfactorily with no crack development at all. Ferrocement structures constructed in Orissa under direction of HUDCO, have withstood fury of cyclone very satisfactory.

1.5.4 Ferrocement membrane waterproofing

Waterproofing to R.C.C. structure is carried out with modern material known as Ferrocement. It is carried out generally in two layers of about 8 mm thickness each layer. It consists of ire mesh reinforced cement matrix layers which are vibrated in situ. The top surface also vibrated finished smooth with non-metallic fibres impregnation. The cement matrix and wire mesh layers are laid alternately. Each cement matrix layer is laid on a bond coat for assured integrity. Each wire mesh layer is fixed with u-clips to the base. The performance of the treatment is most excellent. Because in situ low water cement ratio cement matrix is vibrated and become dense with nil/negligible pores. The wire mesh layers generally two nos. prevent crack formation, if at all due to shrinkage, temperature or structural relative movements. Therefore the treatment is durable and permanent. It takes ware and tare efficiently due to certain admixtures. The wire mesh layers add strength to the main structure in addition to crack formation prevention. It is laid on insulated foundation layer of about average thickness of 40 mm. There will be dead load reduction to conventional brickbat coba treatment. It adds strength to base structure.

1.5.5 Waterproofing of subways and basements by ferrocement waterproof panels

Waterproofing of subways and basements is best carried out using ferrocement waterproof panels boxing. Ferrocement waterproof panels are manufactured on machinery set up under controlled conditions. The panels are manufactured with least water cement ratio of around 0.35, well vibrated mechanically and sand cement ratio about 2.5. Wire mesh layers confine cement matrix and makes all the more resistant to crack formations if at all. The panels are laid horizontally on plain cement concrete for raft and joined with high quality vibrated cement duly welded and wire mesh lapping. Therefore panels are totally waterproof. On these panels reinforcement of raft is laid and concreting carried out with total Waterproofing for walls reinforcement is erected waterproof panels are erected vertically on the outside. The wall panels are connected with ferrocement panels of raft. The panels act as formwork. Concreting of walls is carried out with conventional formwork on the inside. Thus wood/steel shuttering is eliminated on the outside. To that extent, cost of formwork is reduced. The reinforcement of Ferrocement panels for raft as well as walls can reduce the reinforcement of raft and walls to certain extent. The Ferrocement Formwork panels add strength to raft and walls. Ferrocement precast panel boxing is most efficient and assured waterproof treatment leaving no chance for any leakages.

1.5.6 Ferrocement rain water harvesting system- drains & tanks

The drains for flow of rain water and the tank for storage of rain water is best constructed using Ferrocement technology, which is far superior, durable having least maintenance, least self weight and most tidy. The ferrocement drains are machine made precast products about 2.4 to 5 metres long with covers with perforations of the same length about 25 mm thick. The surfaces of these drains are very strong and not eroded by flow of water. The bottom and sides of the water storage tanks consist of ferrocement plates with space frame. These plates are about 25 mm thick, waterproof, strong, durable and have least maintenance.

1.5.7 Ferrocement roof

The ferrocement roof consists of panels of size 1.5m. x 1.2m approximately and ferrocement portal and purlins replacing AC sheets and structural steel trusses and purlins. Unlike AC sheet Metal, FRP roof all the ferrocement panels are joined monolithically. There will be no nuts and bolt arrangement as in the case of AC sheet Metal, FRP roofs. But ferrocement panels shall be connected to the purlins and portal by welding and in-situ vibrated cement matrix application. There will be least heat transfer as compared to AC sheets etc. The space below the roof shall be neat and clean since the steel trusses are eliminated. There will be far better storage space below without obstruction.

1.5.8 Ferrocement is the best fire resistant material

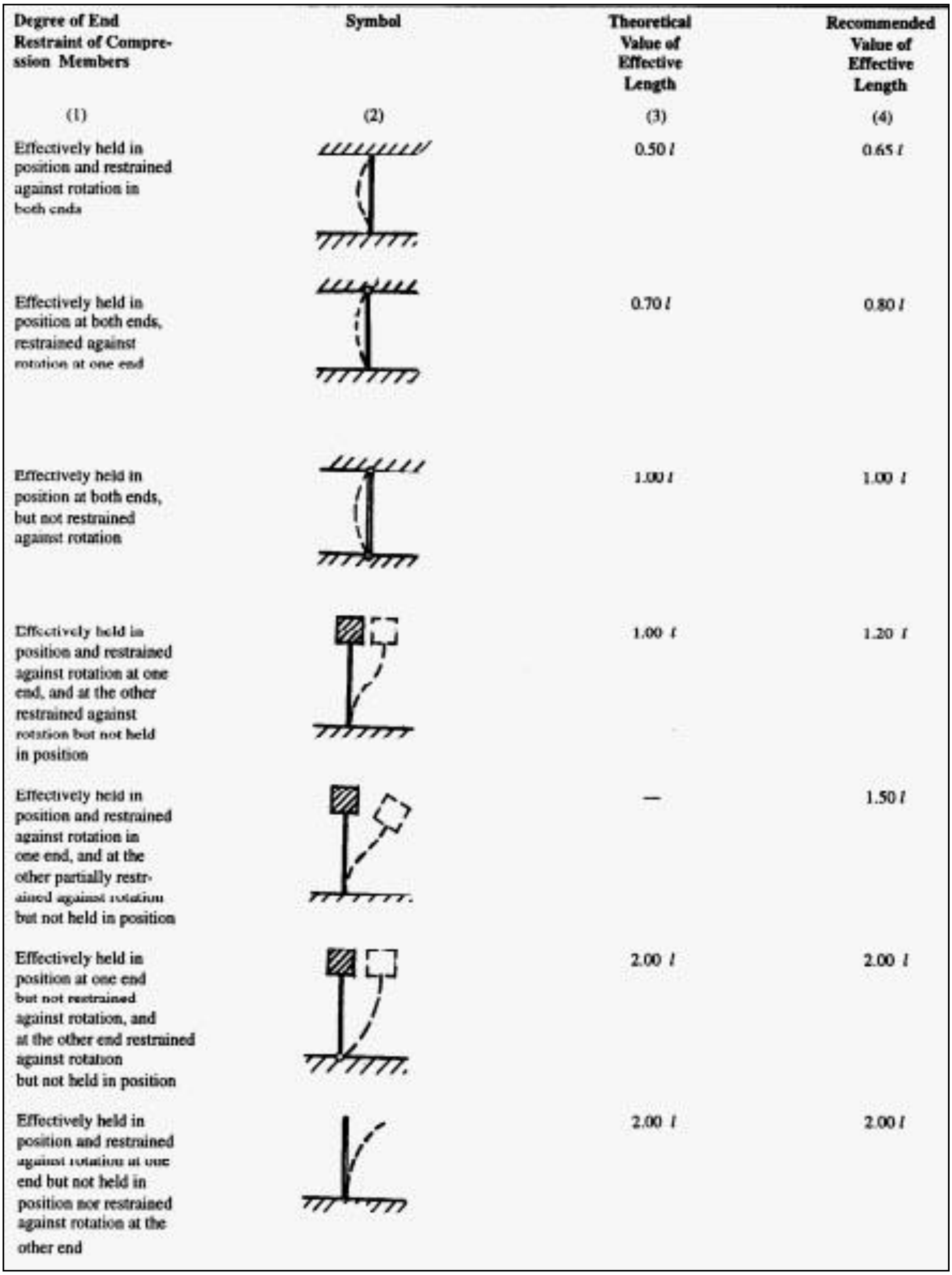
Ferrocement resists fire better than RCC and steel. Ferrocement is efficient fire resistant material. Ferrocement is sustainable against fire. Ferrocement resists fire due to it being almost insulating material at the same time having isotropic feature till about 35% of the yield. The expansion of Ferrocement due to fire is without any splitting, cracking of cement matrix and detachment from steel surfaces, the bond being very high. Also there is almost nil surplus water for steam formation. And this resistance is so strong that no damage is caused even up to high Ferrocement resists fires for 1.5 hours against a temperature of 1700^{o}C. The damage to the houses is negligible and can be repaired.

1.6 Column-the Authoritative Structural Element

Column is the most authoritative structural element because it carries the entire load of the structure. The failure of the column leads to the total collapse of the whole frame structure as it transmits the vertical loads to the foundation. Columns may be cast to any of the following shapes,

- Square
- Rectangular
- Circular
- Hexagonal

The effective length of the column depends on the degree of fixity of the ends of the columns. IS 456:2000 provides recommendations for the effective length of the compression members as shown in Fig. 1.2. The different end conditions govern the behavior of column in different loading conditions.



Degree of End Restraint of Compression Members	Symbol	Theoretical Value of Effective Length	Recommended Value of Effective Length
(1)	(2)	(3)	(4)
Effectively held in position and restrained against rotation in both ends		0.50 l	0.65 l
Effectively held in position at both ends, restrained against rotation at one end		0.70 l	0.80 l
Effectively held in position at both ends, but not restrained against rotation		1.00 l	1.00 l
Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position		1.00 l	1.20 l
Effectively held in position and restrained against rotation in one end, and at the other partially restrained against rotation but not held in position		—	1.50 l
Effectively held in position at one end but not restrained against rotation, and at the other end restrained against rotation but not held in position		2.00 l	2.00 l
Effectively held in position and restrained against rotation at one end but not held in position nor restrained against rotation at the other end		2.00 l	2.00 l

where “ l ” is the unsupported length of the compression member.

Fig. 1.2 Effective Length of Compression Members

As the effective length of the column increases, the load carrying capacity is influenced by the end conditions. The columns are classified on the basis of slenderness ratio (λ) into two categories as under:

- Short Column
- Long Column

Slenderness ratio (λ) is the ratio of length to diameter/ least lateral dimension. If the value of slenderness ratio (λ) is less than 12, the column is considered as Short Column and if the value is greater than 12, the column it is considered as a Long Column. The short column has more load carrying capacity than the long column of the same cross section.

Retrofitting or reconstruction of the cracked or corrosive column is the necessary task to prevent the further damage to the whole structure. External confinement of the RC column increases the ultimate load carrying capacity and imparts ductility to the core concrete. The strength of the column is greatly influenced by the length.

The mode of failure of the short column is mostly in compression whereas the long columns fail with a buckling mode. The slenderness ratio governs the mode of failure. In compression mode of failure, the column has a tendency of failure either near the top or bottom of the column with a brittle fracture followed by the rupture of the core concrete. Long columns fail near the middle of the length showing large lateral deflection as compared to small deflection exhibited by the short columns.

1.7 Objectives

The present research is aimed to evaluate the effectiveness of wire mesh confinement in strength deficient columns. This was achieved by comparing the behavior of ferrocement confined columns with that of the reinforced unconfined columns. For this study the following objectives are framed:

- To study the improvement in load carrying capacity with slenderness effect in columns
- To study the first crack load and mode of failure
- To study the effectiveness of the ferrocement confinement with different percentage of wire mesh

CHAPTER 2

REVIEW OF LITERATURE

2.1 Ferrocement Technology

Ferrocement components are of thickness in the order of 10-25 mm and uses rich cement-sand mortar; only fine aggregate is used; and the reinforcement consists of one or more layers of continuous/ small diameter steel wire. Wire mesh is of different diameter wires woven/ welded in different shapes (rectangular, square, hexagonal etc). Ferrocement uses high volume fraction of reinforcement (2 to 8%) and the specific surface of reinforcement is considerably higher than RCC. In ferrocement, due to small spacing of reinforcement wire mesh it allows better dispersion of the load on the surface and cracks are minimised (Desai, 2011). Also, due to the openings of the wire mesh, it allows the adequate bonding, closer distribution and uniform dispersion of the reinforcement making the brittle mortar into a high performance material distinctly different from reinforced concrete. Moreover, the skeletal of desired shape can be fabricated with help of mild steel bars/ mild steel sections used as spacer material, around which the mesh layers are, attached (Naaman, 2000). As the fabrication and application of wire mesh is easy task so it requires less skilled labour for casting (Ferro 7, 2001). Due to the unique properties of ferrocement it can be widely accepted over conventional material like stone, brick, RCC, steel and timber. Ferrocement can be applied to form structural components such as walls, floors, roofs, beams, columns, silos, swimming pools etc (Divekar, 2011; Dongyen et. al., 2006; Kondraivendhan & Pradhan, 2009).

2.2 Research on Ferrocement Properties

The unique properties of ferrocement have been investigated extensively by many researchers. Naaman (2000) described the distinctive physical and mechanical properties of ferrocement. Ferrocement has high tensile strength and stiffness due to the confinement with two-dimensional reinforcement of the mesh system and undergo large deformations before cracking or high deflections before collapse.

Abdullah and Takiguchi (2003) investigated the square columns using both square and circular ferrocement simultaneously under compressive and cyclic loading. For the study three types of columns were considered. A total of six identical reference RC columns, based on about 1:3–1:8 scale were constructed. Three columns, designated as CJ-AL10-6L, CJ-AL15- 6L, and CJ-AL20-6L were tested under different axial loads after being strengthened with circular ferrocement jackets containing six layers of wire mesh. Specimen CJAL15-6/3L, strengthened with reduced number of layers of wire mesh for the centre portion, was tested to investigate the behavior and strength of the important practical aspect of strengthening RC column with ferrocement. Two reference columns, SJ-AL15-4L and SJAL15-6L, were strengthened with square ferrocement jackets, with four and six layers of wire mesh, respectively, before tested to their failure to study the effects of different shapes of jacketing on lateral load–displacement response. Each of the reference columns was reinforced with 12 deformed D-6 bars distributed evenly around the perimeter of the column cross-section. Smooth R-2 (diameter¼2mm) bars were used as transverse reinforcement spaced at 50 mm.

Kondraivendhan and Pradhan (2009) studied effect of ferrocement confinement on behavior of concrete. The effect of different grades of concrete confined with ferrocement was studied by keeping all other parameters constant. In this investigation, concrete mixes had been chosen over a wide range of grades of concrete, namely M25, M30, M35, M40, M45, M50 and M55. The M25, M30, M35, M40, M45, M50 and M55 have a characteristic compressive strength of 25N/mm^2, 30 N/mm^2, 35 N/mm^2, 40 N/mm^2, 45 N/mm^2, 50 N/mm^2 and 55 N/mm^2, respectively. A total of 42 cylindrical specimens (21 each for controlled and confined specimens) with a diameter of 150 mm and a height of 900 mm, three replicates for each grade of concrete, were cast. Column specimens of size 150mm x 900mm with different grade of plain cement concrete were casted and then confined with ferrocement. It was found that with the increase in compressive strength of the concrete significantly improved in lower grades of concrete such as M25 which showed 78% increase as compared to higher grade of concrete M55 which resulted in an increase of 45.3%.

Turgay et. al. (2010) studied the effect and failure mechanisms of large-scale square/ rectangular columns wrapped with fiber reinforced polymer (FRP). The experimental research program studied the performance of large-scale square RC columns wrapped with carbon fiber reinforced polymer (CFRP) sheets. Moreover, the research was mainly focused on the investigation of the total effect of longitudinal and transverse reinforcement and FRP jackets on the behavior of concentrically loaded columns. A total of 20 large-scale RC columns were fabricated and tested to failure under axial loading in the structural laboratory. Three types of columns were primarily considered: unwrapped; fully wrapped; and partially wrapped. Five different test series were conducted: unwrapped (C1); partially wrapped (C2); fully wrapped (C3); partially wrapped with two-layers (C4); and fully wrapped with two-layers (C5). The dimensions of all the columns were 200 x 200 mm square section and 1000 mm in height. Each column was tested under uniaxial compression using a testing machine with a capacity of 2000 kN. The standard cylinder compressive strength of concrete mix are 18.08 MPa and 19.36 MPa 28 days and 60 days, respectively. All the specimens were subjected to monotonically increasing compression up to the fracture. Fully wrapped specimens with a slenderness ratio of 5:1 fractured at the top or bottom quarters whereas the partially wrapped columns show failure at the ends of confined regions. The partial wrapping with one-layer of CFRP results an increase in ductility and this is much more pronounced for RC columns with eight longitudinal bars. Finally, for all RC columns fully wrapped with one-layer of CFRP, transverse reinforcement with a diameter of 12 mm clearly enhances the beneficial effect of CFRP on ductility.

Xiong et. al. (2011) studied the load carrying capacity and ductility of circular concrete columns confined by ferrocement including steel bars (FS) where they are proposed to increase the compressive strength along with the ductility. The behaviour of the ferrocement strengthened columns was compared with the bar mat-mortar (BS) and fibre reinforced polymer (FRP) wrapped columns under uniaxial compression. The dimensions of the concrete cylindrical columns were, 105 mm (dia) x 450mm and 150 mm (dia) x 450mm. After wet-curing (24 hrs), the samples were transferred to curing room for 27 days. The specimens with 105 mm (dia) were confined with FS or BS whereas 150mm (dia) with FRP. The comparative analyses of these samples show that the compressive strength of FS columns was enhanced by 30% than that of BS columns. Due to ferrocement caging along with steel bars specimens showed higher ductility, compressive strength and energy absorbing capacity than BS or FRP strengthened circular columns.

Kaish et. al. (2012) studied the effect of ferrocement jacketing with some modifications. Three types of ferrocement jacketing techniques were used to confine the column specimens that are; square jacketing with single layer wire mesh and rounded column corners (RSL); square jacketing using single layer wire mesh with shear keys at the centre of each face of column (SKSL) and square jacketing with single layer wire mesh and two extra layers mesh at each corner (SLTL) are considered for this purpose. The specimens were tested under concentric and eccentric modes of loading. These methods of confinement significantly improved the ultimate load capacity, axial deflection and lateral deflections.

In first phase, crushing strength of cylinder was 22.9 MPa and in second phase, crushing strength of cylinder 24.2 MPa. The size of tested column specimens of the first phase of testing was considered as 600 mm long and cross section of 100x100 mm^2 (L : b = 6:1) with reinforcement of 4 deformed 8 mm diameter longitudinal mild steel bars and 5 mm diameter plane tie bar with a vertical spacing of 100 mm c/c. In the second phase of testing, sectional dimension and longitudinal bar specification of column specimens were kept the same as that of the first phase. However in the second phase, tie bars were placed closely at a vertical spacing of 50 mm at both top and bottom parts of column specimens and in middle part, it was placed at the same spacing of the first phase. In the second phase, 3 mm thick steel plates were welded with longitudinal bars at both ends of column specimens so that both the concrete and longitudinal bars come into action together when vertical load is applied. RC column specimens were jacketed with different types of ferrocement jacketing after 7 days of casting. Final cross-section of jacketed specimens was fixed as 124x124 mm^2 including 12 mm thick ferrocement jacketing. After completing ferrocement jacketing, all specimens were cured in the water for 28 days from the date of column specimen casting. All the specimens were tested under hydraulic compression testing machine of capacity of 2000 kN. Load was applied at the top of the specimen until failure. In case of eccentric loading, eccentricity was kept constant for both the benchmark and the jacketed specimens and it was taken as 25 mm from the centre point of the specimen. This report concluded that improved square ferrocement jacketing schemes introduced in this study are effective to overcome the drawbacks of conventional square ferrocement jacketing of square RC column and could be used effectively for re-strengthening of square RC column subjected to both concentric and eccentric loadings after taking proper care in jacketing schemes.

Mourad and Shannag (2012) studied the column specimens for the ultimate load capacity and stressed samples confined with ferrocement using welded wire mesh as the confining material. In case of pre-stressed specimens, the results showed that the confining increased the load carrying capacity to 33%. Ductility of the specimens also increased. In case of stressed samples to a value of 60% and 80% of the ultimate load capacity, the confinement enhanced the ultimate load capacity to 28% and 15% respectively. With the confinement the column specimens failed in a ductile manner as compared to brittle failure of the control specimens.

2.3 Relevance of the Present Study

Column is one of the most important structural members, which is designed to support mainly the compressive load. Lateral confinement by means of lateral individual ties or continuous spiral in RC column enhances the performance of the same against axial as well as lateral loads. It is also necessary to provide lateral confinement to ensure large deformation under load. Sometimes additional confinement may be necessary in case of re-strengthening or rehabilitating of existing substandard columns. Confinement is done to prevent the stress concentration and subsequent cracking at the corners of column and bulging out of confined material.

Experimental and analytical studies on the confinement effect and failure mechanisms of ferrocement jacketed columns have been conducted over several years. The typical axial members are long square/rectangular reinforced concrete (RC) columns in practice; however, most of the studies are concentrated on the behavior of small square/ rectangular or circular concrete columns. The available data for square/rectangular based upon slenderness ratio and ferrocement confined columns is still limited. This study reports the results of an experimental research program on the performance of long columns and square in cross section confined with ferrocement. This report is focused on the investigation of the effects of ferrocement confinement on long columns and its behavior under concentric load. The performance of the ferrocement jacketed long columns is also compared with the confined short columns. Further, the behaviour of confined columns was also studied with their respective controls (unconfined specimens). A total of 27 RC columns were casted and tested to failure under concentric axial loading.

CHAPTER 3

EXPERIMENTAL PROGRAMME

The main object of the present thesis is to study the effect of slenderness ratio on the load carrying capacity of the concrete columns confined with ferrocement. In this study, with two varying properties of columns, slenderness ratios and confinement with ferrocement are considered. For the experimental work twenty seven specimens of different size groups were casted. The load carrying capacity and ultimate deflection are observed and analysed in the subsequent chapters.

3.1 Materials

Cement, fine aggregates, coarse aggregates, reinforcement steel bars are used in casting of columns. For the application of GI wire mesh on column surface cement mortar is used. The detailed specifications of the materials are as under:

3.1.1 Cement

Portland-Pozzolana Cement was tested and used for the concrete mix and mortar. The physical properties obtained from various tests are listed in Table 3.1. All tests are carried out in accordance to procedure laid in IS 1489 (Part 1): 1991.

3.1.2 Fine aggregate

Local sand was used as fine aggregate in concrete mix and cement mortar. The physical properties and sieve analysis results of sand are shown in Table 3.2 Table 3.3.

3.1.3 Coarse aggregate

Crushed stone aggregate of 10mm and 20mm size in ratio of 1:1 were used for concrete. The physical properties and sieve analysis results of coarse aggregate are shown in Table 3.4, Table 3.5 and Table 3.6.

3.1.4 Water

Potable water, free from organic matter, silt, oil, sugar, chloride and acidic material as per Indian Standard was used for the entire concreting and mortar application.

Table 3.1 Physical Properties of Cement

S.No.	Property	Value Obtained Experimentally	Value as per IS: 1489-1991
1	Standard Consistency	34	-
2	Fineness of cement as retained on 90 micron sieve 'in %'	0.5	Min 0.1
3	Setting Time (in minutes)		
	Initial Setting time	130	Min 30 minutes
	Final setting time	460	Max 600 minutes
4	Specific gravity	3.0	
5	Compressive strength (N/mm^2)		
	7 days	24.19	Min 22
	28 days	35.89	Min 33

Table 3.2 Physical Properties of Fine Aggregate

S.No.	Property	Value Obtained Experimentally
1	Specific gravity	2.67
2	Bulk density loose (kg/lt)	1.50
3	Fineness modulus	2.65
4	Water absorption	1.8 %
5	Grading zone (based on percentage passing 0.6 mm)	Zone II

Table 3.3 Sieve Analysis of Fine Aggregate

Total weight taken = 1000 gm

S. No.	Sieve size	Mass retained (gm)	Percentage retained	Cumulative percentage retained	Percentage passing
1	4.75 mm	15.5	1.55	1.55	98.45
2	2.36 mm	101.5	10.15	11.7	88.30
3	1.18 mm	249.5	24.95	36.65	63.35
4	600 µm	139	13.90	50.55	49.45
5	300 µm	221	22.10	72.65	27.35
6	150 µm	202	20.20	92.85	7.15
				∑=265	

Fineness modulus of fine aggregate = 265 / 100 = 2.65

Table 3.4 Sieve Analysis of Coarse Aggregate (20mm)

Total weight taken = 10000 gm

S.no.	Sieve size	Mass retained (gm)	Percentage retained	Cumulative percentage retained	Percentage passing
1	40 mm	0	0	0	100
2	20 mm	0	0	0	100
3	10 mm	4846	48.46	48.46	51.54
4	4.75 mm	3879	38.79	87.25	12.75
5	Pan	1275	12.75		
				∑=135.71	

Fineness modulus of 20 mm coarse aggregate = (135.71+500) / 100 = 6.35

Table 3.5 Sieve Analysis of Coarse Aggregate (10mm)

Total weight taken = 10000 gm

S. No.	Sieve size	Mass retained (gm)	Percentage retained	Cumulative percentage retained	Percentage passing
1	40 mm	0	0	0	100
2	20 mm	0	0	0	100
3	10 mm	985	9.85	9.85	51.54
4	4.75 mm	8345	83.45	93.3	12.75
5	Pan	670	6.7		
				∑=103.15	

Fineness modulus of 10 mm aggregate = (103.15+500) / 100 = 6.03

Table 3.6 Physical Properties of Coarse Aggregate

Total weight taken = 10000 gm

S.No.	Characteristics	20 mm	10 mm
1	Type	Crushed	Crushed
2	Specific gravity	2.60	2.68
3	Total water absorption (% age)	3.62	1.58
4	Fineness modulus	6.35	6.03

3.1.5 GI wire mesh

GI steel wire mesh of 0.45 mm dia wires woven in square pattern was used for confinement in ferrocement. The grid size of mesh was 6mm x 6mm. Steel mesh is shown in Fig. 3.1. Table 3.7 shows the properties of GI wire mesh.

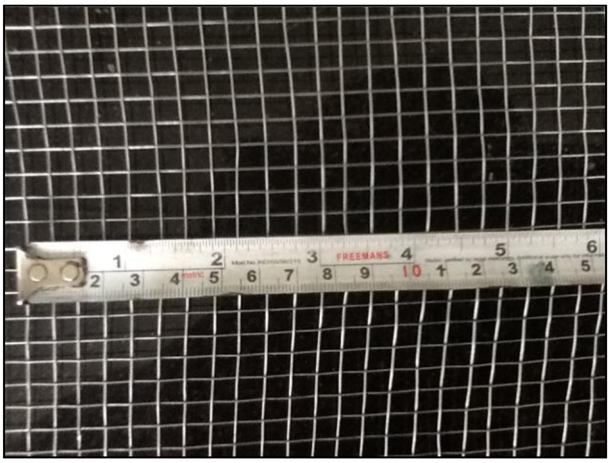


Fig. 3.1 GI Wire Mesh

Table 3.7 Properties of GI Wire Mesh

Diameter of wire	0.44mm-0.46mm
Ultimate Tensile Strength of wire kg/mm^2	88
Mesh opening size	6mm x 6mm square mesh

3.1.6 Concrete Mix

Concrete mix is designed as per Indian Standard using the properties of materials as discussed in Table 3.1 to Table 3.6. The proportions of concrete design mix came out to be 1:1.61:1.475:1.475 (cement: sand: 10mm coarse aggregate: 20mm aggregate) by weight. The water cement ratio was kept 0.5. The cement concrete cubes 150mm x 150mm x 150mm were casted and compressive strength after 28 days was recorded 29.71 N/mm^2.

3.1.7 Mortar Mix

In ferrocement application cement sand mortar of ratio 1:3 was used. The water-cement ratio of 0.4 was used.

3.2 Casting of Reinforced Concrete Column Specimens

Cement Concrete is a mixture of well proportioned cement, coarse aggregates, fine aggregate and water. For the reinforcement steel bars of various diameters are used and for confinement with ferrocement GI wire mesh was used.

The grade of design concrete mix was M20. The column samples in three size groups; nine columns of (100 x 100 x 300mm, λ= 3), nine columns of (100 x 100 x 700mm, λ= 7) and nine columns of (100 x 100 x 1500mm, $\lambda=15$) were casted. Each column was reinforced with 4 bars of 8mm dia as longitudinal reinforcement and 6mm dia stirrups @ 150mm c/c. The reinforcement used was of Fe 415 grade.

For each group, three columns were kept as control samples. Six samples from each were hand chiselled to obtain a rough surface. After surface cleaning, three columns were confined with one layer of steel wire mesh and three columns were confined with two layers of GI wire mesh in each group.

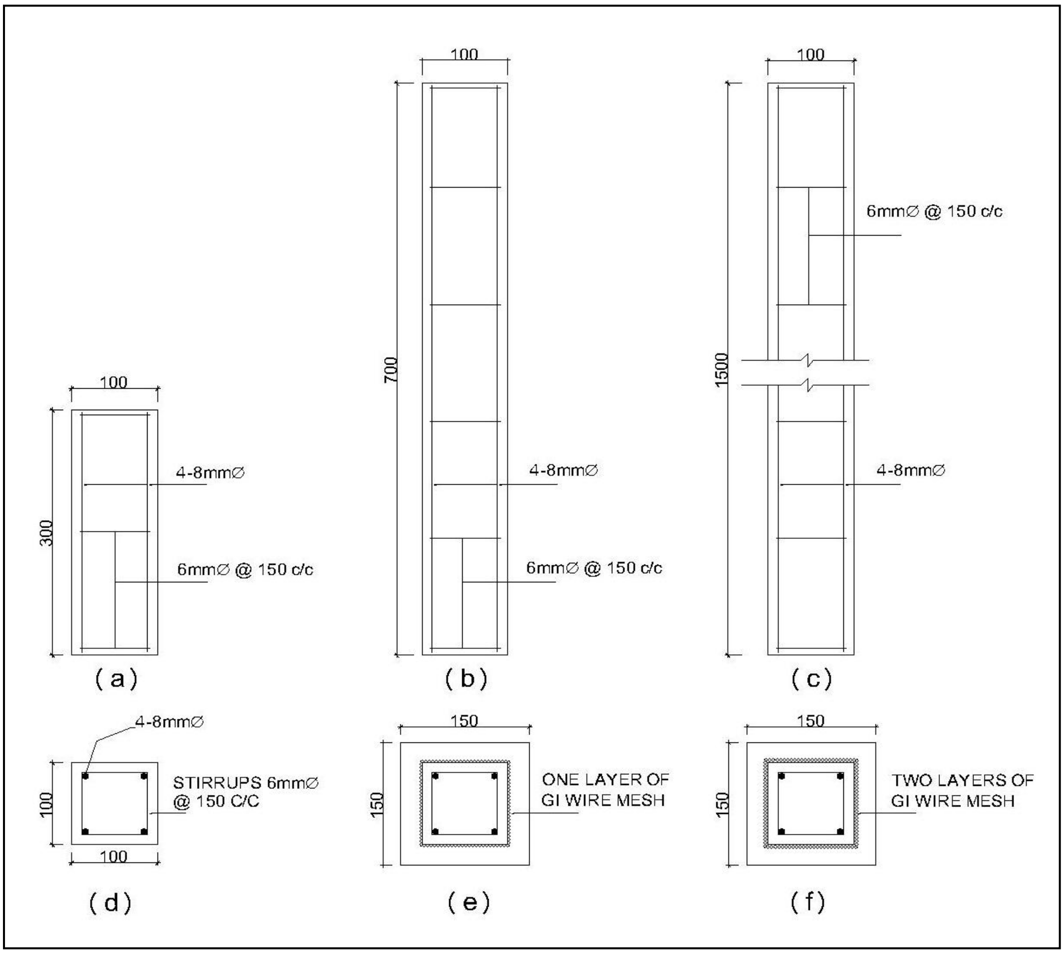


Fig 3.2 Detail of Control and Confined Columns

3.3 Confinement of Column Samples with Ferrocement

For the confinement of the concrete column with ferrocement, the surface of the samples was hand-chiselled and any dust or loose particles were removed with washing and allowed to air dry. After surface preparation column samples were wrapped with one layer of GI wire mesh followed by the application of layer of cement mortar 25mm thick to achieve a square width of 150mm x 150mm.

In the second phase of experiment, column samples were wrapped with two layers of GI wire mesh with continuous wrapping with overlapping of second layer followed by plastering with cement mortar of 25mm thickness to achieve a width of 150mm x 150mm on all faces. Proper curing is necessary to develop the required strength of the mortar. A curing period of 28 days is suggested; however, at least curing in the first two weeks is essential and should start 24 hours after final application of the mortar to avoid shrinkage cracks. Fig. 3.3 shows the confinement of the columns with one or two layers of wire mesh. Fig. 3.4 shows the application of the mortar over wire mesh.

Fig. 3.3 Columns Confined with One or Two Layers of Wire Mesh

Fig. 3.4 Columns Confined with Mortar Layer

The details of control and confined column specimens are described in Table No 3.7

Table 3.8 Detail of Column Specimens

S.No.	Description of Columns	Slenderness ratio (λ)	TAG
1	Three columns of size 100 x 100 x 300mm	3	CS
2	Three columns of size 100 x 100 x 300mm with one layer of GI wire mesh	3	RFCS1
3	Three columns of size 100 x 100 x 300mm with two layers of GI wire mesh	3	RFCS2
4	Three columns of size 100 x 100 x 700mm	7	SC
5	Three columns of size 100 x 100 x 700mm with one layer of GI wire mesh	7	RFSC1
6	Three columns of size 100 x 100 x 700mm with two layers of GI wire mesh	7	RFSC2
7	Three columns of size 100 x 100 x 1500mm	15	LC
8	Three columns of size 100 x 100 x 1500mm with one layer of GI wire mesh	15	RFLC1
9	Three columns of size 100 x 100 x 1500mm with two layers of GI wire mesh	15	RFLC2

3.4 Testing Procedure and Instrumentation

After completing the curing period of the test specimens, all specimens were kept in dry place for few hours for attaining surface dry condition. The testing was carried out in the loading frame and the compressive load was applied with the hydraulic loading jack of capacity of 600 kN. Concentric compressive load was applied on all the specimens. Lateral deflections were measured at mid height using two LVDTs (Linear Variable Differential Transducer) on adjacent faces of the column specimens. LVDTs had an accuracy of 0.01mm. Test setup and the position of the LVDTs and mode of loading are shown in Fig 3.5.

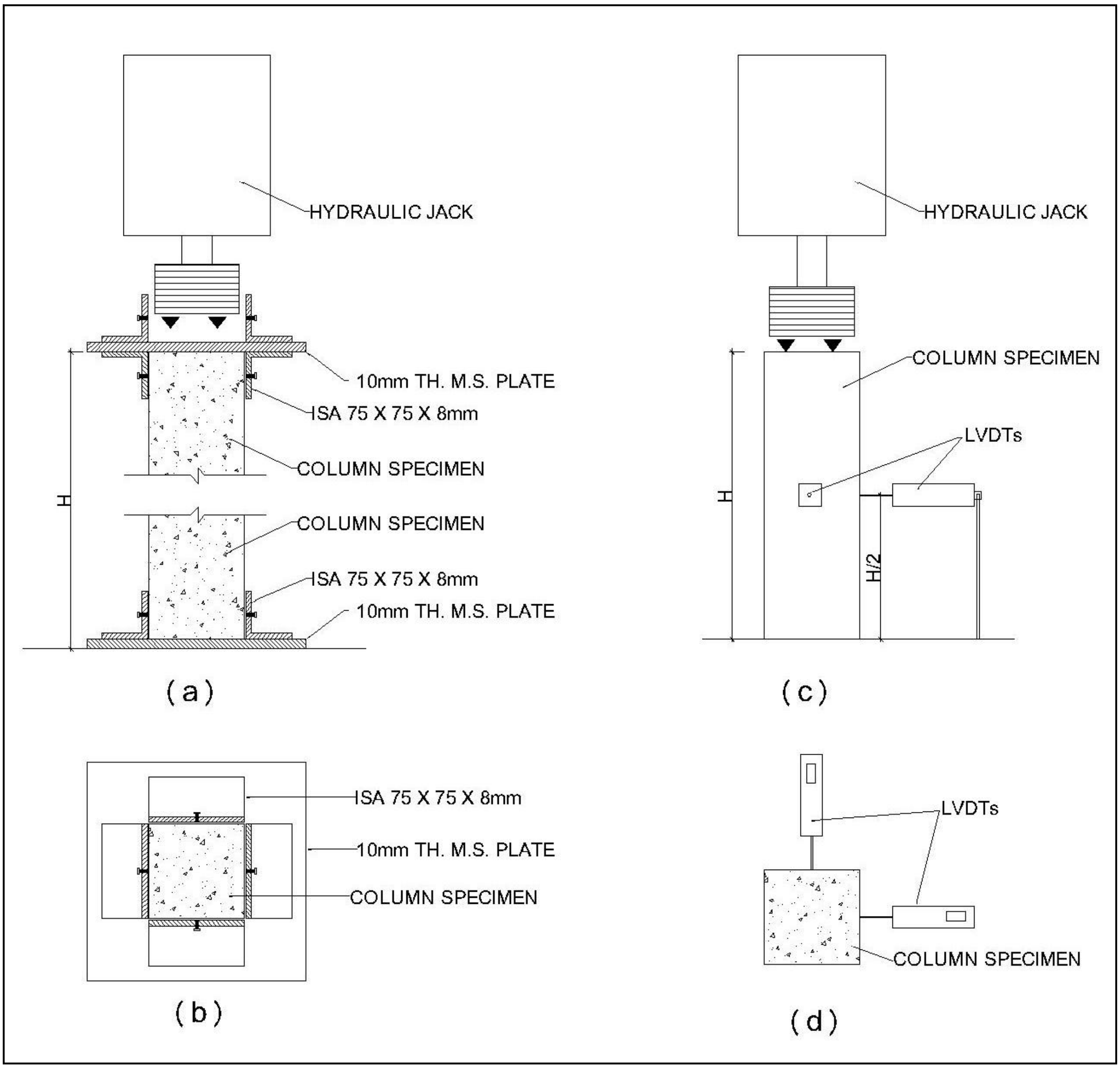
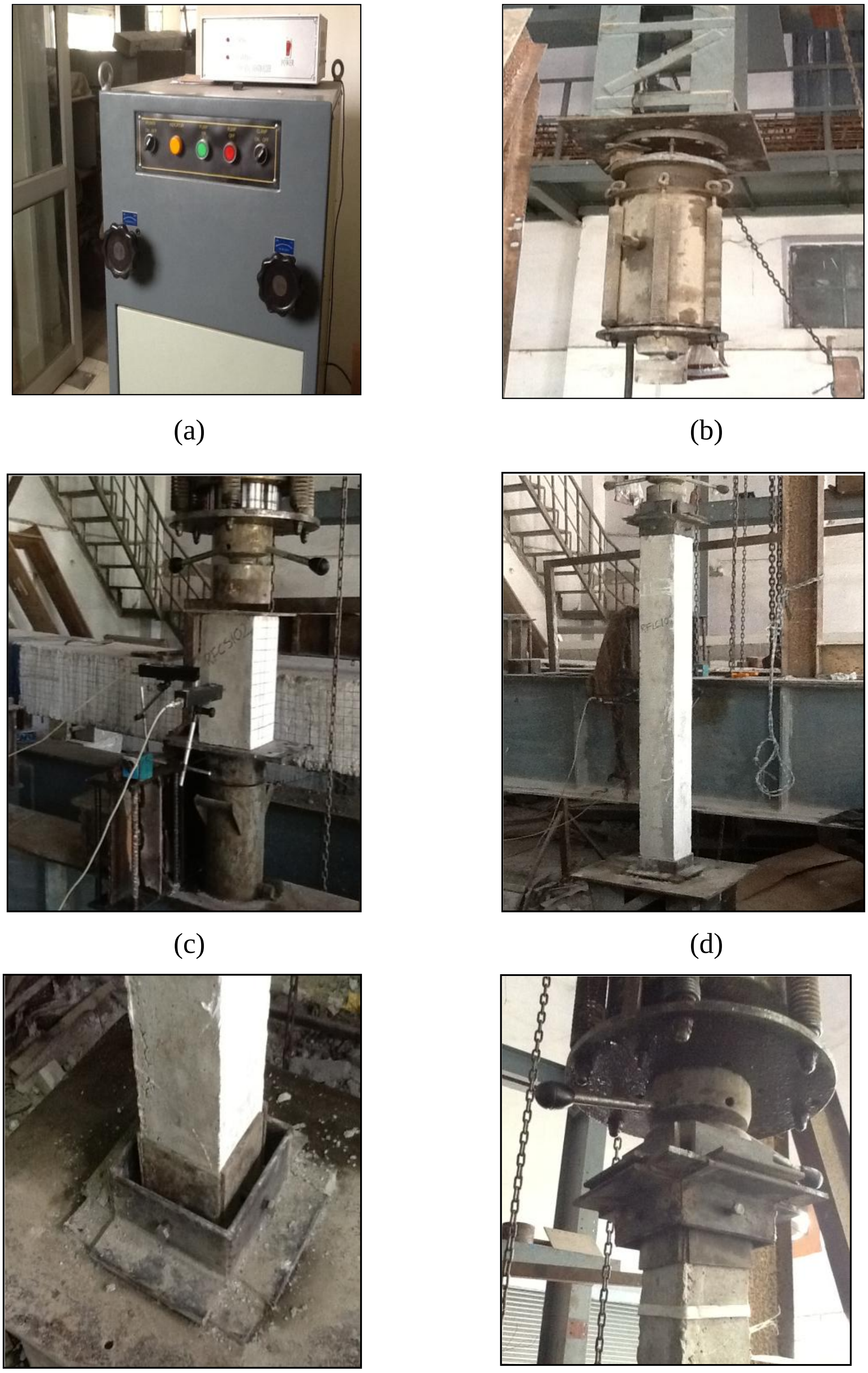


Fig. 3.5 Detail of Test Setup (a) Test setup for type LC (b) Plan of the End Connection Plate (c) Mode of Loading and Position of LVDTs (d) Plan of Position of LVDTs

In test setup of the specimens of category LC, RFLC1, RFLC2 some changes were made in the improving the end conditions of the column specimens. Mild steel plate with special arrangement to keep the column intact in position was made, both on upper and lower end of the specimen; the details are shown in Fig. 3.6.



(a) (b) (c) (d) (e) (f)

Fig. 3.6 Detail of Test Equipment (a) Control Equipment for Loading Jack; (b) Loading Jack of 600 kN Capacity; (c) Typical Test Setup for CS and SC type Columns; (d) Test Setup for LC type Columns; (e) Improved End Condition of LC Column at Bottom (f) Improved End Condition of LC Column at Top

3.4.1 LVDT -Linear Variable Differential Transducer

The lateral deflections during the testing were measured with digital LVDTs. The LVDTs had a least count of 0.01mm and a maximum deflection range of 50mm. These were connected to the automatic data acquisition system. Fig. 3.7 shows a typical LVDT.

Fig. 3.7 Linear Variable Differential Transducer (LVDT)

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The results obtained after testing of the specimens are discussed in this section. The average load-deflection graphs of three unconfined control concrete specimens (type CS, SC and LC with λ=3, 7 and 15 respectively), three specimens confined with ferrocement (one layer of wire mesh in type RFCS1, RFSC1 and RFLC1 with λ=3, 7 and 15 respectively) and three specimens confined with ferrocement (two layers of wire mesh in type RFCS2, RFSC2 and RFLC2 with λ=3, 7 and 15 respectively) were prepared. All specimens were tested under concentric mode of loading. Load vs. deflection values, first crack load, crack pattern and ultimate load capacity were observed.

4.2 Results of Control and Ferrocement Confined Columns (λ=3)

The columns had a slenderness ratio of 3, such short columns are also called Pedestals. The pedestals utilize their whole height in the achievement of the strength. It was observed that after confinement the load carrying capacity of the confined columns increased to almost double as compared to the unconfined control columns. The detail of each tested column is discussed in the sections below.

4.2.1 Control column (CS, λ=3)

As the loading started, some low level cracking sounds were heard which may be due to micro cracking of concrete. As the loading continued the specimen started to show deflection. As the load reached at 115 kN some cracking and spalling of the surface of the concrete at bottom and near the middle width was observed. At a load of 272 kN, first two cracks were observed simultaneously, one near upper left corner extending diagonally towards mid height and another was on right to half width extending in a diagonal pattern equally in height towards top and bottom. As the load reached the ultimate value of 274 kN, the column failed in a compression at one-fourth of the height from the top and a loud noise was heard. The maximum deflection at mid height was 3.81mm. The graph of load vs. mid height deflection is shown in Fig. 4.1 and Fig. 4.2 describes the detail of column during different phases of loading.

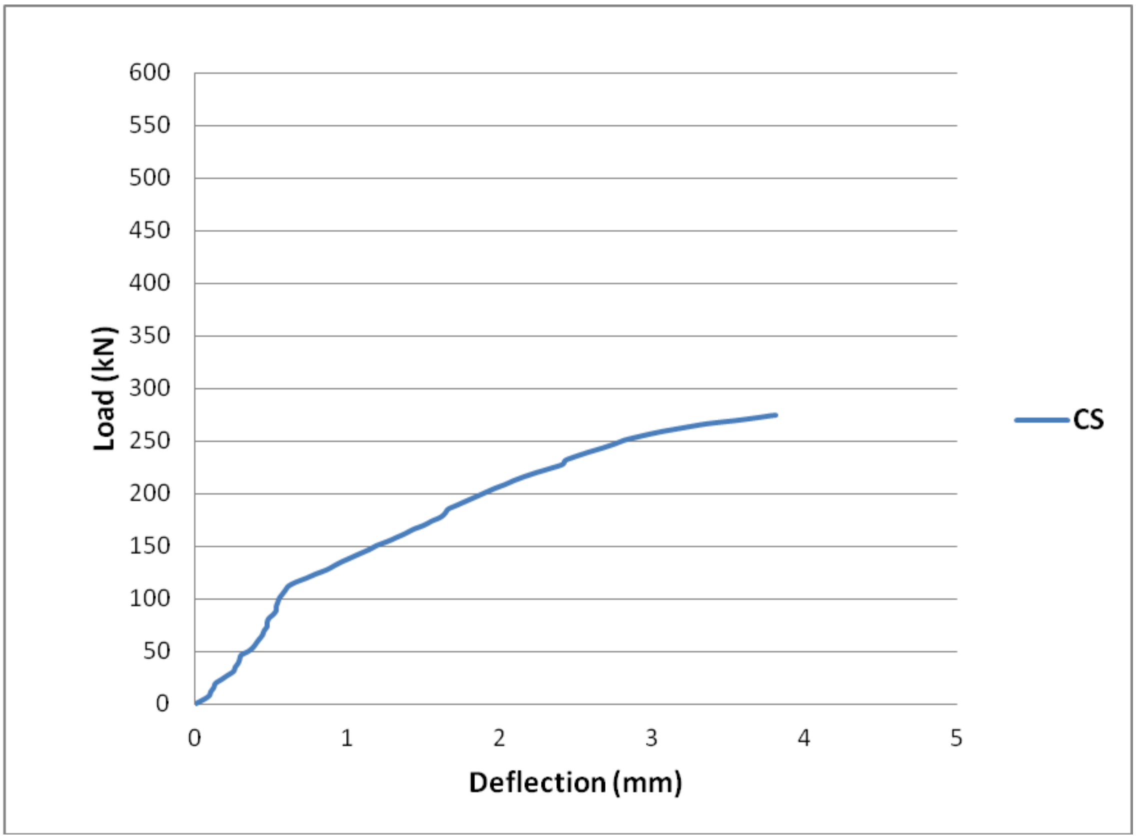
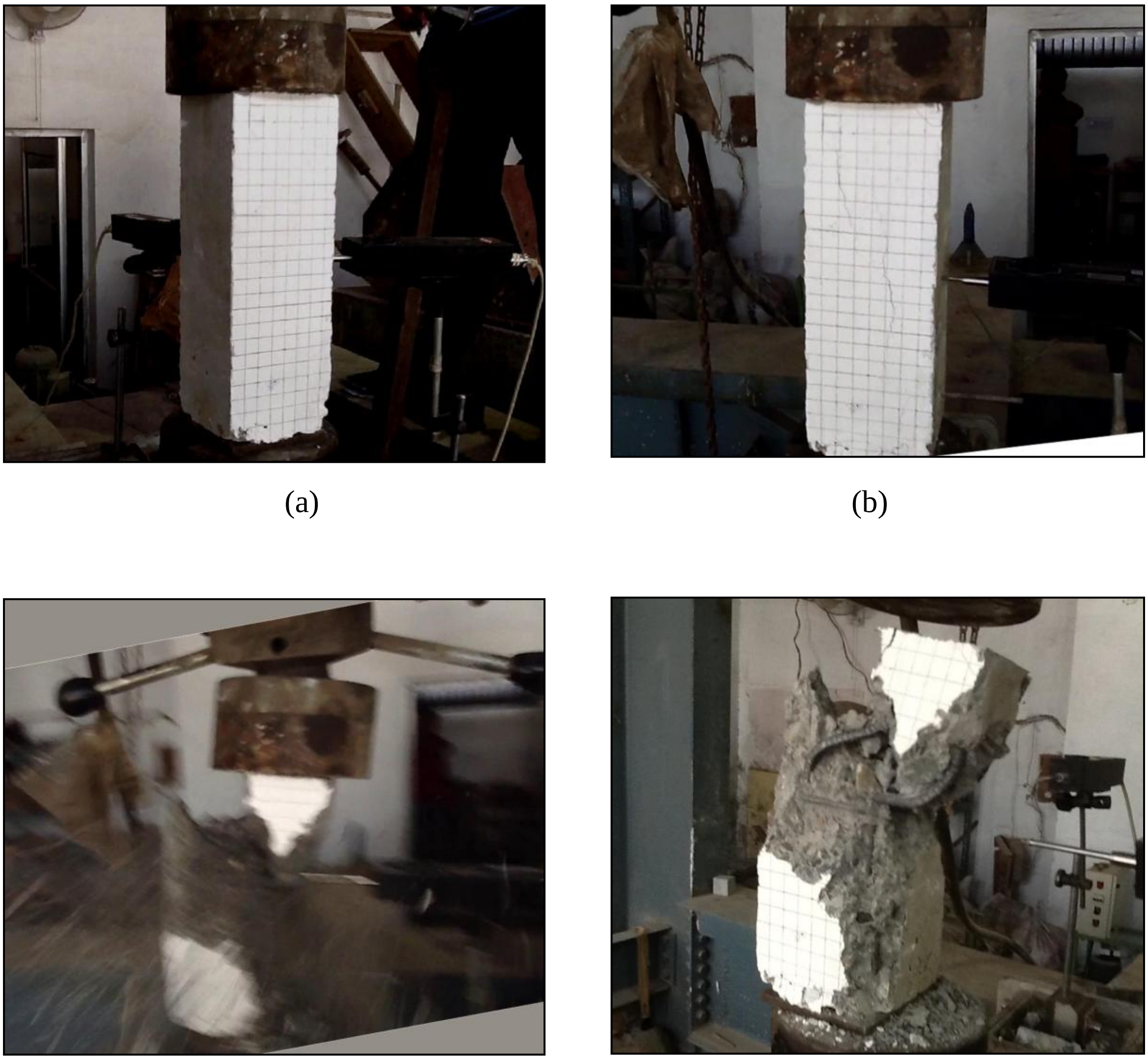


Fig. 4.1 Load vs. Mid Height Deflection of Control Column (CS, λ=3)



(a) (b)

(c) (d)

Fig. 4.2 Different Phases of Control Column (CS, λ=3)

(a) Before Loading (b) First Crack (c) While Failure (d) After Failure

4.2.2 Ferrocement confined column with one layer of wire mesh (RFCS1, λ=3)

The confining increased the value of load and a decrease in the lateral deformation. The first crack was observed at a load of 524 kN. Cracks were vertical on two adjacent faces with spalling of the mortar layer from the wire mesh layer. The wire mesh continued to confine the column till the failure of the core concrete occurred at a load of 527 kN. The delamination of the mortar layer can also be seen in the figures clearly. The longitudinal reinforcement was bent outwards followed by the rupture of the core concrete.

The confining increased the ultimate load capacity almost two times as compared to control column CS. The maximum deflection was 2.25mm. The load vs. mid height deflection graph and column at various stages of loading is shown in Fig. 4.3 and Fig. 4.4 respectively.

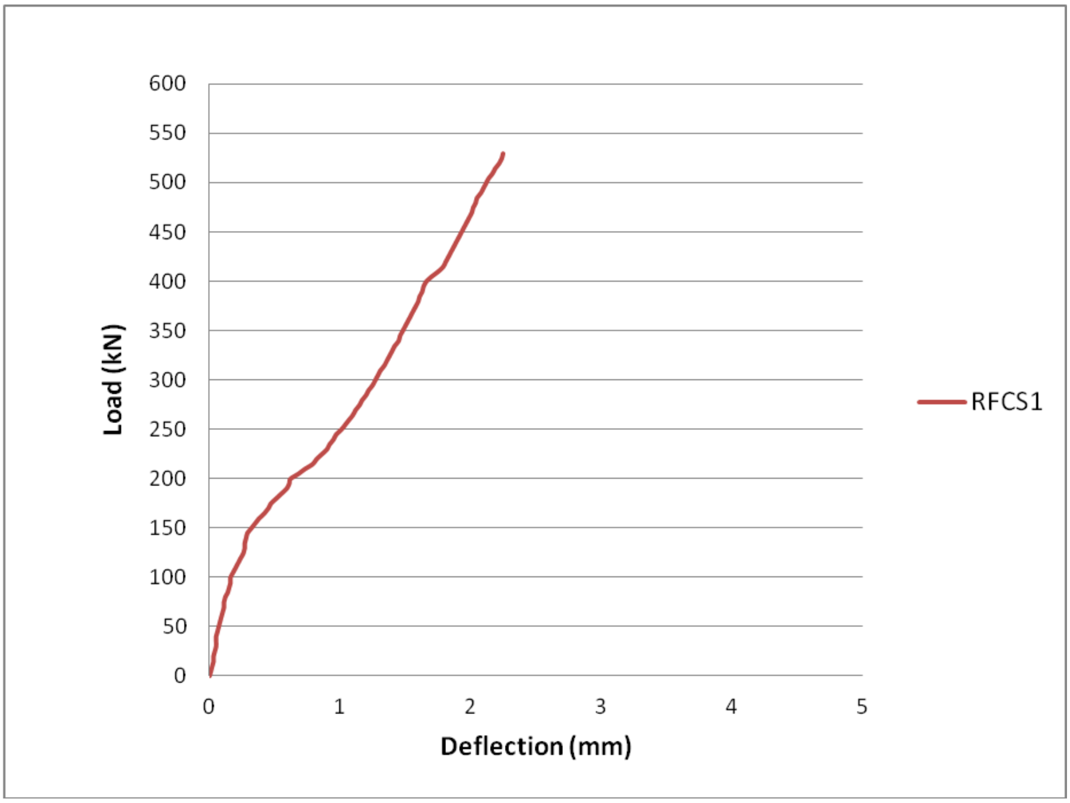
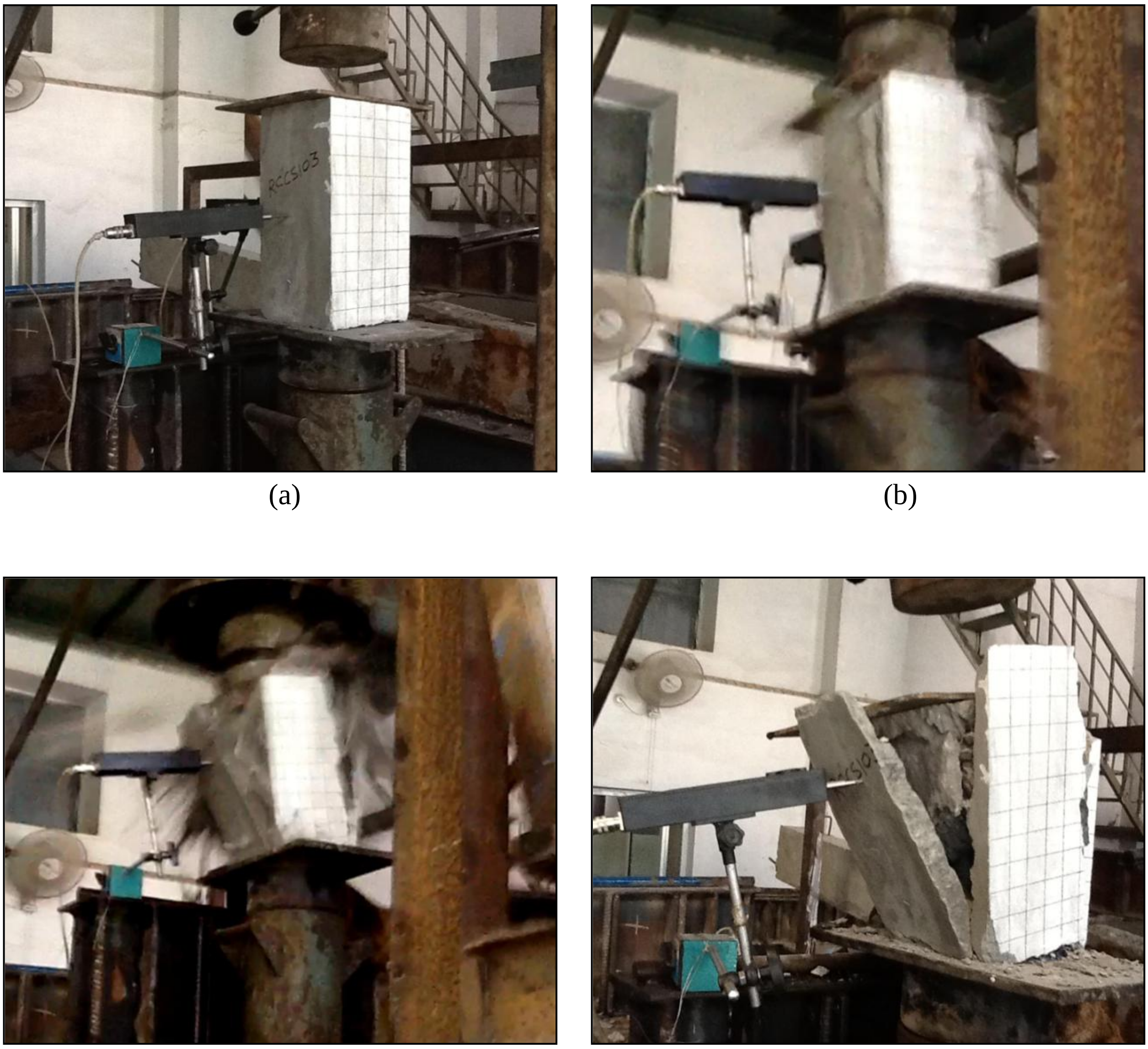


Fig. 4.3 Load vs. Mid Height Deflection of Confined Column With One Layer of Wire Mesh (RFCS1, λ=3)



(a) (b)

(c) (d)

Fig. 4.4 Different Phases of Ferrocement Confined Column with One Layer of Wire Mesh (RFCS1, λ=3) (a) Before Loading (b) First Crack (c) While Failure (d) After Failure

4.2.3 Ferrocement confined column with two layers of wire mesh (RFCS2, λ=3)

As the loading started the behavior of the specimen was similar to the previous samples. The first crack was observed at a load of 548 kN on right side of the column in vertical direction which continued to become wide as the load increased. The failure occurred at an ultimate load of 554 kN. The specimen failed in compression at one-fourth height from top. The maximum deflection was 1.98 mm which is significantly lower than the control specimen CS. The confinement also increased the ultimate load capacity.

It is clear from the results that the increase in ultimate load capacity after confinement with two layers of wire mesh is less significant as compared to the confinement with one layer of the wire mesh. Fig. 4.5 shows the load vs. mid height deflection graph and Fig. 4.6 shows the loading stages of the specimen.

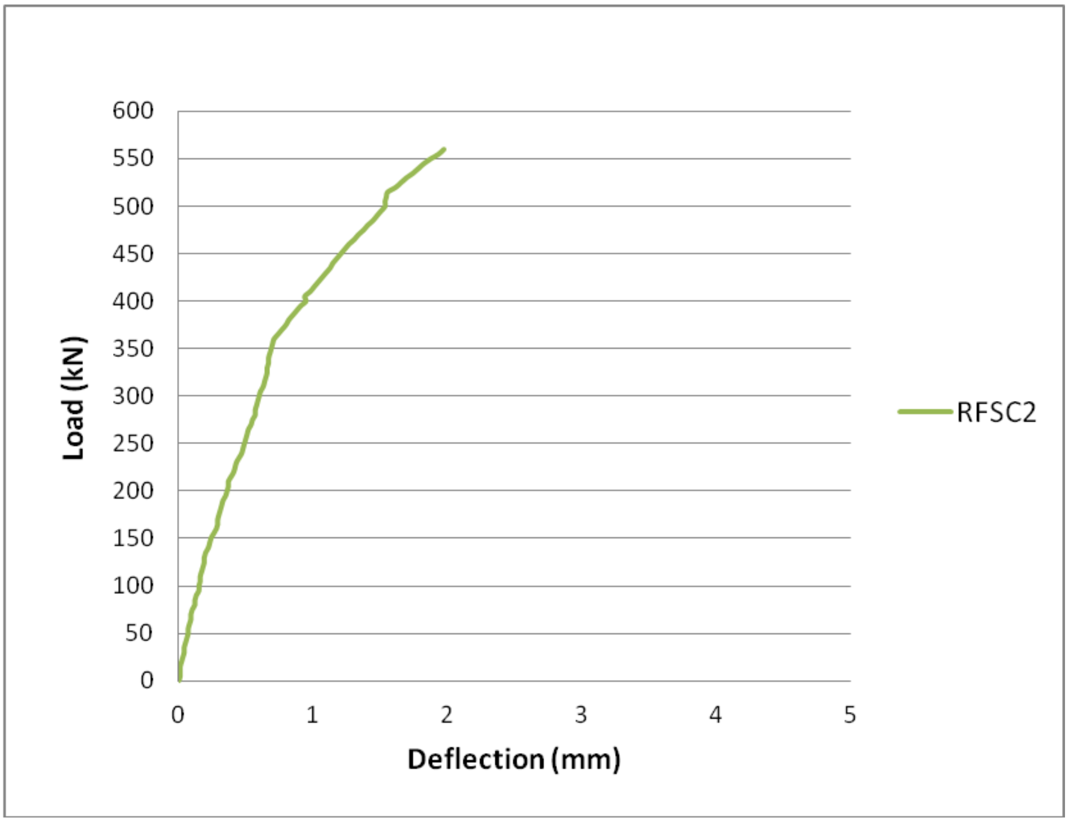
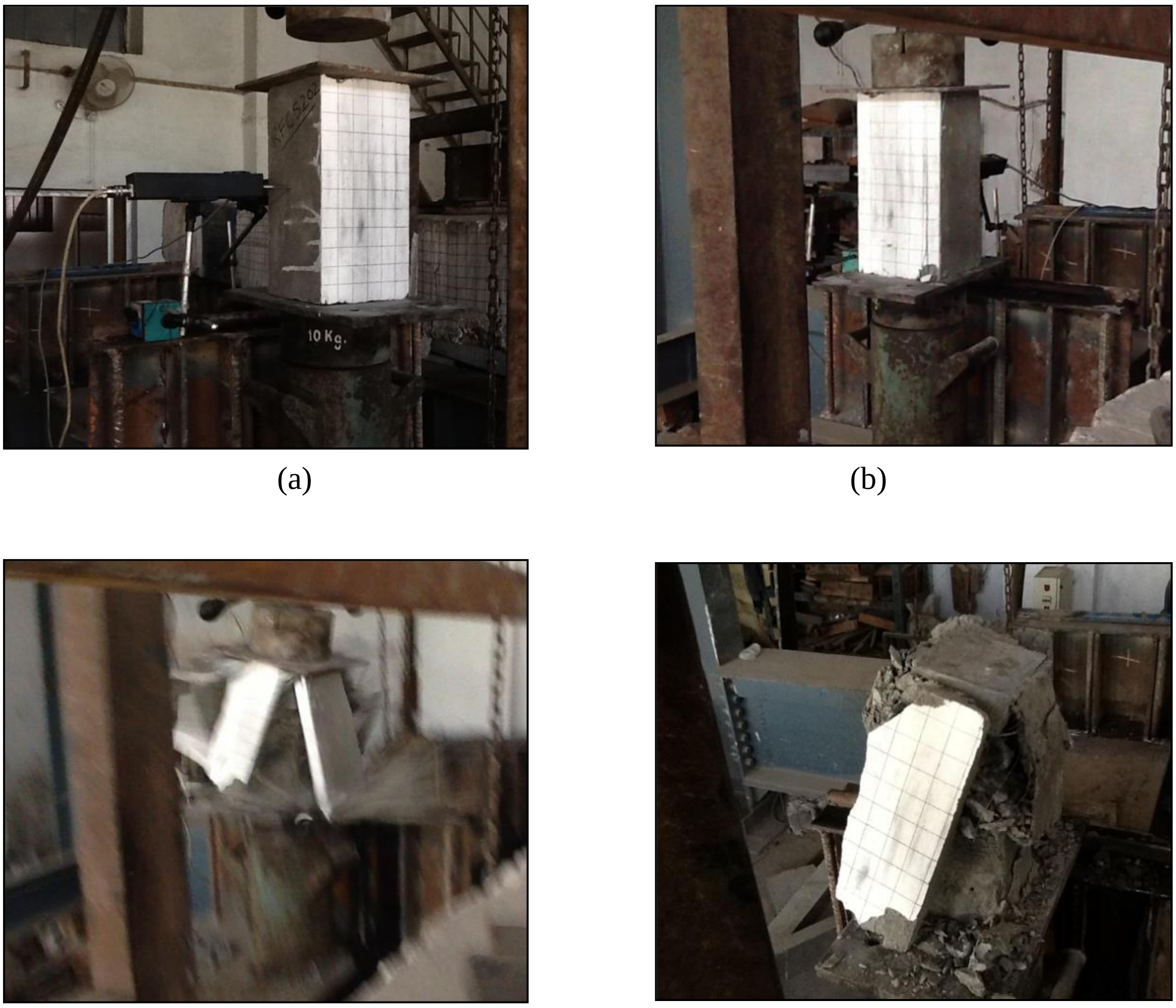


Fig. 4.5 Load vs. Mid Height Deflection of Ferrocement Confined Column With Two Layers of Wire Mesh (RFCS2, λ=3)



(a) (b)

(c) (d)

Fig. 4.6 Different Phases of Ferrocement Confined Column with Two Layers of Wire Mesh (RFCS2, λ=3) (a) Before Loading (b) First Crack (c) While Failure (d) After Failure

4.2.4 Comparison of CS, RFCS1 and RFCS2 (λ=3)

Test results show that after ferrocement confinement to columns there is a tremendous increase in the ultimate load capacity, first crack load and reduction in the deflection as compared to the control column. The column specimens have L/d ratio of 3 (λ=3, short column or Pedestal). The ultimate load value of confined columns RFSC1, RFSC2 is almost two times the value of control column.

Typical failure pattern was observed to be in compression mode, near one-fourth of the height either towards top or bottom. As the failure occurred, the concrete cover near the failure zone spelled, exposing the longitudinal reinforcement followed by the rupture of the core concrete. The crack pattern was similar in the confined specimens as both resulted in the delamination of the mortar layer from the wire mesh.

The sound heard of micro cracking of concrete during the testing of control columns was not noticeable during testing of confined columns. This indicates that confinement also reduces micro cracking. Fig. 4.7 shows the comparison of load vs. mid height deflection values of three column specimens; CS, RFCS1 and RFCS2.

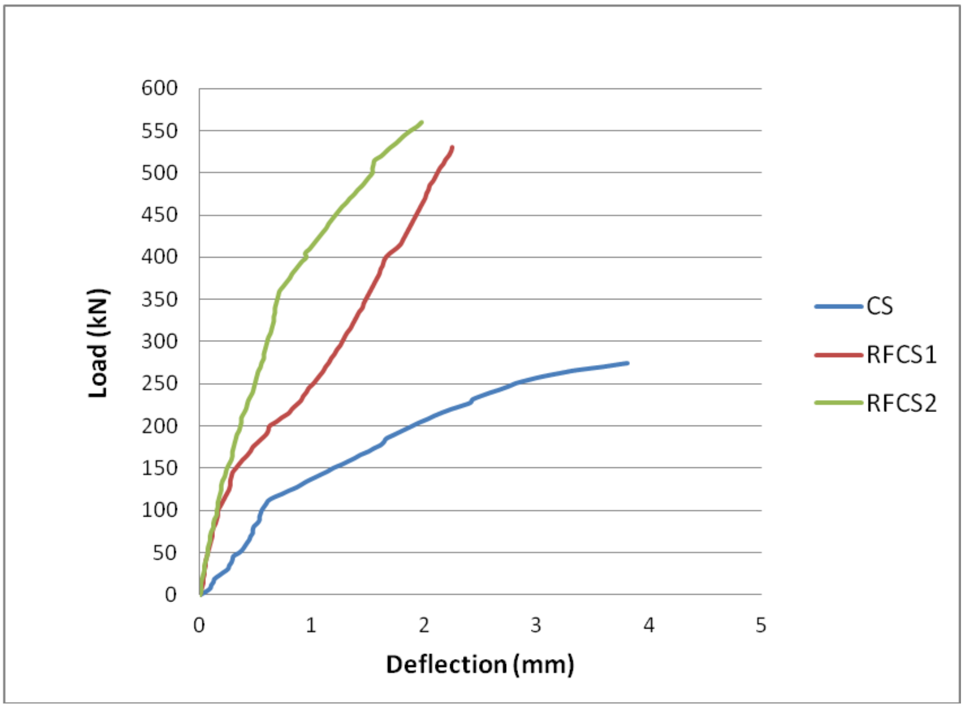


Fig. 4.7 Comparison of Load vs. Mid Height Deflection of Control and Confined Columns (CS, RFCS1 and RFCS2, λ=3)

4.3 Results of Control and Ferrocement Confined Columns (λ=7)

4.3.1 Control column (SC, λ=7)

The load was applied and the specimen continued to show deflection. The first crack was observed at a load of 250 kN near the one-fourth height from bottom diagonally extending upwards, from left to right of the observed face. The brittle failure occurred at an ultimate load of 252 kN. The compression mode of failure was observed. The spalling of concrete was observed entirely from the rupture zone which also resulted in bending of the longitudinal reinforcement as shown in figure. The load vs. mid height deflection graph is shown in Fig. 4.8 and detail of crack pattern, column before, during and after loading are shown in Fig. 4.9.

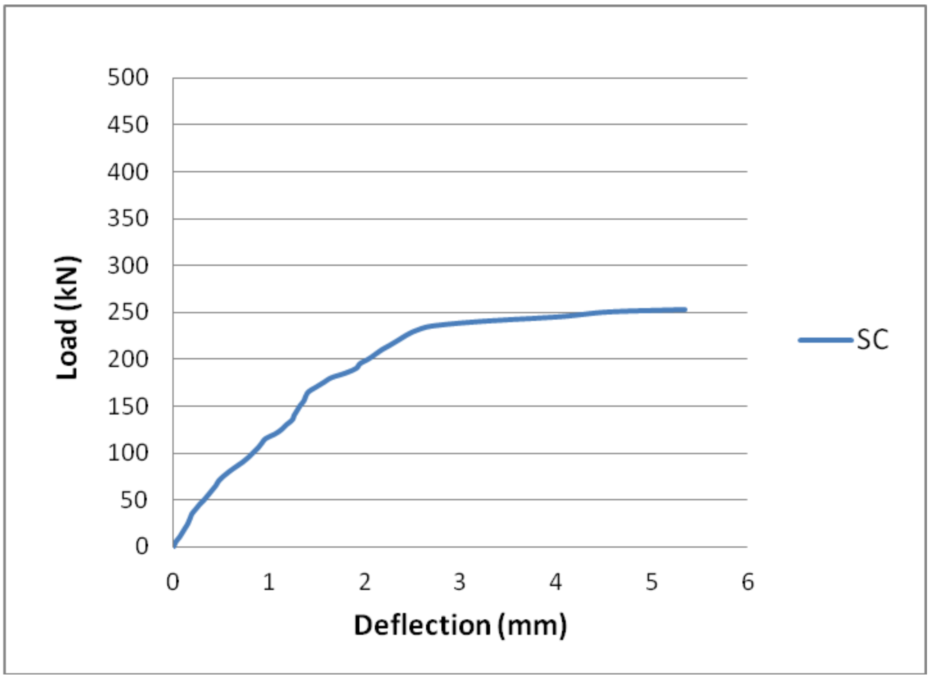
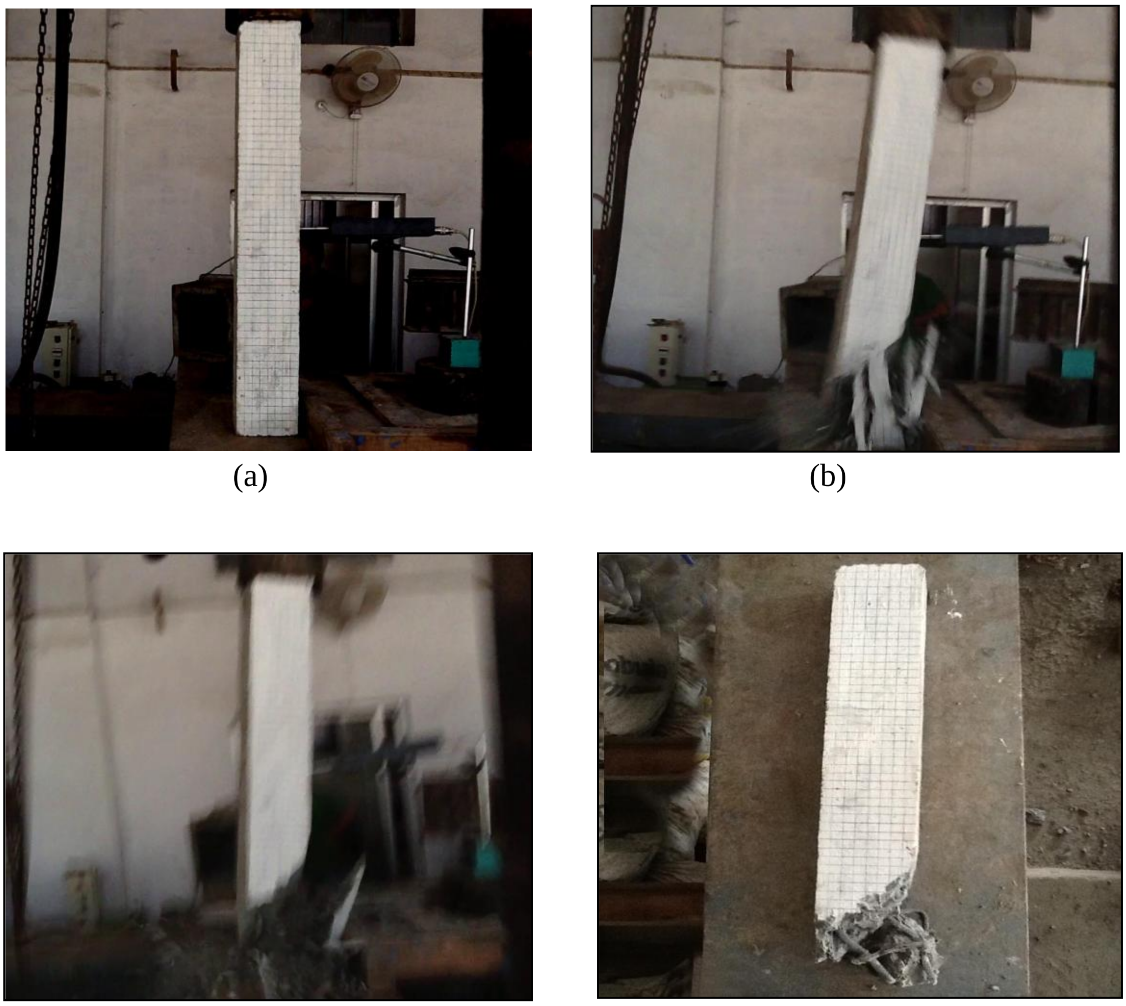


Fig. 4.8 Load vs. Mid Height Deflection of Control Column (SC, λ=7)



(a) (b)

(c) (d)

Fig. 4.9 Different Phases of Control Column (SC, λ=7)

(a) Before Loading (b) First Crack (c) While Failure (d) After Failure

4.3.2 Ferrocement confined column with one layer of wire mesh (RFSC1, λ=7)

After application of the load the column did not show any sign of cracking up to a load of 335 kN. As the load approached to 337 kN first crack was observed in the mortar layer with a cracking sound. The mortar layer of ferrocement was separated from the wire mesh with compression failure of the column near one fourth height from the base. The failure of the beam occurred at a load of 343kN. The maximum lateral deflection was observed recorded as 3.82 mm. The load vs. mid height deflection graph is shown in Fig. 4.10 and detail of crack pattern, column before, during and after loading are shown in Fig. 4.11.

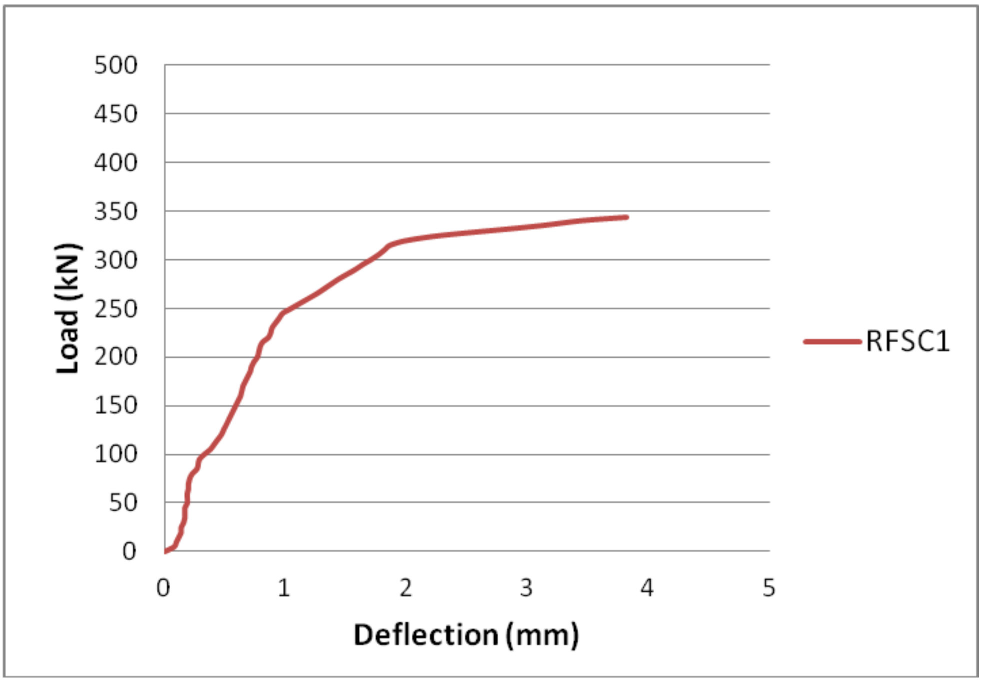
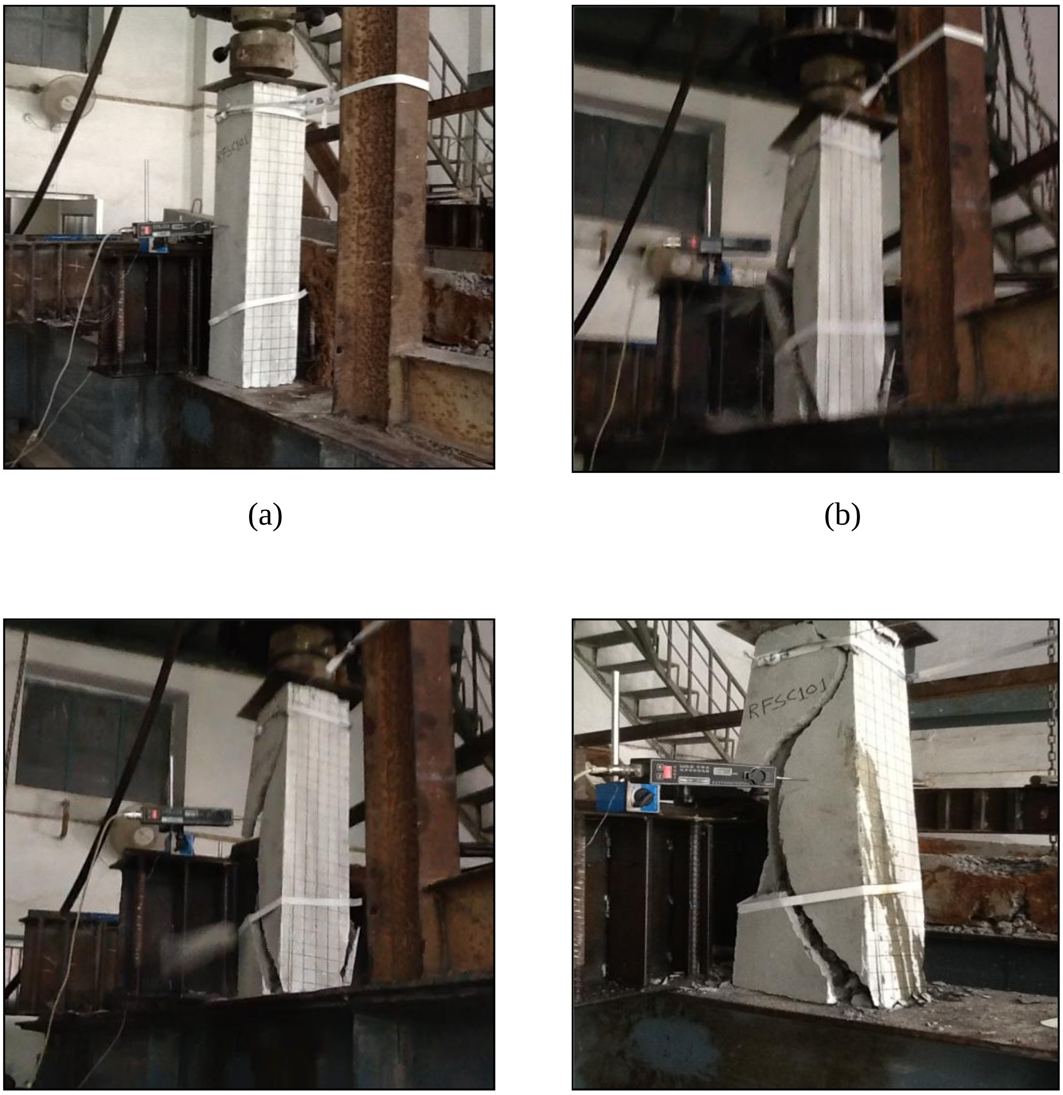


Fig. 4.10 Load vs. Mid Height Deflection of Ferrocement Confined Column With One Layer of Wire Mesh (RFSC1, λ=7)



(a) (b)

(c) (d)

Fig. 4.11 Different Phases of Ferrocement Confined Column with One Layer of Wire Mesh (RFSC1, λ=7) (a) Before Loading (b) First Crack (c) While Failure (d) After Failure

4.3.3 Ferrocement confined column with two layers of wire mesh (RFSC2, λ=7)

The column experienced its first crack at a load of 346 kN on the bottom in the middle width. The crack was in a diagonal pattern staring from bottom up to one-fourth height of column. The deflection at this point was 2.78mm. After application of further load the column deflected up to a maximum value of 2.97mm and failure occurred at 353 kN near the one fourth-height from the base. The column also failed in compression mode. The load vs. mid height deflection graph is shown in Fig. 4.12 and detail of column before, during and after loading are shown in Fig. 4.13.

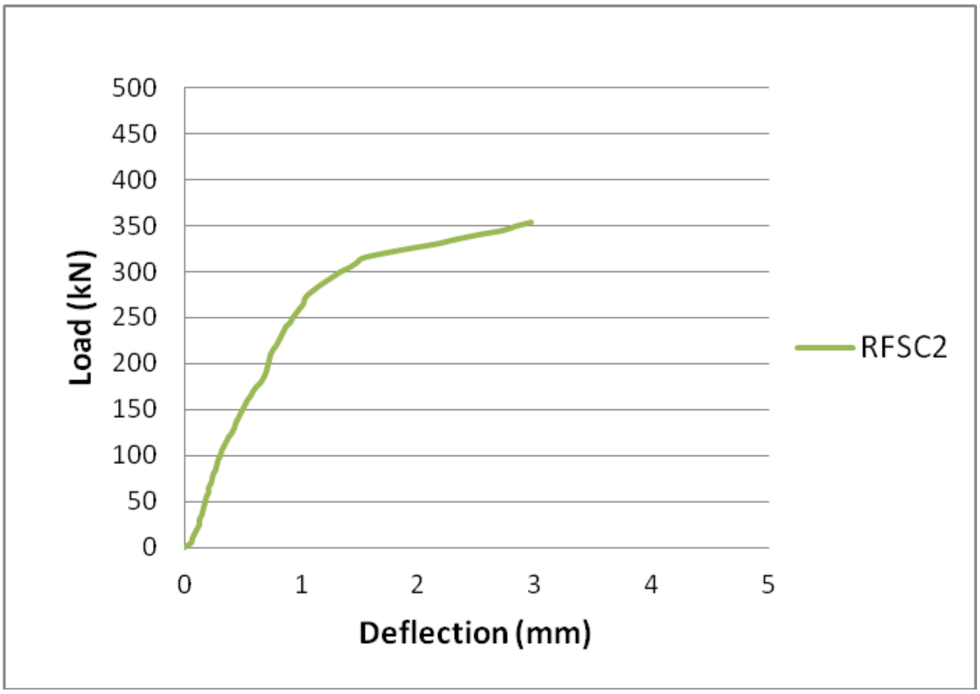
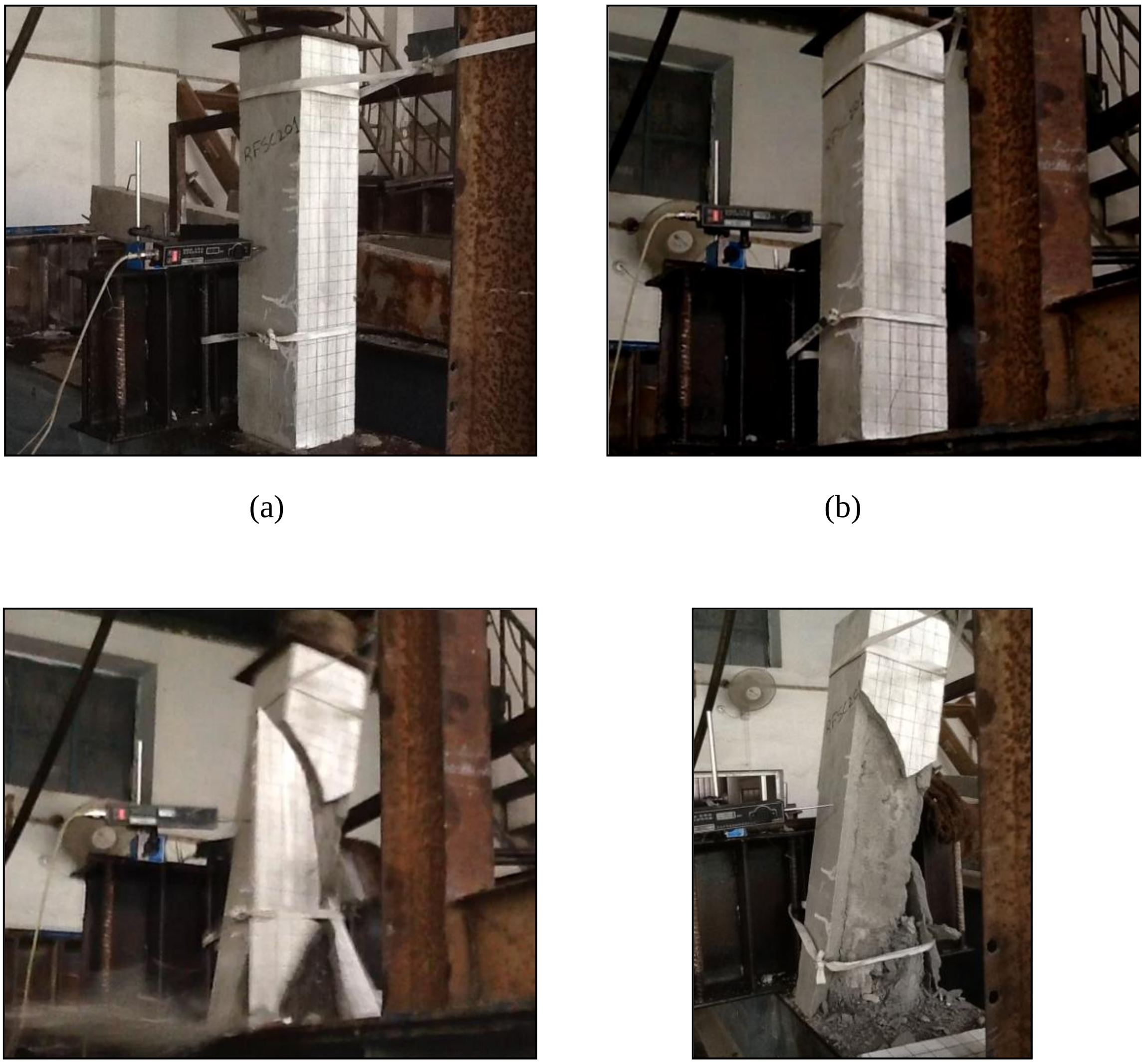


Fig. 4.12 Load vs. Mid Height Deflection of Ferrocement Confined Column with Two Layers of Wire Mesh (RFSC2, λ=7)



(a) (b)

(c) (d)

Fig. 4.13 Different Phases of Ferrocement Confined Column with Two Layers of Wire Mesh (RFSC2, λ=7) (a) Before Loading (b) First Crack (c) While Failure (d) After Failure

4.3.4 Comparison of SC, RFSC1 and RFSC2 (λ=7)

It is clear from the graph in Fig. 4.14 that the ferrocement confined specimens can withstand higher load values and low deflection response. The mode of failure of all the specimens is in compression as it is shown in Figs. 4.9, 4.11 and 4.13. The comparison also indicates that with the confinement of the ferrocement there is a significant improvement in the ultimate load capacity up to one layer of wire mesh. If two or more layers of wire mesh are used, the ultimate load capacity was affected to a less extent but the deflection showed a noticeable decrease. The effect of slenderness ratio is also observed. The load carrying capacity decreases as the slenderness ration "λ" increases.

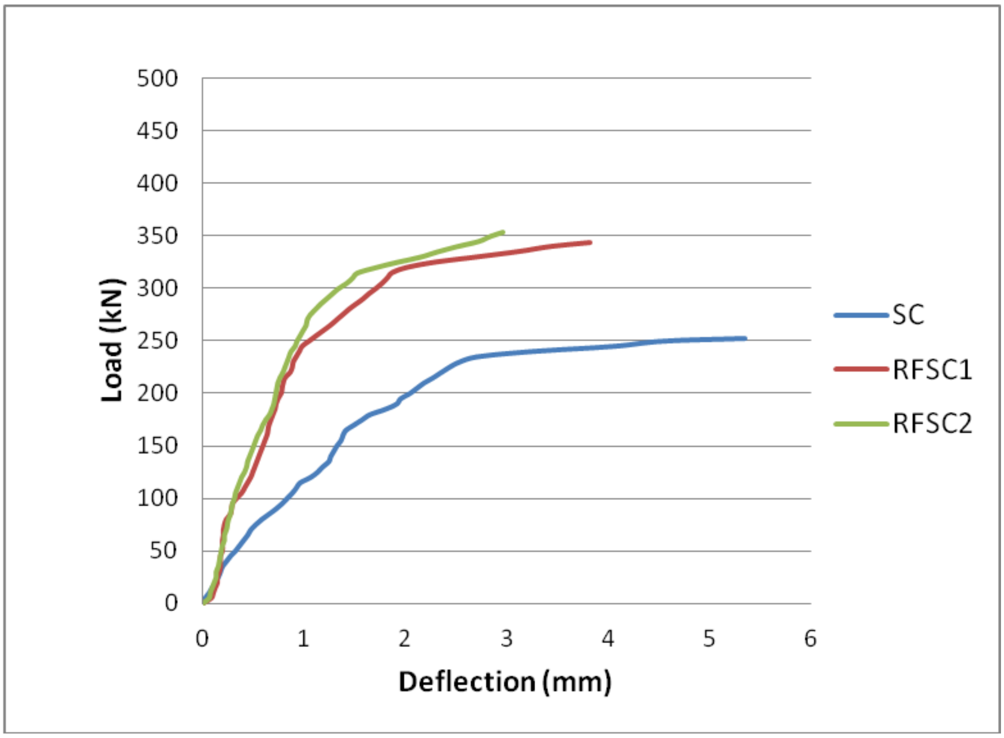


Fig. 4.14 Comparison of Load vs. Mid Height Deflection of Control and Ferrocement Confined columns (SC, RFSC1 and RFSC2, λ=7)

4.4 Results of Control and Ferrocement Confined Columns (λ=15)

4.4.1 Control column (LC, λ=15)

The column, due to its slenderness (λ=15) showed more deflection at a lower load value of 20-25 kN. As the load started to increase the deflection also increased. Some sounds were heard of the micro cracks in concrete. As the load increased to 150 kN, there was an increase in deflection. At 190 kN the deflection increased more in proportion to load. The first crack was observed at a load of 201 kN just above one-fourth height of the column. The column failed at a load of 203 kN. The Fig. 4.15 shows the load vs. deflection graph and Fig. 4.16 shows the column during different phases of loading.

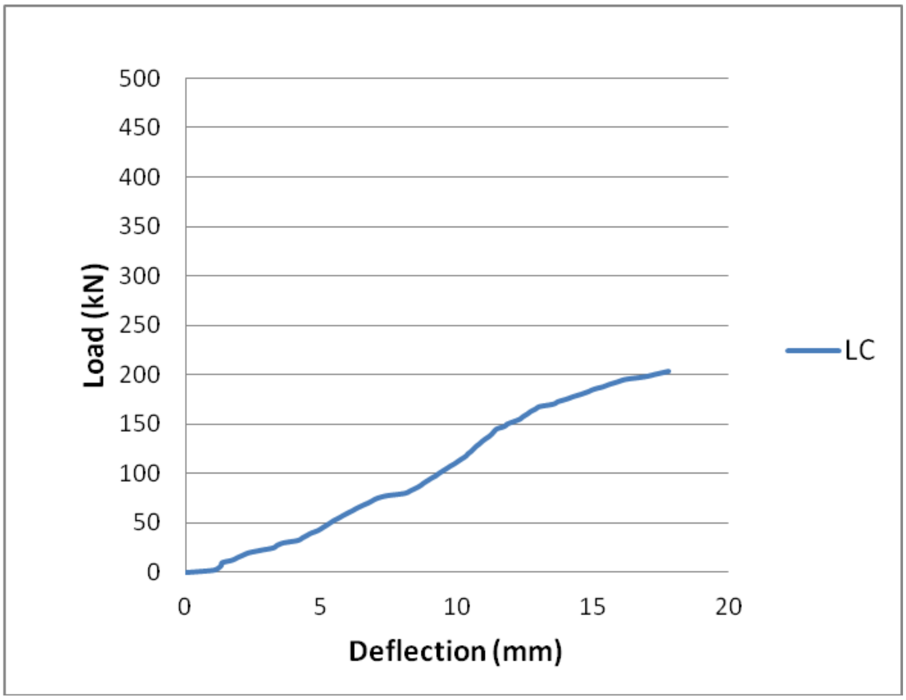
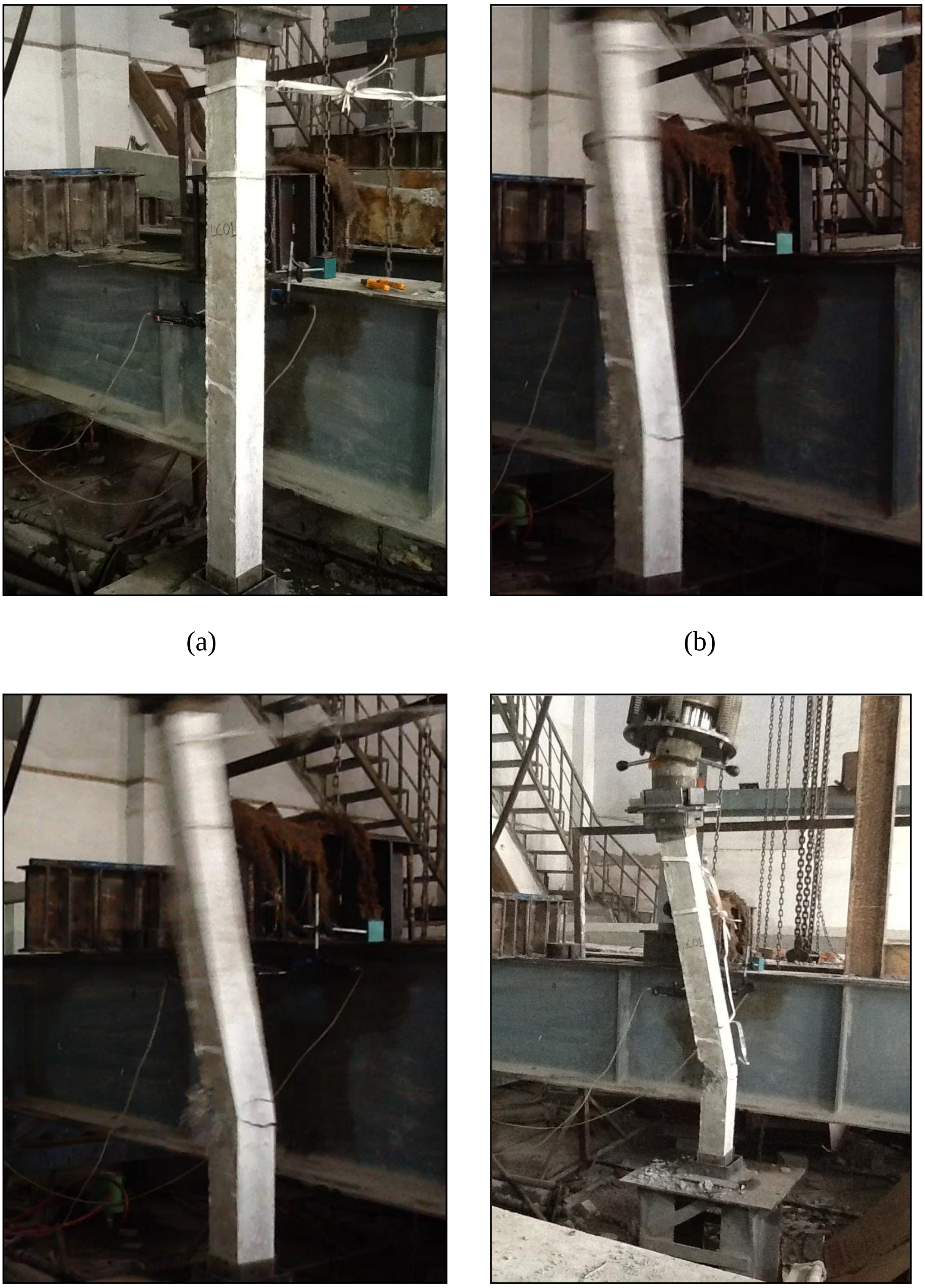


Fig. 4.15 Load vs. Mid Height Deflection of Control Column (LC, λ=15)



(a) (b)

(c) (d)

Fig. 4.16 Different Phases of Control Column (LC, λ=15) (a) Before Loading (b) First Crack (c) While Failure (d) After Failure

4.4.2 Ferrocement confined column with one layer of wire mesh (RFLC1, λ=15)

As the loading started the column showed less deflection as compared to control column LC. First crack appeared at a load of 274 kN followed by failure of the column at an ultimate load of 280 kN. The cracks were near the one-fourth height from bottom. The column collapsed vertically downward without further deflection resulting in the rupture of concrete, ferrocement layers and bending of longitudinal reinforcement. The confinement reduced the deflection to a value of 12.31 mm as compared to the control column LC. Fig. 4.17 shows the load vs. deflection graph of the column and Fig. 4.18 shows the details during different phases of loading.

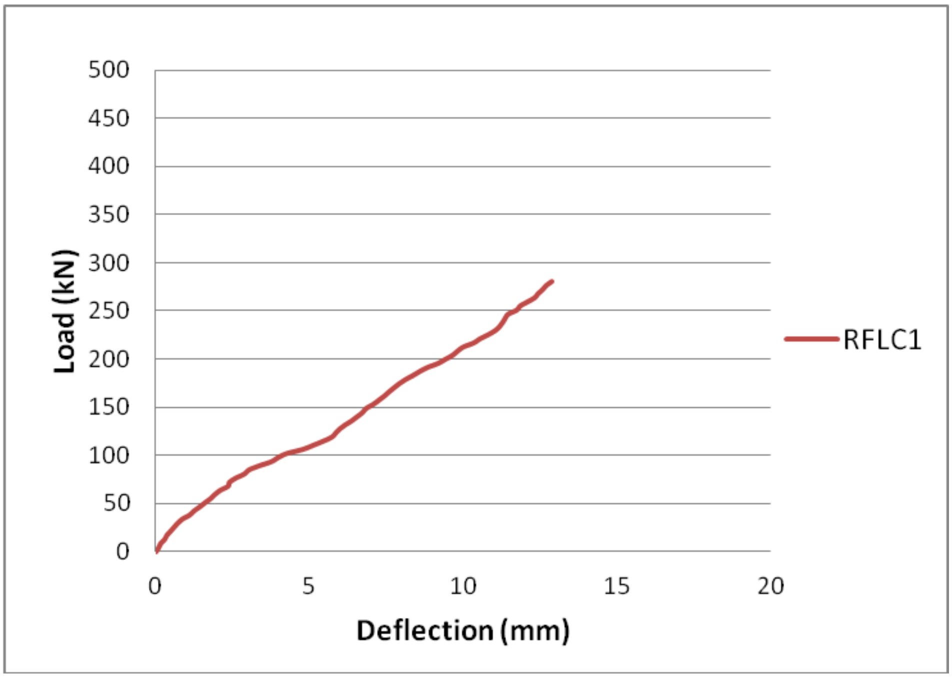
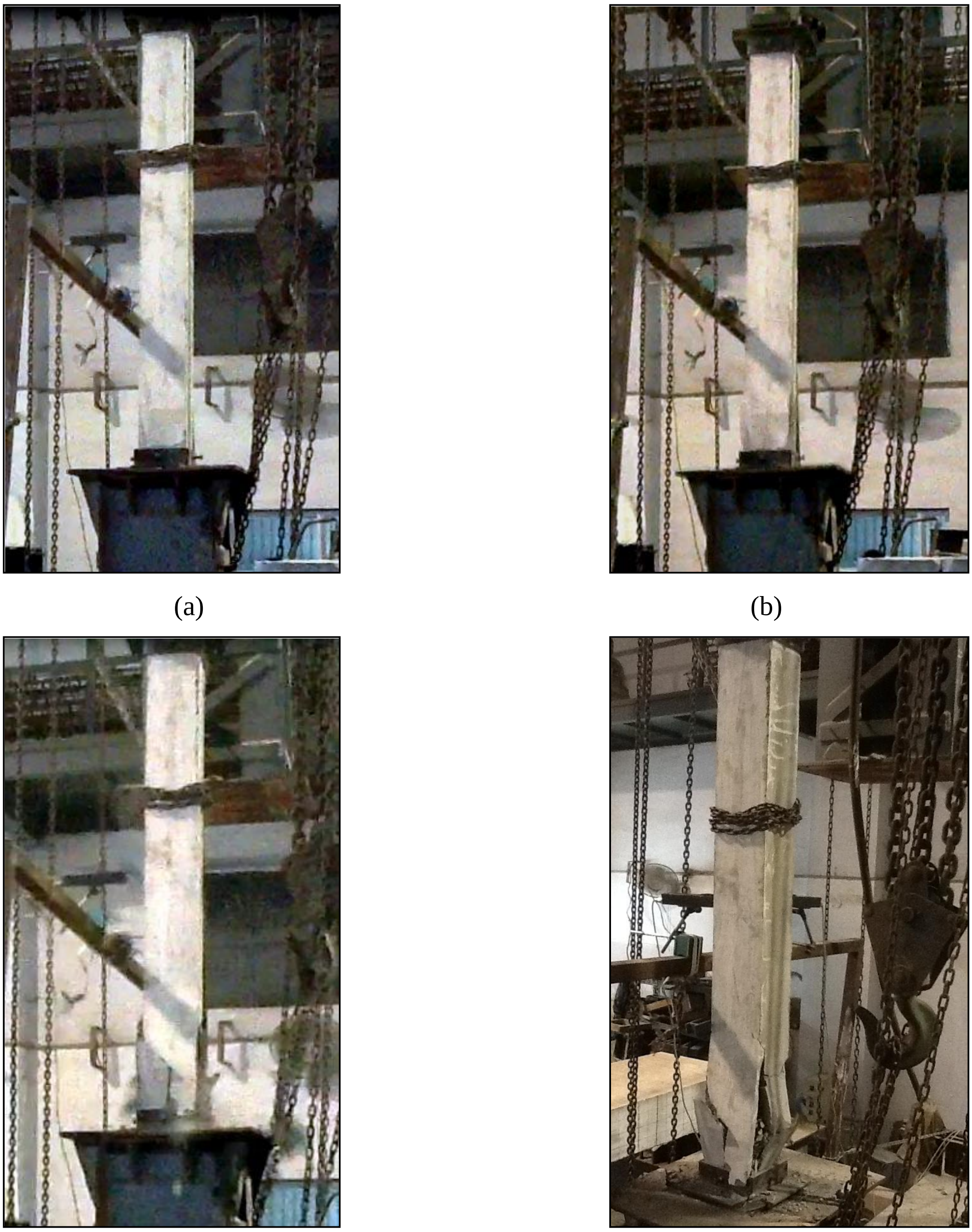


Fig. 4.17 Load vs. Mid Height Deflection of Ferrocement Confined Column with One Layer of Wire Mesh (RFLC1, λ=15)



(a) (b)

(c) (d)

Fig. 4.18 Different phases of ferrocement confined column with one layer of wire mesh (RFLC1, λ=15) (a) Before Loading (b) First Crack (c) While Failure (d) After Failure

4.4.3 Ferrocement confined column with two layers of wire mesh (RFLC2, λ=15)

The column also failed in the same manner as the previous column RFLC1. The first crack at a load of 283 kN was observed near the bottom corner extending up to one-third height of the column. As the load increased the crack started to extend further. At a load of 286 kN sudden failure with delamination of the mortar layer was observed. The mode of failure was compression, near one–fourth height from bottom.

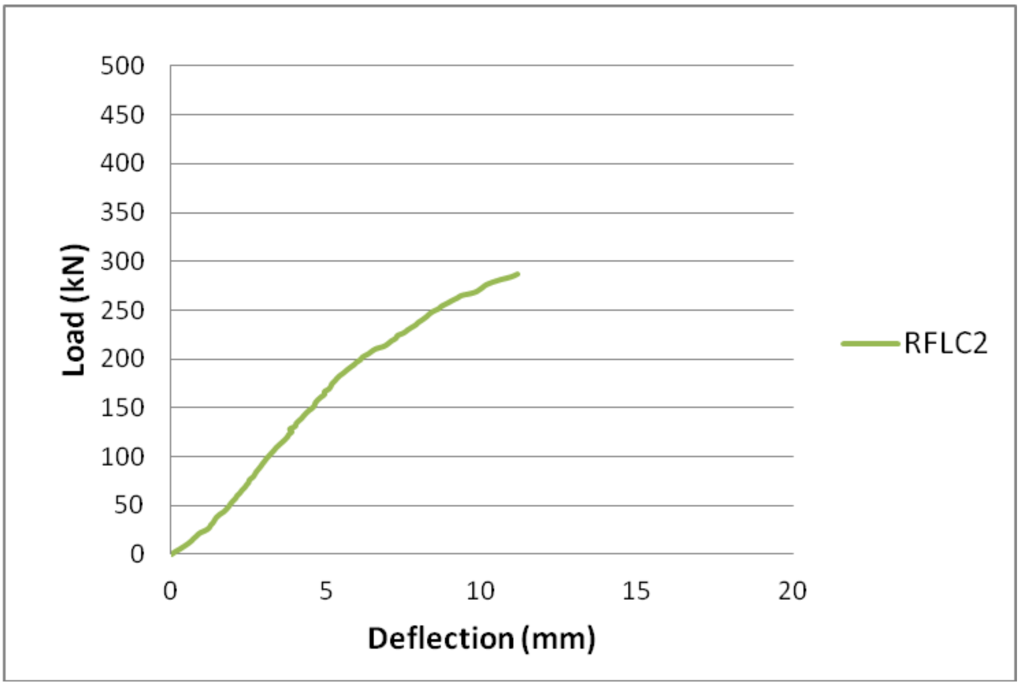
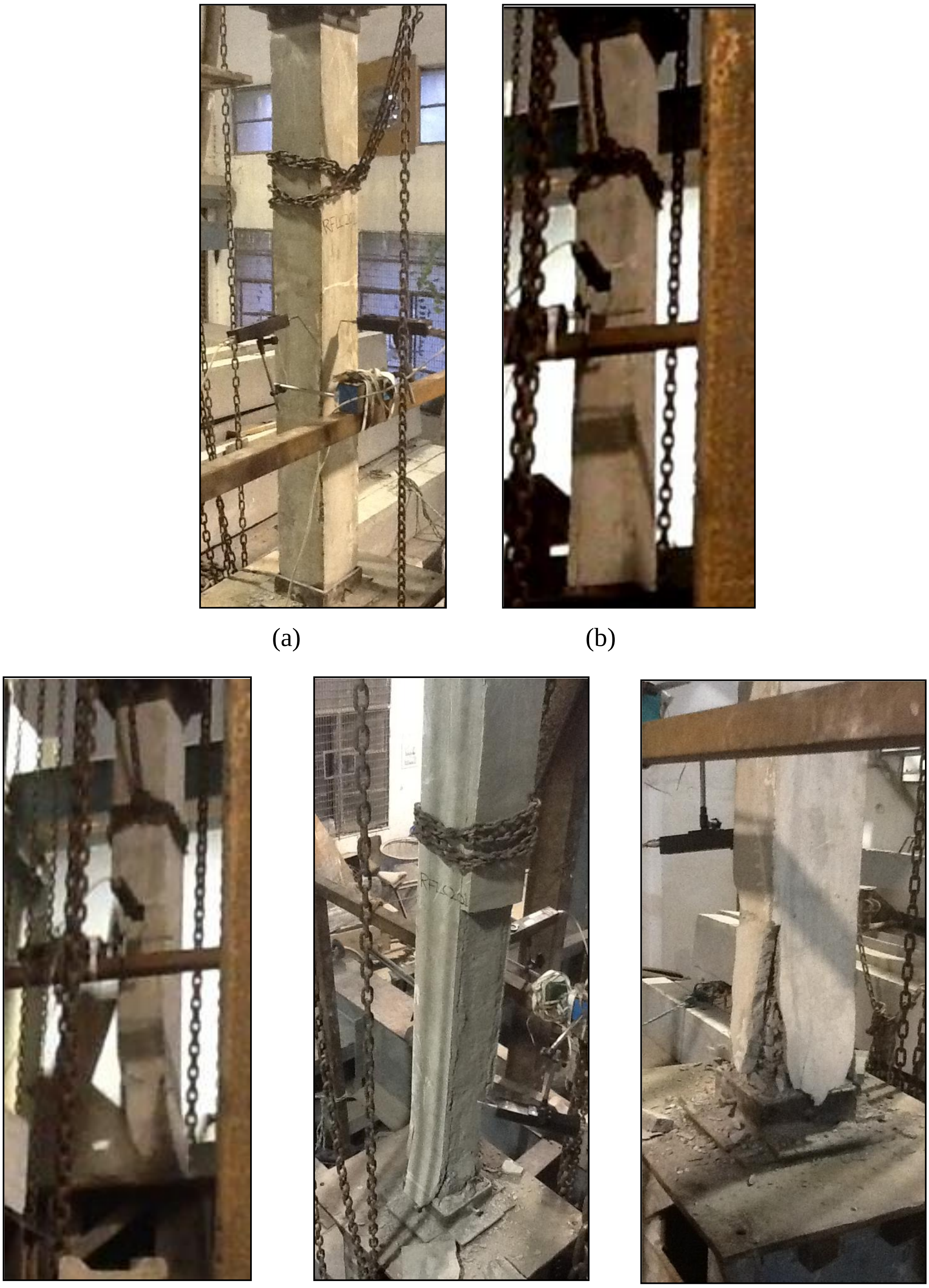


Fig. 4.19 Load vs. Mid Height Deflection of Ferrocement Confined Column with Two Layers of Wire Mesh (RFLC2, λ=15)



(a) (b)

(c) (d) (e)

4.20 Different Phases of Ferrocement Confined Column with One Layer of Wire Mesh (RFLC1, λ=15) (a) Before Loading (b) First Crack (c) While Failure (d) & (e) After Failure

4.4.4 Comparison of LC, RFLC1 and RFLC2 (λ=15)

In case of the unconfined control column LC, both of the ferrocement confined columns RFLC1 and RFLC2 behaved in a linear manner under the load-deflection criteria. The confinement reduced the deflection in case of RFLC1 significantly but minor deflection was controlled in case of RFLC2.

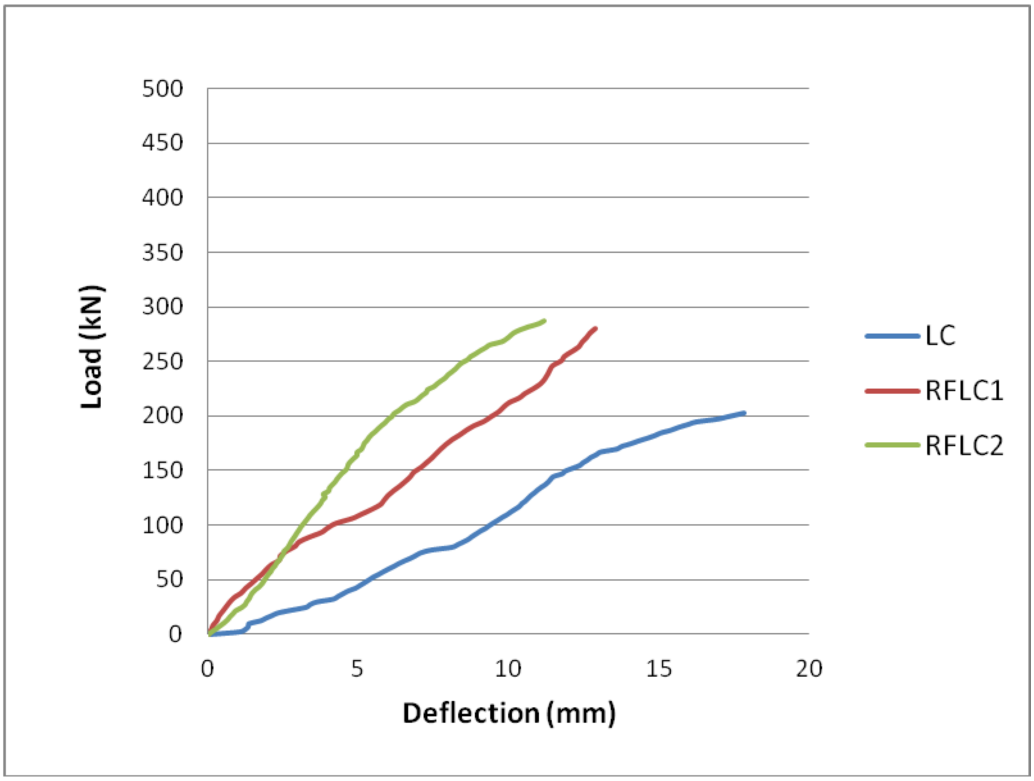


Fig. 4.21 Comparison of Load vs. Mid Height Deflection of Control and Ferrocement Confined Columns (LC, RFLC1 and RFLC2, λ=15)

4.5 Overall Comparison of Test Results of Columns

Comparative analysis of control columns and ferrocement confined columns with different slenderness ratio and wire mesh layers is given in Table 4.1. The Fig. 4.22 shows the comparison between the slenderness ratio and ferrocement confinement on the load carrying capacity of the column.

Table 4.1 Test Results of Control and Ferrocement Confined Columns

Specimen	Slenderness ratio λ	Number of Specimens	Avg. Ultimate load (kN)	% Increment in ultimate load	Avg. ultimate lateral deflection (mm)	First crack load (kN)
CS	3	3	274	-	3.81	272
RFCS1	3	3	527	92	2.25	524
RFCS2	3	3	554	102	1.98	548
SC	7	3	252	-	5.35	250
RFSC1	7	3	343	36	3.82	337
RFSC2	7	3	353	40	2.97	346
LC	15	3	203	-	17.81	201
RFLC1	15	3	280	38	12.31	274
RFLC2	15	3	286	41	11.16	283

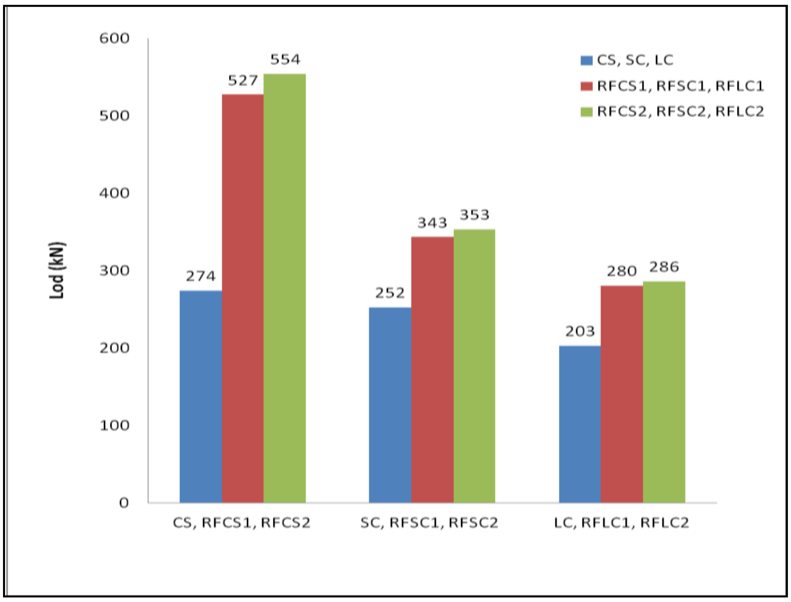


Fig. 4.22 Comparison of Effect of Slenderness Ratio and Ferrocement Confinement on Ultimate Load Capacity

4.5.1 Effect of slenderness ratio and ferrocement confinement on ultimate load capacity

There is an increase in the ultimate load carrying capacity of confined columns RFCS1 and RFCS2 as compared to the control column CS. The ultimate load capacity of the control columns SC (λ=7) and LC (λ=3) is also lower than the control column CS (λ=3), which clearly indicates the effect of slenderness ratio. The comparison within the confined columns i.e. with one layer of wire mesh (RFCS1, λ=3) and with two layers of mesh (RFCS2, λ=3) did not show any significant increase in load carrying capacity. The percentage increase with one layer of wire mesh in RFCS1 (λ=3), RFSC1 (λ=7) and RFLC1 (λ=15) is 92%, 36% and 38% respectively in comparison to the control columns of the same slenderness ratio.

4.5.2 Effect of slenderness ratio and ferrocement confinement on lateral deflection

The lateral deflection during compression was also reduced with ferrocement confinement. In case of short columns with slenderness ratio (λ=3), the deflection is considerably reduced, to 2.25mm (RFCS1) and 1.98mm (RFCS2) as compared to that of control column CS, 3.81mm. The similar pattern was observed with other column specimens of different slenderness ratio. The short column with slenderness ratio, λ=7, showed decreased lateral deflection i.e. 3.82mm (RFSC1) and 2.97mm (RFSC2) when compared to that of control column SC, 5.35mm. Similarly long column with slenderness ratio λ=15, exhibited the decreased lateral deflection to 3.82mm (RFLC1) and 2.97mm (RFLC2) when compared with that of control column LC, 5.35mm. All the categories of the columns show similar pattern, i.e. lateral deflection decreased with ferrocement confinement. And test results show that with increase in the slenderness ratio the lateral deflection also increases.

4.5.3 Effect of ferrocement confinement on first crack load and crack pattern

In case of short columns, which fail in compression the first crack load value was observed just before the ultimate load value. It is because in columns with small slenderness ratio the full height is involved into the damage. The zone of rupture in short columns was observed near one-fourth height of the column either from top or bottom. Typically, in case of unconfined control columns the first crack appeared on the corner portion and diagonally propagated towards the middle of the width.

With ferrocement confinement, for the first crack load the column behaved in a similar manner as the control column. It also occurred just before the ultimate failure but at higher value of load. The first crack appeared near the corner and propagated vertically, thereby separating the mortar layer from the wire mesh followed by failure of core concrete.

In case of long control columns of the failure zone was observed to be above the one-fourth height, instead of mid height. The crack was horizontal followed by the rupture. After the confinement, the column showed first crack near the bottom corner which became wide with increase in load. The crack propagated vertically near the corners and the ultimate failure was followed by delamination of the ferrocement layer up to mid height. It shows that the confinement is better in the center of the width and reduced strength of confinement is observed near corners.

CONCLUSION

This experimental study is carried out to analyse the behaviour of RCC columns with different of slenderness ratio and ferrocement confinement on the strength of the columns. Based on test results, the following conclusions are obtained:

1. Ferrocement confinement increased the ultimate load carrying capacity of columns.
2. With the increase in slenderness ratio of columns the strength provided by ferrocement confinement decreases. In short column (λ=3) confinement with one layer of wire mesh increased the strength up to 92% as compared long column (λ=15) which exhibited an increase of only 36%
3. Lateral deflections are significantly minimised with ferrocement confinement up to first layer of wire mesh but there is marginal decrease with second layer.
4. Ultimate load capacity of control sample is increased with single layer up to 92% and with two layers it increased to 102% which is marginal.

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