

BEHAVIOUR OF LOADED RC COLUMNS ENCASED WITH POLYMER MODIFIED FERROCEMENT UNDER CONCENTRIC LOADING

A dissertation

*Submitted in partial fulfillment of the requirement for the
award of the degree of*

Masters of Engineering in Structural Engineering

Under the guidance of

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DECLARATION

I hereby declare that this thesis titled "BEHAVIOUR OF LOADED RC COLUMNS ENCASED WITH POLYMER MODIFIED FERROCEMENT UNDER CONCENTRIC LOADING" is an authentic record of the work carried out as per the requirement for the award of degree of **Masters of Engineering in Structural Engineering** in the Civil Engineering Department of **Thapar University, Patiala** under the guidance of **Dr. Prem Pal Bansal, Associate Professor**, Department of Civil Engineering, Thapar University, Patiala during July 2015 to July 2016. The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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I hereby certify that the above statement made by the student concerned is correct and true to the best of my knowledge and belief.


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ABSTRACT

Concrete structures are the pivot of civil engineering due to its extensive use; they provide excellent performance in terms of structural behavior and durability. The zones which are exposed to severe mechanical and environmental loading require rehabilitation. Rehabilitation is provided to the structures which are deteriorated and to those elements whose load carrying capacity is decreased due to cracks. Rehabilitation of deteriorated concrete structures leads to significant user costs and is also a heavy burden from the socio- economic viewpoint. As a consequence, Rehabilitation of structures must be developed.

The rehabilitation and strengthening of pre-existing reinforced concrete columns using wire mesh jacketing is done based on a well-established fact that due to application of jacketing lateral confinement of concrete is decreased and its axial compressive strength can sustainably increase. In recent years, various methods of external confinement of concrete are being used such as jacketing using Steel Angle, FRP, Bracing Infill walls, Ferrocement has emerged as a popular method of column retrofit. Retrofitting of element reduces the damage of an existing structure during a future earthquake. The basic aim is to strengthen a structure in accordance to the requirements of the current codes for seismic design. Therefore, rehabilitation of deficient columns is required to increase load carrying capacity and decrease the lateral deflection of column due to buckling. External confinement of the damaged column can be done by different materials such as Ferrocement and Polymer. Ferrocement confinement for re- strengthening of deteriorated columns is one of the oldest, efficient and cost effective techniques. Polymer induced Ferrocement is a form of thin wall reinforced concrete using wire mesh and high strength mortar mixed with polymer. The wires used as reinforcement in wire mesh provide a higher specific surface hence providing strength to the ferrocement.

Considering all these points, the present study focused on the behavior of RCC columns with different slenderness ratios on the Polymer induced Ferrocement confined. In the experimental part of this thesis, column specimens with three different slenderness ratios (λ) were casted. Three slenderness ratios were considered $\lambda = 3$, $\lambda = 6$, $\lambda = 12$.

These specimens were further divided into three categories. The first category was of control samples consisting of no loading and no Ferrocement columns from each size group, second category consisted of normal samples and pre-loaded samples confined with Polymer (SBR) Ferrocement using one layer of wire mesh and third category consisted of normal samples and pre-loaded samples confined with Polymer (SBR) Ferrocement using two layers of wire mesh. In second and third category the 80% loading was done with respect to the peak load of control samples and the polymer used was SBR. All the columns were tested under monotonic uni-axial compression loading. As the slenderness ratio increased from $\lambda = 3$, $\lambda = 6$ to $\lambda = 12$ the load carrying capacity decreased from 180kN, 154kN to 132kN, there was a different trend while increasing the number of mesh as the load carrying capacity increased 53.1% to 70% in $\lambda = 3$ and the similar trend was seen in $\lambda = 12$, increased from 39.8% to 51.2%.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The factors affecting deterioration of reinforced concrete structures, pre-stressed concrete structures and the mechanisms of deterioration are well understood today. The major factors responsible for the deterioration of structures are faulty design, unsuitable materials, improper workmanship, overloading and exposure to an abnormally aggressive environment. The main causes of deterioration of concrete structures are:

- Cracking and spalling of concrete
- Environmental factors such as corrosion
- Extremely heavy loads

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. Once a structure is built in concrete, it is more or less considered permanent and does not need much attention for maintenance. However, over the years a number of structures have manifested deterioration thereby exploding this myth. The concept of durability and serviceability of a structure has been considered by Indian engineers during design and construction. New materials, methodologies and construction techniques have been developed and used to ensure durability of structures. . To restore the required strength of the deteriorated structure, retrofitting is the solution

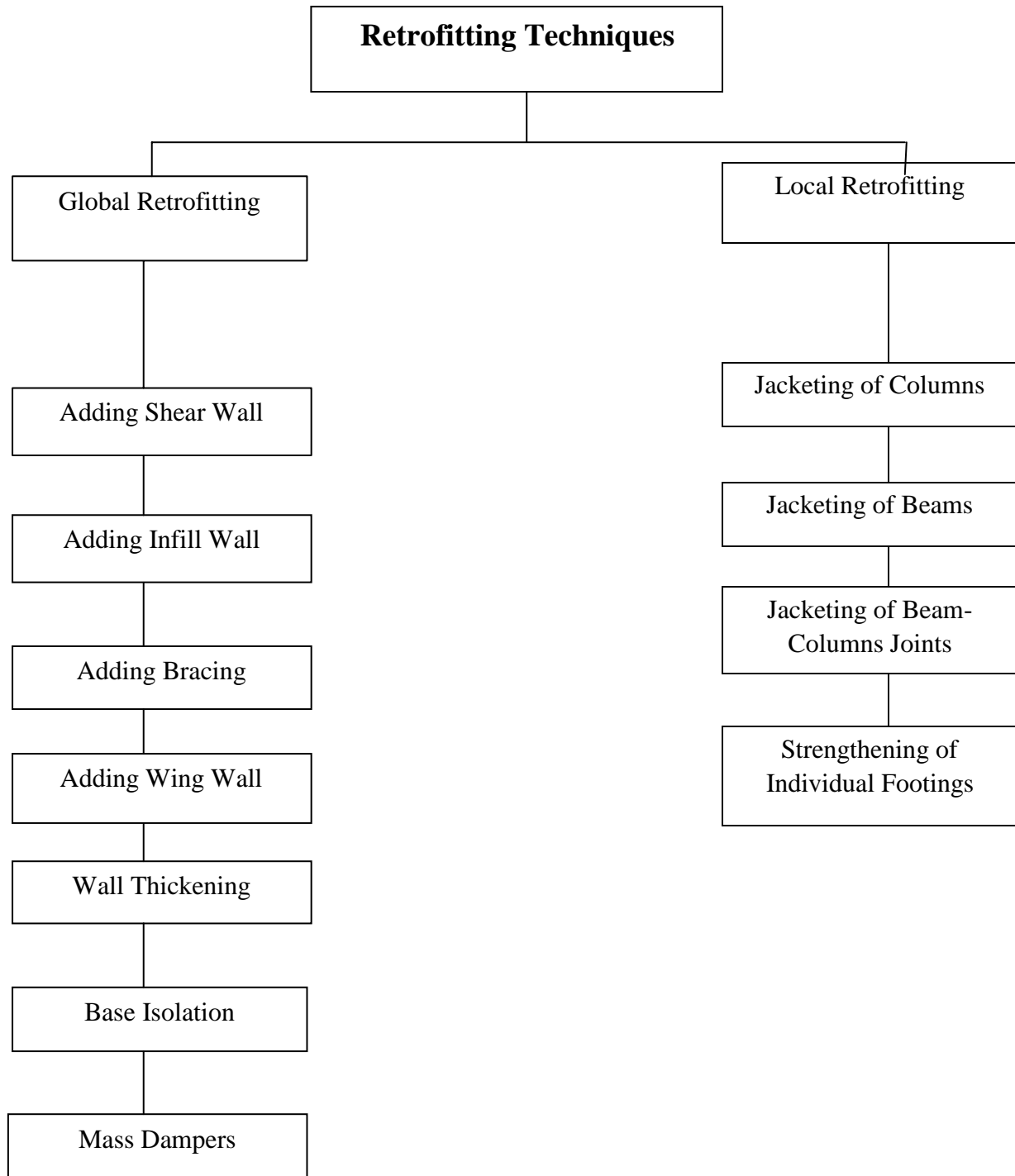


Fig. 1.1 Retrofitting Technique

The process of selection of repair technique is one of the most important tasks for determining durable and effective repair. The basic pre-requisite for rehabilitation is the detailed investigation of structure and determining the cause of distress. The availability of skilled

labor, equipment and materials by relevance has to be explored before deciding upon the type of repair. From all the above techniques jacketing construction is most preferred method of retrofitting that is applied by following techniques,

- Confinement with Ferrocement
- Confinement with external steel caging techniques
- Confinement with CRPF, Glass Fibers, Polymers

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.

Retrofitting is the technical aspect of rehabilitation which refers to the identification of a structure partly or wholly which is damaged in appearance and serviceability. Retrofitting consists of restoring the structure to service level, it once had and that too at low cost. The rehabilitation envisages restoration of structural system as close to the original configurations as possible. The structures in distress are to be brought in line and require strength so that they could be put back in service without endangering their safety and utility.

The basic aims of Retrofitting work would be as under:

- To prevent harmful development to restore the integrity of the structure and to provide effective protection.
- To improve functional utility and service life.
- To reduce distress and remove defects which involve hazards to life and affect durability of a structure.
- To improve the aesthetic appearance



Fig. 1.2 Retrofitted Boat (Image source: Naaman, 2000)

1.2 FERROCEMENT- A BLENDED MATERIAL

Ferrocement is defined as a “type of thin wall reinforced concrete construction where usually hydraulic cement is reinforced with layers of continuous and relatively small diameter mesh throughout the matrix, the material under stress acts approximately as a homogenous material” as shown in Fig. 1.2. An important advantage of Ferrocement over other repairs is that it enhances resistance to cracking and decreases deflection which is due to very closely spaced small diameter reinforcements. Owing to its ability to be molded into any shape with high crack resistance combined with enhanced toughness, and rapid building with no or little bulky machinery requirement, it presents a structurally and economically effective solution for use in rehabilitation applications.

Conventional reinforced concrete is very different from Ferrocement due to its layering of externally bonded elements. It is composed of closely bonded multiple layers of wire mesh which are completely indulged in cement mortar. This results in a composite material which is completely different from RC in terms of crack formation and strength.

It can be formed into thin bands or sections generally 15 mm to 25 mm thick, which are

applied over the outermost layer of the wire mesh. Unlike normal concrete, in the process of Ferrocement application form work is not required and it can be assembled into any desired shape by directly plastering mortar over the specimen. In comparison to normal concrete; superior cracking behavior and high tensile strength can be observed in Ferrocement concrete. Ferrocement structures are relatively lighter and water-tight as compared to that of conventional concrete. That's why Ferrocement can be used with confidence on suitable rehabilitation and re- strengthening material for a wide range of applications such as:

- Tanks, containers and silos.
- Floors and Roofs.
- Heavy duty floor tiles.
- Water proofing.
- Decorative panels and tiles.
- Cooling towers.
- Telephone and electric power poles.
- Wall paneling, Strengthening of RCC structures.

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). These materials are discussed individually in the section below. The constituent materials of Ferrocement are:

- ***Reinforcing Mesh:*** The most important components of ferrocement is wire mesh and polymer induced mortar , types of wire mesh are shown in Fig. 1.3 these type of mesh are available everywhere. They are generally made of thin woven wires to make a mesh, it should be flexible so that it can easily be wrapped and bend around corners. The main function of wire mesh is to provide bonding between structure and mortar when fresh and to absorb stress during hardened state. They also help in the lateral confinement.

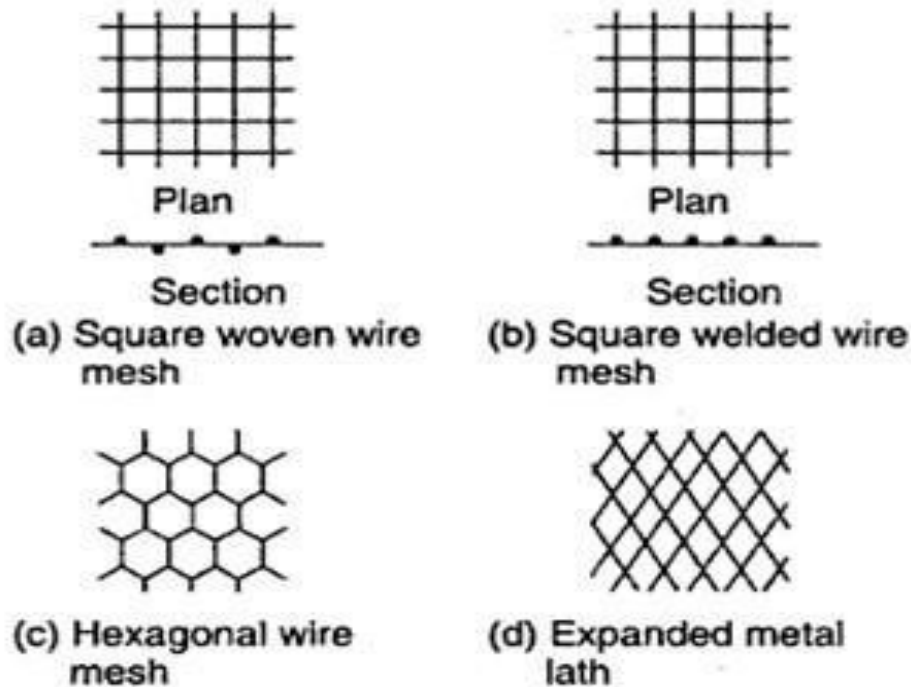


Fig. 1.3 Types of Wire Mesh (Image source: Naaman, 2000)

- **Cement:** There are different types of cement which are available in the market, the most common is Portland cement which is available everywhere and is well-known. The cement should be in accordance with the IS specification.
- **Aggregates:** Sand is the most important aggregate used in formation of Ferrocement. The fine aggregate (sand) should satisfy the requirements of IS 383:1970. Aggregate in total occupy around 65 to 85 % of space in aspect of volume of mortar. Ferrocement structures should be strong enough to take higher load and stresses for which high quality mortar should be prepared. The water/cement ratio should be minimum so that permeability is low and a workable mix is prepared which can penetrate into the wire mesh confined over the specimen.
- **Water Mixing:** The quality of Ferrocement is dependent on the quantity and quality of water mixed to form the mortar mix. Undesirable impurities in mix may hamper the setting time of cement and adversely affect the capacity. These impurities can also cause corrosion of ferrocement. The water generally used in process is used from the public supply and is termed as satisfactory. Water of $\text{pH} \geq 7$ should be used for mortar mix.

- **Admixtures:** The properties of concrete and cement mortar are enhanced by the use of Admixtures, they are used to provide maximum workability without hampering the water/cement ratio of the mix. The water demand is reduced and setting time of the mortar is increased. Admixtures can be named into different groups according to the effect they have over the mix. These admixtures are mixed with water and then used with the dry mix to produce mortar. By adding admixtures the water used can be adjusted The commonly used admixtures are:
 - Acceleration admixtures
 - Retardation admixtures
 - Water reduction admixtures
 - Air entrainment admixtures.

- **Mortar Mix:** This is a hardened cement paste formed by the reaction of Portland cement with water. For the formation of mortar mix for Ferrocement different proportions of sand-cement and water cement ratio are recommended. By making trial batches water/cement ratio, fineness modulus of sand and sand to cement ratio can be examined. The mix should be able to strengthen the bond between wire mesh and specimen and should be able to penetrate into mesh. To retard initial setting time and enhance mix plasticity water reducing admixtures should be mixed with conventional concretes. The behavior of mortar is similar to that of plain concrete.
 - Sand to cement ratio by weight, 1.5 to 2.5.
 - Water to cement ratio by weight, 0.35 to 0.5.

For adequate bonding the reinforced steel wire mesh should have a larger opening; the closer spacing and uniform extension of Reinforcement, transform the brittle behavior of mortar into a high performance material as compared to conventional 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 has high tensile strength.*** Ferrocement is thin section of wire mesh and mortar, which has high tensile strength. As compared to matrix mortar the wire mesh is much stronger in tension, the basic role of matrix is to properly hold the wire mesh in correct position, to transfer loads and stresses by enhanced bonding and to give proper protection to structural material which is highly waterproof, crack formation resistant, energy absorbing material.
- ***Ferrocement is light weight.*** It is light weight, because of very high water cement ratio of 0.45, light structural wire mesh made of steel in a box structure with high cement concentration and addition of admixtures which are very light as compared to aggregates particularly if Ferrocement is cast-in- situ. Therefore weight of Ferrocement structure is very less.
- ***Ferrocement can be constructed in any shape.*** As it is very light weight due to its matrix and mortar, it can be molded into any desired shape. Construction of Ferrocement is very easy as it is light weight. It is highly efficient and durable.
- ***Ferrocement is highly ductile, resilient, energy absorbing material.*** It confines the structure and absorbs energy to maximum limit without transferring it to the main structure. When put under load it develops cracks at much higher load beyond the elastic limit. Because of this property a Ferrocement structure can with stand higher deformation prior to collapse. The debris formation will also be the less and generally easier to repair.
- ***Ferrocement is an isotropic material.*** RCC material is a heterogeneous material and consists of voids and capillaries which are induced during construction. Therefore, water and other gases easily entrapped in the Concrete material can cause crack formation due to presence of air, spalling and corrosion of Reinforcement. Moreover, the cracks formed over RCC structures are wide and deep whereas minute and small 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. As it is very light weight due to its matrix and mortar, it can be molded into any desired shape. Construction of Ferrocement is very easy as it is light weight. It is highly efficient and durable.

1.4 FERROCEMENT STRUCTURALELEMENTS

Ferrocement confined structures are constructed with Ferrocement as a confining skin on the periphery surface which is being tied up. These layers consist of wire mesh, welded wire mesh, high tensile strength wires, mild steel flats, etc. The core on which it is being tied up consists of high strength Concrete. The resistance to bending moment, shear, and torsion increased due to its better crack arresting property and high ductility this arrangement increases. The crack formation on the surface can be further delayed by addition of fibers on the surface if feasible. Ferrocement confined structures can be further strengthened by welding bracing bars, tie up bars and round bars at top and bottom crossing. Therefore it provides a resistance to deflection during fabrication stage itself. This process makes the Ferrocement structures highly energy absorbing, resilient and ductile. Ferrocement slab is about 15 to 25mm thick consisting of grid of Mild Steel flats, wire mesh layers on top and bottom. Welded wire mesh of high Tensile Strength wires can be used in case greater thickness is required.

1.5 APPLICATIONS OF FERROCEMENT TECHNOLOGY

Ferrocement is a versatile material and can be used in construction of different structural members subjected to various types of loads and stresses. Horizontal stiffeners which are used in hollow columns can be cast in Ferrocement. Damaged columns or masonry walls can be encased in Ferrocement to enhance their strength due to lateral confinement. Structural elements such as circular slabs, shells, domes, pyramids which are subjected to membrane stresses can be cast in Ferrocement very easily; the full section of member is used in resisting the membrane loads owing to its homogenous nature. Applications of Ferrocement technology in various structures is discussed below.

1.5.1 Ferrocement in Slabs

RCC is commonly used for construction and protection of structures. Moreover, concrete structures may be subjected to dynamic loads and stresses produced due to various sudden explosive loads. The response of the structure under such loading is significantly different from a statically loaded structure. The structural element now is subjected to a combination of different blast and fragments loads which form small charges and also cause the structure to

shake thoroughly. Strong vibrations may result in crushing of concrete and crater formation in concrete, and may result in severe rupture in worst case scenario. Further, if large load is applied, crushing and penetration will be large and risk of injury to people inside the structure increases. The application of Ferrocement over the structure decreases its heat transfer and enhances the perforation resistance of steel mesh of reinforced cement matrix. The Ferrocement layers are able to resist fire and crack propagation at 700°C for 30 minutes in a structure. An increase in volume fraction of steel wires also improves the fire resistance of slabs.

1.5.2 Ferrocement for Structural Beam

A large number of civil constructions which were build are deteriorated due to loads, stresses and sulphate chloride attacks overtime. Some of these structures have been weakened to the point of being unsafe due to an increase in load beyond the structural and codal specifications (i.e. due to overloading of the structure) or due to lack of regular quality control and maintainanance required during the service life of the structure. In order to maintain serviceability during the intended design life, these deteriorated older structures must be repaired to meet the service requirements throughout the design life. Ferrocement due to its properties and encouraging results over the years in real-life applications is being looked upon as solution to this problem. Through experimental testing, the researchers are exploring its potential for use in retro fitting and strengthening of damaged structural members. The Ferrocement material is usually applied as a layer of cement mortar reinforced with closely spaced layers of relatively small diameter wire mesh. For the thin Ferrocement layer to be applied to a surface it is necessary to choose the properties of constituent materials in accordance with the type of construction and loads acting on the structures to obtain adequate strength, restrain cracking, and improve stiffness, ductility and impact resistance.

For providing strengthening in reinforcement in column and beams ferrocement laminates are applied over the specimen play a significant role, Ferrocement laminates are being casted onto soffits for providing flexural strengthening to the concrete beams, this application of ferrocement laminates does not change the dimensions of the beams including the width of the beam. As the technology is improving the strength of Ferrocement laminates is also increasing, thus it is very commonly available technique used for beams.

1.5.3 Ferrocement Water Tank

Ferrocement composed water tanks are lighter in weight due to properties of Ferrocement and exhibit large value of strength as compared to normal reinforced concrete tanks. The construction of Ferrocement tanks requires minimum skill, and incurs lesser overall project cost for fabrication while providing maximum utility, durability and enhanced service life. Ferrocement tanks are Eco-friendly and easy to make as compared to that of steel and poly-vinyl chloride tanks. These tanks keep the water cooler in summer.

In addition to their use as water tanks, Ferrocement tanks can be used across diverse applications such as septic tanks, door shutters, cup-boards, grain storage silos, animal feed tanks, boundary wall, irrigation channels, segmented roofing sheets, man-hole covers (light, medium and high duty), flower pots etc.

1.5.4 Roofing Applications

Ferrocement application in roofing is very economic and eco-friendly as compared to other materials. Ferrocement roofing provides a higher value of heat transfer absorption and due to its water-proofness it is highly used in major countries.

Slab consisting of ferrocement with a span of 17m (56 ft) with a thickness of 30 mm (1.2 in.) have been constructed till now. As the Ferrocement technology advances , the span can be increased with mixture of different compositions of ferrocement to be applied over roof.

1.5.5 Ferrocement is an effective fire resisting material

Ferrocement is an efficient fire resistant material, which resists fire better than RCC and steel. The expansion of Ferrocement due to fire is without any splitting, cracking of cement matrix and detachment from steel surfaces, the bond between mortar matrix and steel mesh being very strong. Further, there is almost no surplus water for steam formation. This resistance is so strong that Ferrocement houses have been observed to resist fires for 1.5 hours against a temperature of 1700°. The damage to the houses is negligible and can be repaired at a relatively much lower cost. Ferrocement has a low value of heat transfer so it can withstand higher values of temperature as compared to conventional concrete structures.

1.5.6 Applications in Housing:

Ferrocement due to its enhanced properties and load carrying capacity as compared to normal concrete is widely used in housing application. Ferrocement can also be easily cast into complex membrane shapes such as span roofs, angled roofs, channeled roofs , girder box, and other primary roofs.

1.6 BEHAVIOR OFFERROCEMENT

The three major behavior characteristics of Ferrocement elements that should be considered are tension, compression, flexure and shear.

1.6.1 Behavior under tension

Normally, tensile behavior of Ferrocement can be classified in three stages.

1. Elastic stage (OA in Fig.1.4): The matrix and reinforcement mesh are assumed to be acting as one with linear elasticity. This is similar to the behavior of reinforced concrete. No cracking occurs in this stage.
2. Elastic-plastic stage (AB in Fig.1.4): Multiple cracks start to form and propagate. In this phase, that Ferrocement differs from reinforced concrete as uniform fine cracks (less than 100 micron) form rather than the larger cracks found in reinforced concrete structure.
3. Plastic stage (after point B in Fig.1.4): This is the crack stabilization and opening phase, and is when the ultimate load occurs.

One interesting part in the elastic-plastic stage is that the primary cracks occur randomly at critical sections when the tensile stress exceeds the matrix tensile strength. As the load rises, new cracks may occur in the matrix due to the tensile stress exceeding the matrix tensile strength. In order to transfer stress between cracks, more cracks will continue to occur at this stage until the stress in the matrix will not exceed the matrix tensile strength again and the number of cracks in the matrix stabilizes. An advantage of Ferrocement is that there is a substantial reserve strength and ductility after the occurrence of visible cracks. One can decide on appropriate repair and strengthening measures based on visual inspections.

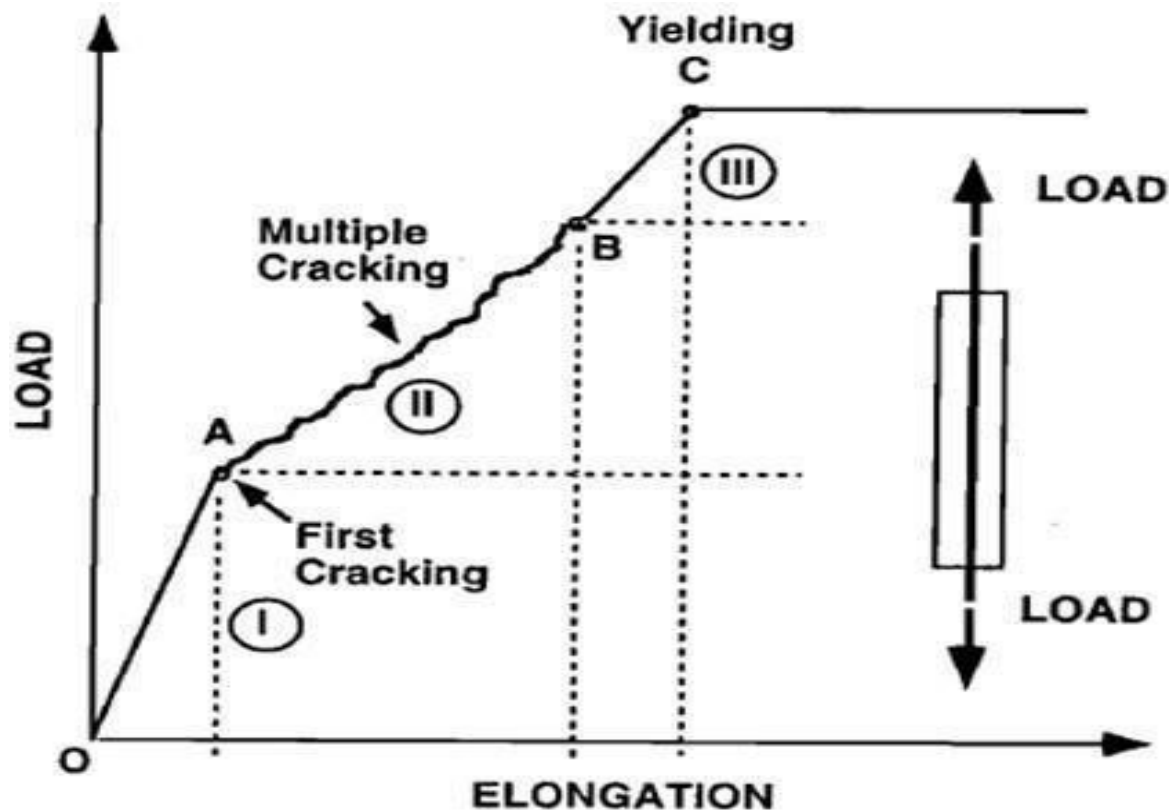


Fig. 1.4 Ferrocement Under Tension (Naaman, 2000)

1.6.2 Behavior under compression

Most of the research on the compression behavior of Ferrocement was conducted more than three decades ago. In compression, the load carrying capacity of the matrix strongly influences composite behavior. Desayi and Joshi (1976) reported that the compressive strength of Ferrocement depends mainly on the matrix and it is possible to control and predict this behavior within certain limits. A large increase of volume fraction cannot affect the compressive strength.

Sufficient ties across the mesh layers are critical for avoiding delaminating due to compression buckling of mesh and splitting transverse tensile stress.

1.6.3 Behavior under flexure

Ferrocement behavior under flexure is combined behavior in tension and compression, and is influenced by matrix strength, mesh type, mesh properties and mesh orientation. Fig 1.5 shows

the flexural behavior of Ferrocement, which is similar to tensile behavior. It can be categorized into three stages, the elastic stage, the elastic-plastic stage, and the plastic stage.

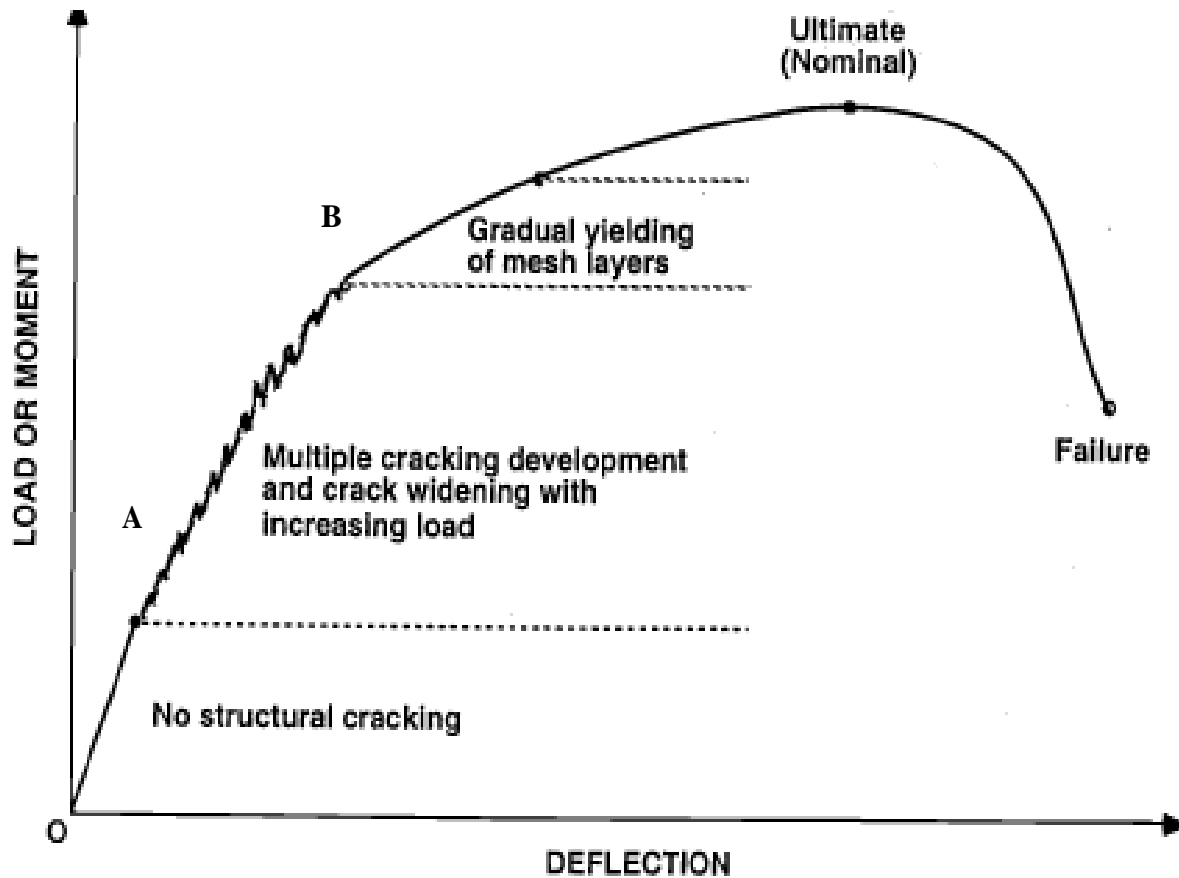


Fig. 1.5 Typical Load-Deflection Response of Ferrocement (Naaman, 2000)

The specific surface has less contribution to flexure. This is because the outer most layers mainly control the flexural cracking.

- 1) Elastic stage (OA in Fig.1.5): It is the initial portion without structural cracking.
- 2) Elastic-plastic stage (AB in Fig.1.5): It is also called a multiple cracking stage. This stage sees multiple cracking and crack widening with increasing load.
- 3) Plastic stage (After point B in Fig.1.5): The Ferrocement starts to yield and the mesh layer gradually yields, thus achieving the peakload.

The orientation of meshes in Ferrocement has a considerable effect on the maximum strength.

Studies reported that the weakness of the Ferrocement under flexure in different directions, therefore orientation is important. When the mesh wire direction is along the principal stress direction, the peak flexural strength may achieve a maximum value.

1.7 CLASSIFICATION OF COLUMN

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 framed structure as it transmits the vertical loads to the foundation. Columns may be cast to any of the following shapes, Square, Rectangular, Circular and Hexagonal.

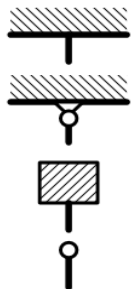
Buckled shape of column shown by dashed line						
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value K	0.65	0.80	1.2	1.0	2.10	2.0
End condition key	 <ul style="list-style-type: none"> Rotation fixed and translation fixed Rotation free and translation fixed Rotation fixed and translation free Rotation free and translation free 					

Fig. 1.6 Effective Length of Compression Members (Image source: IS456 :2000)

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. 1.6. The different end conditions govern the behavior of column in different loading conditions. Where “ l ” is the unsupported length of the compression member. Slenderness ratio (λ) is the ratio of effective length to least lateral dimension.

- **Short column:** If the value of slenderness ratio (λ) is less than 3, the column is considered as Short Column. A short column has higher load carrying capacity as compared to long column of same cross-section. The strength of the column is greatly influenced by the length. The slenderness ratio governs the mode of failure. The mode of failure of the short column is mostly in compression by crushing of concrete.
- **Long column:** If the value of slenderness ratio (λ) is greater than 12, the column is considered as a Long Column. Long columns fail within global buckling. 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.

1.8 POLYMER

The word polymer is derived from Greek words poly meres, where poly meaning “many” and meres mean “parts”. So polymers are long chain structures which are composed of repeated units . Homo-polymers are single unit monomers, which when combined in a long chain form polymer, if there are different monomers they are called co-polymers.

1.8.1 Structure of Polymer

Polymers can be divided into 3 main types based on their structure:

- Polyethylene Latex
- Poly-Vinyl Alcohol
- Polyvinyl Chloride(PVC)
- Styrene Butadiene Rubber(SBR)

Polymer-modified mortar and Concrete are prepared by mixing either a polymer or monomer dispersed in a powdery or liquid form with fresh cement mortar and Concrete mixtures. The mix is subsequently cured, and if necessary, the monomer contained in the mortar or Concrete is polymerized in situ. Several types of polymer-modified mortars and Concretes, i.e., latex-redispersible polymer powder-, water-soluble polymer-, liquid resin-, and monomer-modified mortars and Concretes, are produced by using the polymers and monomers shown in Fig.1.7 .

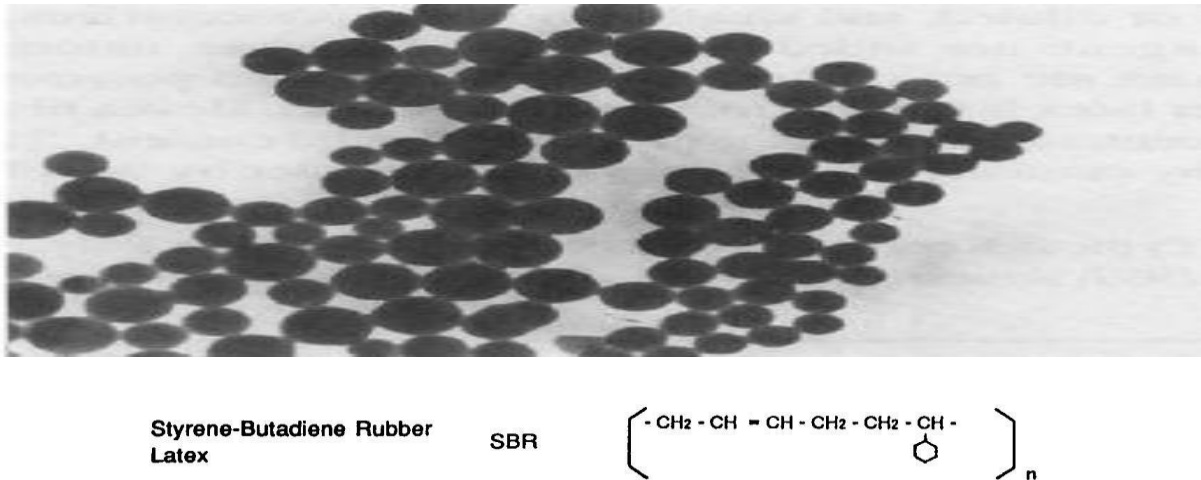
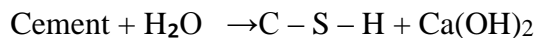


Fig. 1.7 Styrene Butadiene Polymer (Image source: of the Japan Synthetic Rubber Co., Ltd.)

1.8.2 Hydration Process

Cement concrete is cured for 28 days to develop its strength. When cement is exposed to water, chemical reactions begin to take place. These reactions are called hydration process, which in turn will produce a firm and hard mass. In these reactions, it is of interest to know which hydration products contribute to the strength of the hydrated cement at different stages of hydration (Mindess and Young, 1981).



In the early stage, gypsum will react to control the setting time and the reaction that takes place is exothermic. For the first 14 days, the strength of Concrete is provided by C₃S. For the next two weeks, it is then taken over by C₂S, which reacts much more slowly. Rates of reactions bear no relation to strength development as both C₃S and C₂S contribute equally to ultimate strength. C₃A have high early strength but does not contribute significantly to the ultimate strength and is prone to sulphate attack. C₄AF only gives a small effect on the strength of Concrete (Zakaria, 1987).

1.8.3 Polymer-Modified Mortar

The incorporation of polymers into mortar system requires compatibility between both polymer and aqueous solutions. Polymer may be added in a dispersed, powdery, or liquid form into the fresh mortar. Among the few types of polymer-modified mortars are latex-dispersible polymer powder, water-soluble polymer, liquid resin, and monomer-modified mortar. Of these, the latex-modified mortar is the most widely used cement modifier. In the polymer-modified mortar, aggregates are bound by monolithic phase and polymer phase inter-penetrate. This co-matrix phase results in an improved properties of polymer-modified mortar compared to ordinary mortar (Ohama, 1995).

1.8.4 Principles Of Latex Modification

The co-matrix phase of latex modification of cement mortar and Concrete is formed by both cement hydration and polymer film formation processes. Generally, the polymer film formation comes after the cement hydration process.

Polymers Improve Mortars In four main ways

1. **More extensive cement cure.** Cement/Concrete strength depends on proper curing, a chemical reaction (hydration) between water and cement that causes crystals to grow and wrap around the mix components. During the early stages of curing (roughly the first five to seven days), there must be enough water to maintain the hydration process or the cement/Concrete will not harden properly. Polymers reduce the rate of water evaporation, allowing the crystal structure to keep growing and building strength during these critical early curing stages. This reduced water evaporation is especially important in thin applications, where the surface area for evaporation is high, relative to the volume of the mortar.
2. **Improved workability.** Polymer modification noticeably improves application characteristics, making the mortar more fluid and easier to handle and apply. Certain polymers also prolong the hydration period, which can increase working time, an important characteristic in hot climates. This means contractors can use less water for workability purposes. The polymer acts as a water reducer, ultimately leading to a stronger mortar with fewer voids, or weak spots.

3. **Improved adhesion.** Polymer modifiers act as an adhesive to enable the modified mortar overlay to stick to a variety of surfaces such as Concrete, masonry, brick, wood, rigid polystyrene and polyurethane foam, glass, and metals. Adhesion is an important property, especially in thin section overlay mortar applications such as spray coatings, stuccos, and underlayment, and applications with excessive vibration and heavy traffic.
4. **Improved strength and durability.** Cured polymer-modified mortars generally have improved tensile strength, flexural strength, impact and abrasion resistance, water resistance, and chemical resistance compared to unmodified mortars. Also, the polymer in the mortar helps restrain micro-crack propagation, which improves the overall toughness of the mortar

1.8.5 Mixing

Latex-modified mortar and Concrete can be easily prepared by using all conventional mixing equipment and tools such as mortar or Concrete batch mixers and ready-mix trucks, as well as by hand-mixing in mortar boxes or Concrete mixing vessels.. Polymer latexes are initially mixed with mixing water, and directly added to the cement and aggregate mixes. The speed and time of mixing should be properly selected to avoid unnecessary entrapment of air even though antifoaming agents are used. Air-entraining agents cannot be used because the polymer latexes entrain air. The mix design of latex-modified mortar and Concrete is usually carried out in much the same way as that of ordinary cement mortar and Concrete, depending on the workability, strength, extensibility, adhesion, waterproofness (or watertight ness) and chemical resistance requirements. Latex-modified mortar and Concrete mix design should recognize its improved properties such as tensile and flexural strengths, extensibility, adhesion, and durability over conventional mortar and Concrete. These properties are controlled more by the polymer-cement ratio rather than the water cement ratio. Therefore, the polymer-cement ratio should be determined to meet desirable requirements. The polymer-cement ratio is defined as the weight ratio of the amount of total solids in a polymer latex to the amount of cement in a latex-modified mortar or Concrete mixture. The mix proportions of most latex-modified mortars are in the range of the cement-fine aggregate ratio = 1:2 to 1:3 (by weight), the polymer cement ratio of 5 to 20% and the water-cement ratio of 30 to 50%, depending on the required workability.

1.9 OBJECTIVES

The present research is aimed to evaluate the effectiveness of wire mesh confinement in strength deficient columns and columns which are pre-loaded. This was achieved by comparing the behavior of Ferrocement confined columns with that of the reinforced unconfined columns. The samples were casted and cured for 28 days and then were tested under uni-axial monotonic load.

For this study the following objectives are framed:

- To study the improvement in load carrying capacity with slenderness effect in columns.
- To study the effectiveness of the Ferrocement confinement with different layer of wire mesh.

1.10 DISSERTATION OVERVIEW

This research has the following structure:

- *Chapter 1* gives an introduction and a discussion on the retrofitting of column with wire mesh, polymer ferrocement and the objectives of this study.
- *Chapter 2* provides an insight on the relevant literature needed to conduct this research.
- *Chapter 3* covers the details on the various material used and explains the test adopted with some preliminary results to carry out this research.
- *Chapter 4* explores the detailed test results and achievement of the objectives.
- *Chapter 5* discusses the test results and conclusions are made along with the future scope of work is discussed.

CHAPTER 2

REVIEW OF LITERATURE

2.1 FERROCEMENT TECHNOLOGY

Concrete structures are the pivot of civil engineering due to its extensive use; they provide excellent performance in terms of structural behavior and durability. The zones which are exposed to severe mechanical and environmental loading require rehabilitation. Rehabilitation is provided to the structures which are deteriorated and to those elements whose load carrying capacity is decreased due to cracks. Rehabilitation of deteriorated concrete structures leads to significant user costs and is also a heavy burden from the socio- economic viewpoint. As a consequence, Rehabilitation of structures must be developed.

The rehabilitation and strengthening of pre-existing reinforced concrete columns using wire mesh jacketing is done based on a well-established fact that due to application of jacketing lateral confinement of concrete is decreased and its axial compressive strength can sustainably increase. In recent years, various methods of external confinement of concrete are being used such as jacketing using Steel Angle, FRP, Bracing Infill walls, Ferrocement has emerged as a popular method of column retrofit

As the fabrication and application of wire mesh is an easy task so it requires less skilled labor for casting. 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. Retrofitting of element reduces the damage of an existing structure during a future earthquake. The basic aim is to strengthen a structure in accordance to the requirements of the current codes for seismic design. Therefore, rehabilitation of deficient columns is required to increase load carrying capacity and decrease the lateral deflection of column due to buckling. External confinement of the damaged column can be done by different materials such as Ferrocement and Polymer. Following are the studies done in accordance to observe the properties and load capacity of the Ferrocement and SBR polymer.

2.2 STYRENE BUTADIENE POLYMER TECHNOLOGY

Polymers and monomers in any form such as latexes, water-soluble polymers, liquid resins, and monomers are used in cement composites such as mortar and concrete. To form a structure in which the polymer phase interpenetrates and the cement phase is hydrated both polymer phase formation and cement hydration should proceed well. The coalescence of polymer particle and polymerization of monomer is important. In the polymer-modified mortar and concrete structures, a co-matrix phase binds the aggregates, resulting in the superior properties of polymer-modified mortar and concrete compared to conventional concrete.

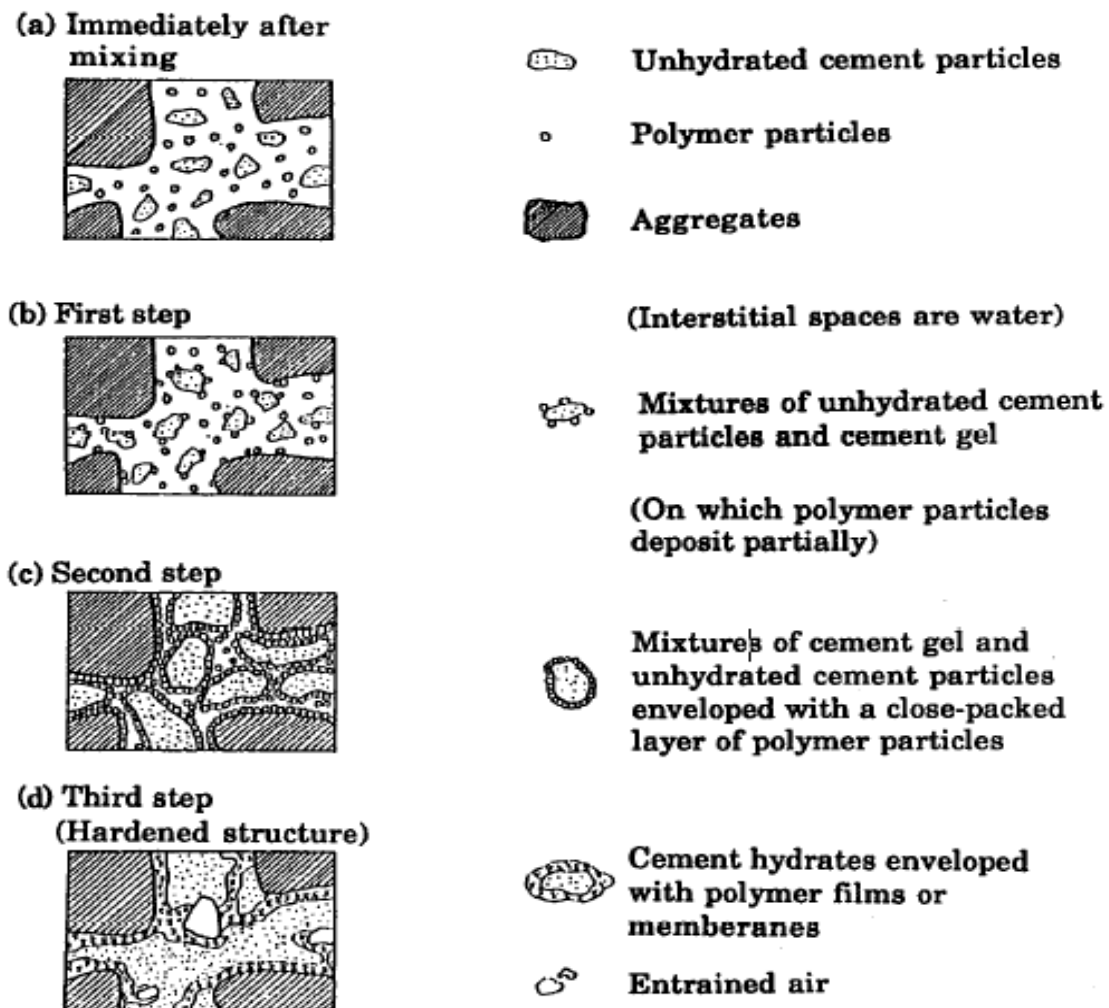


Fig.2.1 Formation of Polymer Cement Matrix

2.3 RESEARCH ON FERROCEMENT PROPERTIES AND SBR 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 can undergo significant deformations before cracking and withstand large deflections prior to collapse. As compared to mortar and concrete, polymer modified mortar and concrete provide high values of strength and enhanced properties including chemical resistance, high abrasion resistance, flexural strength, excellent adhesion, high tensile strength as compared to normal cement mortar combination. Further, they are used extensively in much important and specialized application where cement mortar have limited use

Murat and Alper (2016) Currently, as the technology is improving the quality of concrete is also increased. High Strength Concrete (HSC) is a very unique and special kind of concrete produced in extensive fluidity by adding chemical admixtures which are also called plasticizers. For this study C50 and C60 design high strength concrete were produced. In place of cement, Styrene Butadiene Rubber (SBR) is used in different weight ratios, such as 0%, 1%, 5%, 8% and accordingly strength properties were examined of SBR. For this study compressive strength, water absorption, unit weight, ultrasonic pulse velocity, frost resistance test and split tensile test were applied for 3,7,28 days. And also EDS and SEM (scanning electron microscope) analysis of the produced samples were determined. As the result of study, it was concluded that the higher values and enhancement in strength was observed in 1% SBR admixture samples.

Ghai and Bansal (2016) In order to improve the performance of ferrocement, the effects of addition of polymers namely; styrene-butadiene-rubber latex (SBR) and vinyl-acetate-ethylene polymer (VAE) in its mortar matrix, have been studied. The polymer-modified mortar (PMM) matrices were prepared with the addition of 0%, 5%, 10%, 15% and 20% polymers by weight of cement. Two and three layered wire mesh polymer modified ferrocement (PMF) elements were casted and tested. The test result reflects that the performance of SBR modified ferrocement is better as compared to VAE modified ferrocement. Flexural strength, tensile strength and elongation of three layered PMF on addition of 15% SBR showed an enhancement by 48.04%, 39.41% and 17.59% respectively, as compared to conventional ferrocement. This is attributable to the development of a polymeric layer, in which the polymer elements merge, a polymeric

compound is propagated and an interlocked mesh composition is formed. This study, therefore, recommends the use of 15% SBR modified mortars in three layered wire mesh ferrocement elements for better durability and strength.

Anant and Alam (2015) In this study, the mechanical and physical properties of hardened and fresh mortar with different combinations of styrene-butadiene-rubber latex (SBR) were investigated. The basic purpose of addition of styrene-butadiene-rubber latex (SBR) in the mortar mix is to enhance and improve the physical and mechanical properties of mortar. There is a increase in flexural and compressive strength due to the bond between cement mortar and SBR which is due to SF and FA. Moreover, there was a reduction in percentage of water absorption, alkali reaction (ASR) , rate of water absorption due to addition of SF, FA and RGP than that of control mix. This study shows 25% of styrene-butadiene-rubber latex (SBR) can be successfully utilized as an admixture.

Shete and Upase (2015) In this study, the effect of addition of styrene-butadiene-rubber latex (SBR) known as RIPSTAR-148” is investigated on the compressive strength, normal strength and water absorption of concrete. In measuring resistance against carbonation migration the most important parameter is water absorption, In cement based composites, the information about the porosity of concrete is indirectly provided by the value of water absorption. 7 and 28 days compressive strength was studied and investigated.

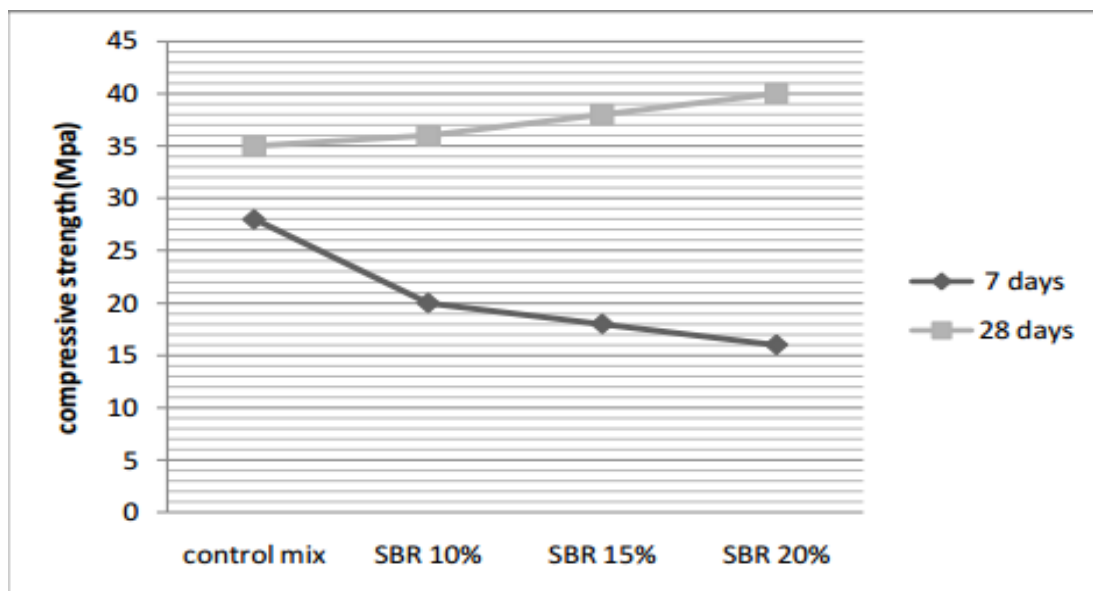


Fig.2.2 Compressive Strength of RIPSTAR 148-latex

Kapil and Joshi (2014) In this study, polymer are mixed with concrete to improve the performance of concrete. It has been investigated that due to high durability and high strength polymer modified concrete is more durable than conventional concrete. In this study optimum styrene-butadiene-rubber latex (SBR) polymer- cement ratio for concrete is determined , the effect of styrene-butadiene-rubber latex (SBR) on flexural and compressive strength of concrete has been studied. For this study concrete mix design of same water- cement ratio at room conditions were prepared to investigate the effect of styrene-butadiene-rubber latex (SBR) polymer addition on flexural and compressive strength. Different styrene-butadiene-rubber latex (SBR) polymer – cement ratio were investigated such as 0%,5%,10%,15%,20%. It was observed that the maximum increase of 21% in compressive strength was due to the addition of 15% of styrene-butadiene-rubber latex (SBR) polymer.

Tarkhan (2015) The variables considered in this study are the slenderness ratio of column, the pre-loading level of the original column, and the orientation of ferrocement mesh. Initial cracking load, ultimate capacity, and mode of failure were recorded and discussed for different models. It was investigated that the ferrocement jacket increases the load capacity and ductility of the columns depending on the parameters. To achieve the main purpose of this study, fourteen reinforced concrete (RC) columns were casted, strengthened and tested under concentric loading. The experimental program includes twelve strengthened RC columns in addition to two RC columns without strengthening as controls. The original RC columns have rectangular cross-section of 60×130 mm and RC slab of 230×160×60 mm thickness at the ends to overcome the excessive tensile stresses in the lateral direction. Seven columns have 600 mm clear height between the RC slabs to represent the short columns, while the others have 950 mm to represent long columns. The full details of the tested columns are given. All original columns were provided with 6 Φ 6 mm as vertical steel reinforcement and Φ 2.5 mm / 50 mm as stirrups. In all tested columns, the characteristic concrete compressive strength (f_{cu}) was 26 MPa, while the yield stresses for vertical reinforcement and stirrups were 256 and 265 MPa, respectively.

The parameters of the study are:

- Slenderness ratio of the column (short or long),
- Orientation of the ferrocement meshes (17 or 73 Degree),

- Pre-loading level of the original column before strengthening.

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

The ultimate load of short column is more by 17 %, 7.6%, and 43 % than that of the long column, respectively. High pre-loading levels resulted in lower gain in the load carrying capacity and energy absorption, yet increase in gain in the ductility ratio. Columns pre-loaded to 50% of the ultimate load of control column showed higher gain in the ultimate load and energy absorption than those pre-loaded to 75% however the increase in the ductility ratio was the least.

Manikandeswaran (2015) The main purpose of this study was to evaluate the effectiveness of two methods used for strengthening of columns. This was done by examining and comparing the behavior of columns strengthened by steel angles and strips with that of ferrocement jacketing. The parameters involved in this study are load-carrying capacity, deflection and ductility of columns. The proposed jacketing technique could be considered as a competitive alternative to enhance the performance of concrete columns especially in developing countries.

A total of 9 RC column specimens were cast in this study, 3 reference columns, 3 columns strengthened by ferrocement jacketing and 3 columns strengthened by steel angles and strips. The tests were conducted using compression testing machine with a capacity of 5000KN. A dial gauge was fixed to the loading setup to measure the deflection of the columns. The loading was done vertically and the reading was noted from the dial gauge at every load increment of 50KN. The loading was done until the ultimate failure of column occurs. Therefore the ultimate load and corresponding deflection were noted for each specimen. A series of tests were carried out to

study different properties of the concrete mix also. They include split tensile strength, flexural strength, compressive strength, water absorption test, and durability tests. Durability tests include marine attack and acid attack. For all the tests, concrete specimens were cast in respective steel moulds and compacted in a table vibrator to ensure complete compaction. After 24 hours the specimen were de-molded and allowed for curing till the date of testing. After 28-days curing the concrete specimens were taken out of the curing tank and the surface water was wiped off. Three specimens were tested as a representation of a batch.

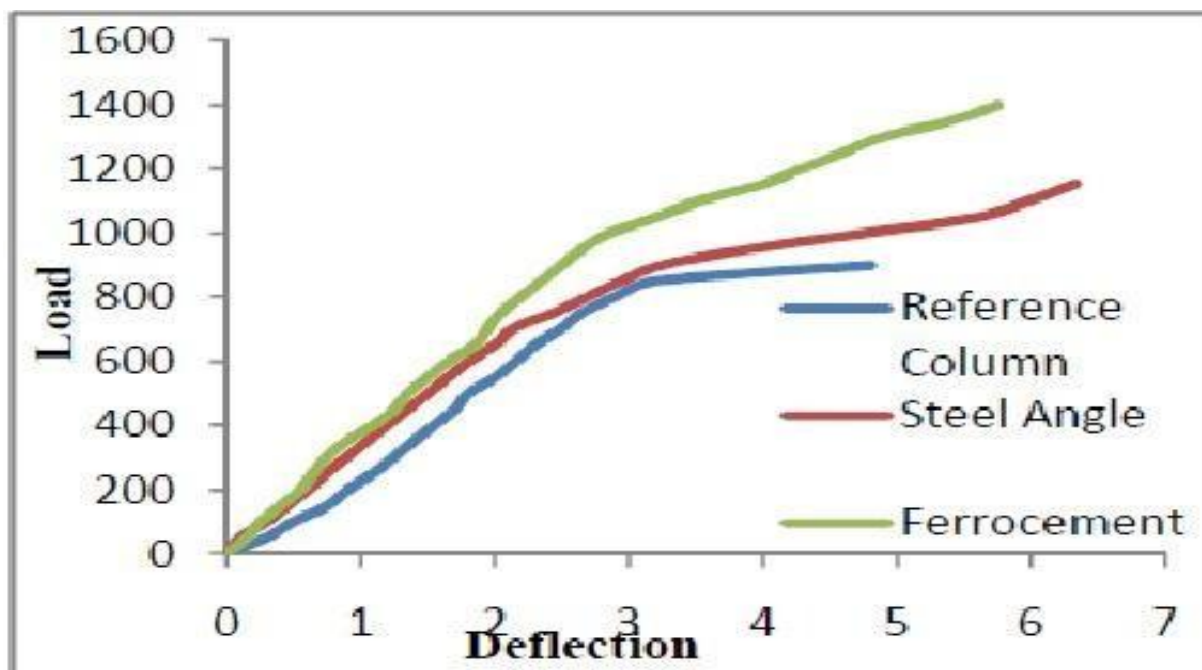


Fig.2.3 Load deflection curve (Manikandeswaran; 2015)

In the case of reference columns the ultimate load obtained was 890KN. The deflection corresponding to the ultimate load was 3.70mm, but in the case of columns strengthened by steel angles and strips the ultimate load was 1246KN and the corresponding deflection was 6.33mm. For columns strengthened by ferrocement jacketing the ultimate load was obtained as 1470KN and the deflection corresponding to that load was 5.60 mm.

- The ultimate load carrying capacity of columns strengthened by steel angles and strips were found to be increased by 40%.
- The ultimate load carrying capacity of column strengthened by ferrocement jacketing was found to be increased by 65%

Makki (2014) In this study, shear and flexure behavior of reinforced concrete beams which are retrofitted with ferrocement is investigated. Different parameter such as , different diameter of wire mesh opening , shear reinforcement were studied, In order to study those properties ten reinforced concrete beams ere casted there were two types of rehabilitation program used:

- Strengthening of beams
- Repairing of beams

To achieve the full bonding and tensile strength of Ferrocement , mechanical methods were used to confine the wire mesh of ferrocement , the basic aim was to avoid the de-bonding of ferrocement from the specimen. The beams were pre-stressed to a different level to that of the ultimate load carrying capacity. It was investigated that the load carrying capacity was increased from 51%- 125% in repairing program and 70% - 175% in case of strengthening program. Thus , it was determined that both the technique of ferrocement were useful in increasing the capacity.

Bishnu and Lakshmipathy (2014) In this study, two methods of retrofitting of short Reinforced Concrete square columns were attempted. Wire mesh mortar jacketing (WMM) and Steel Cage Mortar jacketing (SCM) were used to wrap the Reinforced Concrete column. For analysis of test results, a plain Reinforced column (CS) was also tested. A total of 9 column specimens were tested after 28 days and results were analyzed. From the result analysis, it was found that the compressive strength when compared to control specimen CS, WMM was 1.75 times greater, SCM was 2.28 times greater. The stiffness of WMM was the highest, initially it was 1.2 times higher that CS. The energy absorption was 5.01 times higher for WMM than CS. Therefore, it was concluded that SCM can be preferred. From the stiffness and energy absorption consideration, WMM should be preferred.

Mourad and Shannag (2012) studied the behavior of pre-stressed column samples confined with Ferrocement using welded wire mesh as the confining material. In this study consists of testing one-third scale square (150*150 mm) column specimens with a height of 1000 mm in three phases as follows:

- *Phase 1:* Control column specimens without Ferrocement confinement and without any pre-loading.

- *Phase 2*: Jacketed column specimens with ferrocement confinement but without any preloading.
- *Phase 3*: The columns were pre-loaded to 60% and 80% to that of ultimate load capacity and then strengthened by Ferrocement confinement.

The samples which were pre-loaded to 60% and 80% to that of ultimate load carrying capacity showed enhanced load capacity by 28% and 15%. There was a brittle failure in control specimen as compared to confined column which failed in ductile manner. There is a 33% increase in load carrying capacity of pre-stressed specimens, due to confining of the specimen ductility also increased.

Kaish et. al. (2012) In this study the effect of jacketed ferrocement on behavior of square column with modified alternatives is investigated. For this study three types of techniques were used to confine the column with ferrocement jacketing were used:

- Square ferrocement jacketing with one layer wire mesh (RSL).
- Square jacketing with one layer wire mesh, each face of column having shear keys at center (SKSL).
- Square ferrocement jacketing with one layer wire mesh and at corners 2 layer wire mesh (SLTL).

The size of the column being tested were 100×100mm cross section and 600mm length with 5mm diameter vertical bars 100mm c/c and 4 nos 8mm diameter longitudinal bars. The testing was performed in two phases:

- The columns tested in phase 1 were tested in concentric loading.
- The columns tested in phase 2 were tested in eccentric loading

In first phase, crushing strength of cylinder was 22.9 MPa and in second phase, crushing strength of cylinder 24.2 MPa. It is studied that normal square ferrocement jacketing of square reinforced column having drawbacks which are minimized by square ferrocement confinement technique. Columns subjected to both concentric loading in phase and eccentric loading in phase 2 are strengthened by square ferrocement jacketing. By, providing two layers at corners the deflection of column is also reduced.

Xiong et. al. (2011) In this study, confinement of circular concrete column including steel bars (FS) by ferrocement is achieved and ductility, load carrying capacity is examined. Two sets of concrete columns were casted confined with FRP.

- 105mm (Dia) × 450mm (Height).
- 150mm (Dia) × 450mm (Height).

They were cured for 27 days after 24 hours of wet curing. It was observed that compressive strength of FS columns was increased by 30% more than that of BS column, It also showed high compressive strength , energy absorption capacity and higher ductility as compared to normal concrete.

Turgay et. al. (2010) In this study the effect and failure mechanism of pre-loaded FRP wrapped large square column is observed. Moreover, the study was mainly focused on the behavior of concentrically loaded column by FRP jacketing, transverse and longitudinal reinforcement.

A total of twenty large square columns were casted and tested till they were crushed under uni-axial loading. There were five sets of column:

- Unwrapped columns (C1)
- Partially wrapped (C2)
- Fully wrapped (C3)
- Partially wrapped with two layers of FRP (C4)
- Fully wrapped with two layers of FRP (C5)

The dimensions of the column were 1000mm in height and cross section of 200mm×200mm, They were tested under uni-axial compressive machine of capacity 5000kN. 28 and 60 days cylindrical compressive strength of concrete mix was observed as 18.08MPa and 19.36MPa. Fully wrapped specimen failed at the top and bottom area. The wrapping with 1 layer of FRP results in increased ductility. Partially wrapped columns had a failure at ends. For all reinforced columns fully wrapped with 1 layer of FRP there was an increase in ductility.

Kondraivendhan and Pradhan (2009) In this study, behavior of different grades of concrete confined with ferrocement is observed, while all the other parameters were constant. The grades observed were M25, M30, M35, M40, M45, M50, M55, M60.

For this study 42 cylindrical specimens were casted, in which 21 were controlled samples and other 21 were confined with ferrocement. The dimensions of the specimen were 900mm in height and 150 mm in diameter. It was observed that in lower grades of concrete the confinement by ferrocement improved the compressive strength such as in M25 grade there was an increase of 78% as compared to that of M60 which showed an increase by 46% in compressive strength.

Alrifaie (2000) Investigated uniformly loaded ferrocement slabs (500x500 mm) in which three different arrangements.

- Uni-directional orientation of all layers.
- Orthogonal orientation of all layers.
- Two wire mesh orthogonally oriented in contact with each other, twin layered.

A total of 12 square slabs (20 mm and 30 mm thick) were tested under uniform load. Based on the above studies they concluded that the arrangement consisting of twin layers with two meshes orthogonally placed two meshes twin layer are superior to the other two arrangements having of all the meshes uni-directionally oriented or alternate layers which have been equally spaced with orthogonally oriented meshes. The first cracking load is increased from 16% to 24% for 20 mm slabs. The above increase is increased 13.1% and 11.75% in the ultimate load value for the 20 mm respectively. Hence, it was observed that twin layer mesh arrangement should be used for biaxial bending. They recommended that for the slabs under bi-axial state of bending the meshes should be arranged in twin layers.

2.4 RELEVANCE OF THE PRESENT STUDY

Column is one of the most important structural members, which is primarily designed to support the compressive loads. The performance of column is increased against lateral loads as well as axial loads due to continuous spiral and lateral individual tie large deformation and hence significant ductility and energy absorption prior to failure. Sometimes additional confinement

may be necessary in case of re-strengthening or rehabilitating of existing substandard columns. Confinement is done to prevent the stress accumulation and cracking at the corners of column of the specimen. The zones which are exposed to severe mechanical and environmental loading require rehabilitation. Rehabilitation is provided to the structures which are deteriorated and to those elements whose load carrying capacity is decreased due to cracks. Rehabilitation of deteriorated concrete structures leads to significant user costs and is also a heavy burden from the socio- economic viewpoint. As a consequence, Rehabilitation of structures must be developed. The rehabilitation and strengthening of pre-existing reinforced concrete columns using wire mesh jacketing is done based on a well-established fact that due to application of jacketing lateral confinement of concrete is decreased and its axial compressive strength can sustainably increase. In recent years, various methods of external confinement of concrete are being used such as jacketing using Steel Angle, FRP, Bracing Infill walls, Ferrocement has emerged as a popular method of column retrofit

Analytical and experimental studies on the confinement effect and failure mechanisms of Ferrocement jacketed columns have been conducted over several years. However, most of the studies are concentrated on the behavior of short square/ rectangular Concrete columns. The available data on behavior of Polymer Ferrocement confined circular column with varying slenderness ratio and Ferrocement confined columns is still limited, further no studies have been conducted to report the effect of pre-load on the behavior of Ferrocement Confinement of columns.

This study reports the results of an experimental research program on the performance of short long columns (normal, pre-loaded) circular in cross section confined with Polymer Ferrocement. This report is focused on the investigation of the effects of Polymer Ferrocement confinement on columns under concentric load. The performance of the normal and pre-loaded Ferrocement jacketed columns is compared for columns of different slenderness ratio. Further, the behavior of confined columns was also studied and compared with their respective control specimen (unconfined specimens). For this study the following objectives are framed:

- To study the improvement in load carrying capacity with slenderness effect in columns.

- To study the effectiveness of the Polymer Ferrocement confinement with different layer of wire mesh.
- To study the effect of pre-load retrofitting on columns.

CHAPTER 3

EXPERIMENTAL PROGRAMME

The main objective of this is to study the effect of SBR polymer modified ferrocement on two types of specimen. In one set there is no initial loading to the column and in second set 80% of loading is applied to the specimen according to ultimate load carrying capacity of control specimen. In this study, three dimensions of columns with varying slenderness ratios were casted.

They were confined with one layer and two layer of Polymer modified Ferrocement. In total 42 specimens were casted for the experimental work as shown below.

- Slenderness ratio ($\lambda=3$) 100mm (Dia)×300mm (Height).
- Slenderness ratio ($\lambda=6$) 100mm (Dia)×600mm (Height).
- Slenderness ratio ($\lambda=12$) 100mm (Dia)×1200mm (Height).

The load carrying capacity and ultimate deflection are observed and analyzed in the subsequent chapters.

3.1 MATERIALS

This section deals with the physical and mechanical properties used in this study. 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

Ordinary-Portland binani Cement (Grade 43) was tested and used for the concrete mix and mortar. All the properties were determined. The physical properties obtained from various tests are listed in Table 3.1. All tests are carried out in accordance with procedure laid out in IS 1489 (Part 1): 1991.

Table 3.1 Physical Properties of Cement

S.No.	Property	Value Obtained Experimentally	Value as per IS: 1489-1991
1	Standard Consistency	30%	-
2	Fineness of cement as retained on 90 micron sieve 'in %'	1.5	Min 0.1
3	Setting Time (in minutes) Initial Setting time Final setting time	80 115	Min 30 Max 600
4	Specific gravity	2.67	Max 3.0
5	Compressive strength (N/mm ²) 7 days 8 days	23.2 34.5	Min 22 Min 33

3.1.2 Fine aggregate

Local sand was being used in the preparation of cement mix and mortar mix. The results and physical properties of sieve analysis of sand (as per IS: 383) are shown in Table 3.2 and Table 3.3 respectively.

Table 3.2 Physical Properties of Fine Aggregate

S.No.	Property	Value Obtained Experimentally
1	Specific gravity	2.70
2	Bulk density loose (kg/m ³)	1500
3	Fineness modulus	2.68
4	Water absorption	1.5 %
5	Grading zone (based on percentage passing 0.6 mm)	Zone II (As per IS:383-1970)

Table 3.3 Sieve Analysis of Fine Aggregate

Total weight taken = 1000 gm

S. No.	Sieve size	Mass retaining (gm)	Percentage retaining	Cumulative percentage retaining	Percentage pass
1	4.75 mm	20	2	2	98
2	2.36 mm	27.5	2.75	4.75	94.25
3	1.18 mm	19	1.9	6.65	88.35
4	600 µm	34.5	3.45	10.1	78.25
5	300 µm	667.5	66.7	76.8	3.56
6	150 µm	212	21.25	98.05	1.95
				Σ=261	

Fineness modulus of fine aggregate = $261 / 100 = 2.61$

3.1.3 Coarse aggregate

Crushed stone aggregate were used for concrete. The sieve analysis results of coarse aggregate of different size are shown in Table 3.4. Table 3.5 shows the properties of coarse aggregates.

Table 3.4 Sieve Analysis of Coarse Aggregate

Total weight taken = 3000gm

S.no.	Sieve size	Mass retaining (gm)	Percentage retaining	Cumulative percentage retaining
1	40 mm	0	0	0
2	20 mm	0	0	0
3	10 mm	549	18.3	18.3
4	4.75 mm	2077	69.2	87.5
5	Pan	374	12.4	
				Σ=105.71

Fineness modulus of coarse aggregate = $(105.71+500) / 100 = 6.05$

Table 3.5 Physical Properties of Coarse Aggregate

Total weight taken = 3000 gm

S.No.	Characteristics	20 mm
1	Type	Crushed
2	Specific gravity	2.61
3	Total water absorption (% age)	2.95
4	Fineness modulus	6.05

3.1.4 Water

The water used in the mix should be free from impurities which might lead to decrease in strength by corrosion. It should also be free from any other oil and chloride particles.

3.1.5 Wire mesh

Square steel wire mesh of 0.45 mm diameter wires woven in square pattern of 6mm*6mm was used for confinement in Ferrocement. The grid size of mesh was 1.5 cm. Steel mesh is shown in Fig. 3.1

Table 3.6 Properties of Square Wire Mesh

Wire Gauge(BWG)	22
Specification in Metric Unit	1.5 cm
Opening size	6mm × 6mm
Ultimate Tensile Strength of wire N/mm ²	88



Fig. 3.1 Square Wire Mesh

3.1.6 Concrete Mix

M20 grade Concrete mix is produced as per Indian Standard (IS:10262-2009) using the properties of materials as described in Table 3.1 to Table 3.5. The proportions of concrete design mix came out to be 1:1.65:2.95 (cement: sand: coarse aggregate) by weight. The water cement ratio was kept as 0.45. The cement concrete cubes 150mm x 150mm x 150mm were casted and tested as per (IS:516-1959). The compressive strength after 7 days was recorded 23.05N/mm^2 and 28 days strength was 34.5N/mm^2

3.1.7 Mortar Mix

In Ferrocement application cement sand mortar of ratio 1:3 was used. The water-cement ratio of 0.45 was used and 15% SBR was homogeneously mixed w.r.t cement. The mortar is to be applied uniformly over the surface of the column.

3.1.8 Polymer mix

The polymer – cement ratio is taken as 15% SBR to that of cement as being discussed in the previous chapter. According to which 15% is the optimum vale of mixture.

3.1.9 Pre Loading of Column

The pre-loading of column is based on the peak load of sample column, 80% of the peak load is applied on the remaining half samples whereas the other half is not loaded.

3.2 CASTING OF REINFORCED CONCRETE COLUMN SPECIMENS

Cement Concrete is a mixture of well proportioned cement, coarse aggregates, fine aggregate and water. In our study all the columns were made of M20 concrete mix designed in accordance with IS:10262:2009. All the columns were reinforced longitudinally with steel bars. Each column was reinforced with 4 bars of 8MM diameter. The transverse reinforcement was 6mm dia stirrup @ 150mmC/C, All the reinforcement used was Fe 500 grade. In all, a total of 42 specimens were cast in 3 size groups as shown in Table 3.7 and Fig. 3.2.

Table 3.7 Detail of Column Specimens

S.No	Description of Columns	Slenderness ratio (λ)	TAG
1	Two columns of size 100 x 300mm	3	Control short(CS)
2	Three columns of size 100 x 300mm with one layer of wire mesh	3	RFCS1
3	Three columns of size 100 x 300mm pre-loaded with one layer of wire mesh	3	RFPCS1
4	Three columns of size 100x 300mm with two layers of wire mesh	3	RFCS2
5	Three columns of size 100x 300mm pre-loaded with two layers of wire mesh	3	RFPCS2
6	Two columns of size 100 x 600mm	6	Control medium(CM)
7	Three columns of size 100 x 600mm with one layer of wire mesh	6	RFCM1
8	Three columns of size 100 x 600mm pre-loaded with one layer of wire mesh	6	RFPCM1

9	Three columns of size 100 x 600mm with two layers of wire mesh	6	RFCM2
10	Three columns of size 100 x 600mm pre-loaded with two layers of wire mesh	6	RFPCM2
11	Two columns of size 100x 1200mm	12	Control Long(CL)
12	Three columns of size 100 x 1200mm with one layer of wire mesh	12	RFCL1
13	Three columns of size 100 x 1200mm pre-loaded with one layer of wire mesh	12	RFPCCL1
14	Three columns of size 100 x 1200mm with two layers of wire mesh	12	RFCL2
15	Three columns of size 100 x 1200mm pre-loaded with two layers of wire mesh	12	RFPCCL2

The column samples in three size groups; fourteen columns of (100 x 300mm, $\lambda= 3$), fourteen columns of (100 x 600mm, $\lambda= 6$) and fourteen columns of (100 x 1200mm, $\lambda=12$) were casted. For each group, two columns were kept as control samples. After surface cleaning, each sample was hand chiseled to obtain a rough surface, six columns were confined with one layer of steel wire mesh and of these, three specimens were retrofitted with steel mesh , while the other three specimens were loaded to 80% of the peak loading and then were confined with one layer of wire mesh. In second set Six columns were confined with 2 layer wire mesh onto columns without loading and with pre-loaded, three specimens were retrofitted without loading and three with 80% loading. The detailed procedure for application of Ferrocement is given in section 3.3.

3.3 CONFINEMENT WITH POLYMER FERROCEMENT

For the confinement of the concrete column with Polymer Ferrocement, the surface of the samples was hand-chiseled 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 Square wire mesh. Thereafter, a layer of cement mortar or polymer mortar with 15% of SBR, 15-25mm thick was applied on the circular column .In the second phase of experiment, column

samples were wrapped with two layers of Square wire mesh with continuous wrapping with overlapping of second layer over the first layer. This was followed by plastering with cement mortar of 15-25mm thickness to achieve a diameter of 150mm.

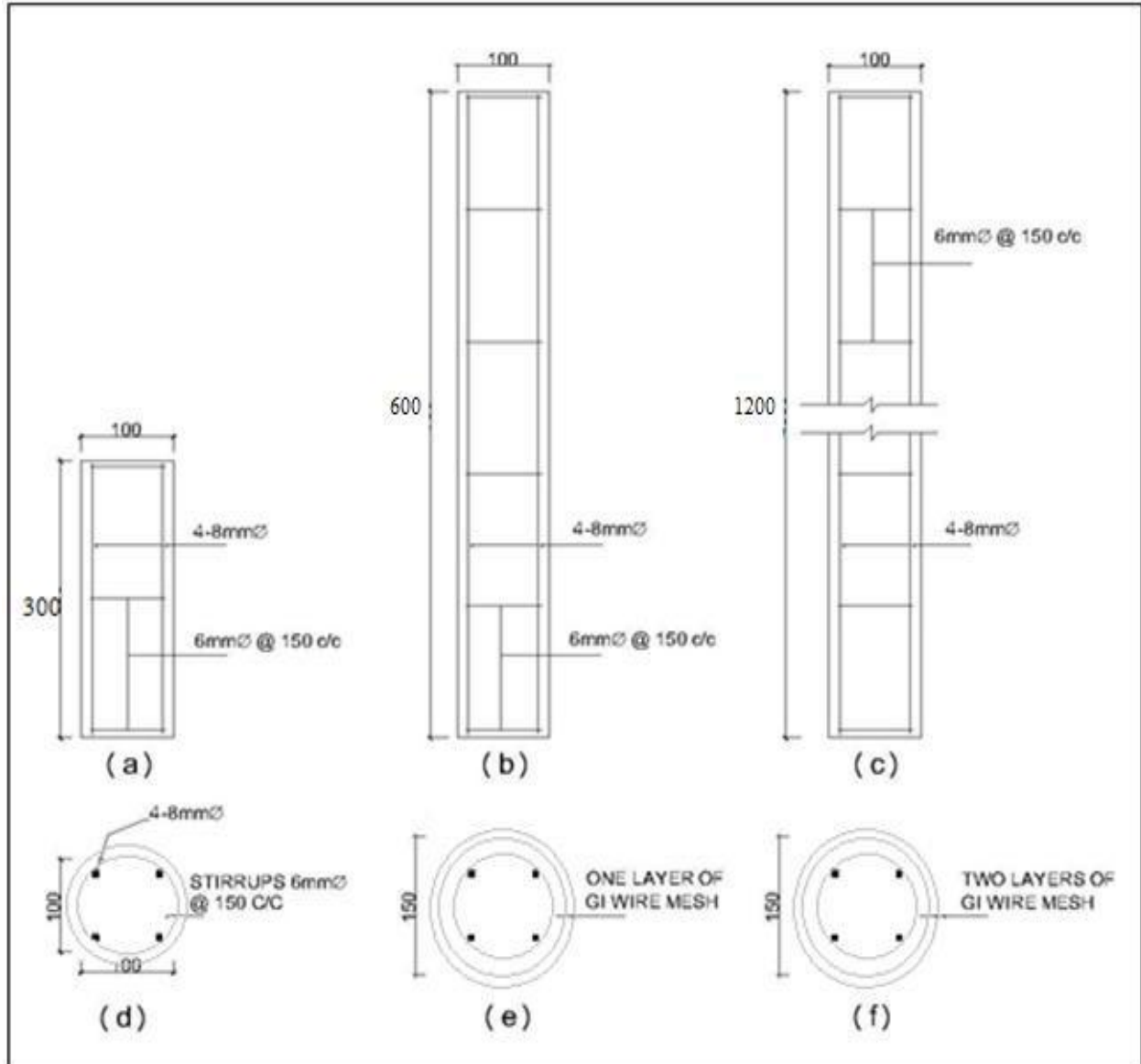


Fig 3.2 Detail of Control and Confined Columns

All specimens were cured for 28 days starting from 24 hours after final application of the mortar. 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. After curing the columns were allowed to air dried and then cleaned carefully to remove any surface residue and undesirable material.

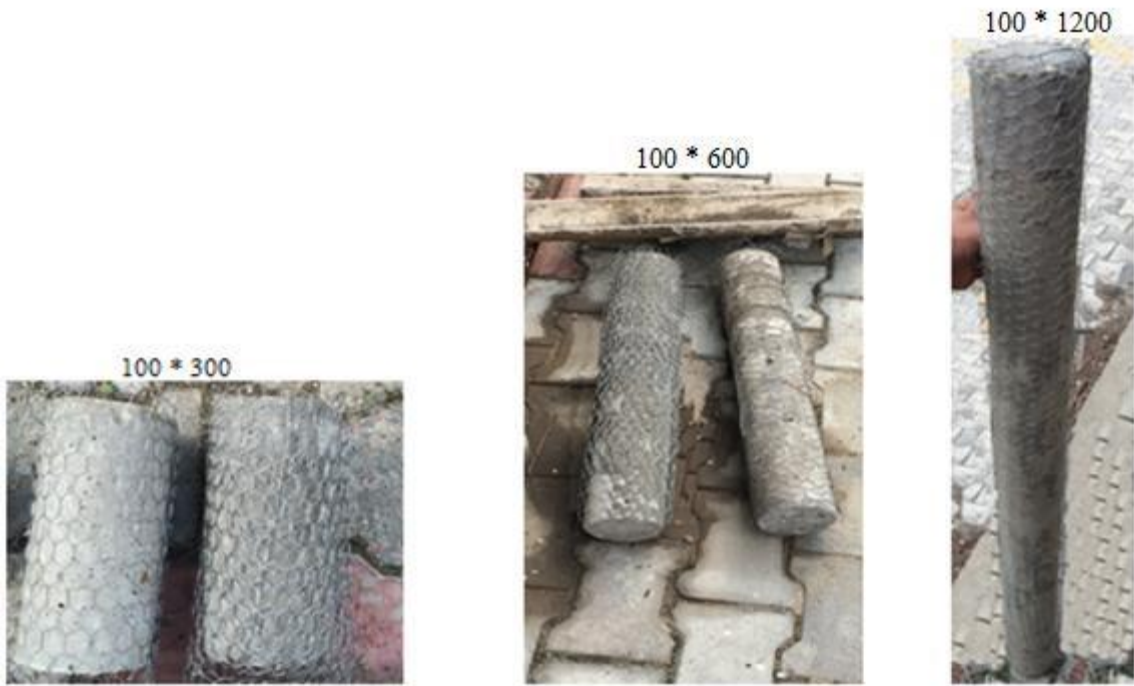


Fig. 3.3 Columns Confined with One or Two Layers of Wire Mesh



Fig. 3.4 Columns Confined with Mortar Layer

3.4 TESTING PROCEDURE AND INSTRUMENTATION

The specimen were kept away from water after 28 days of curing to achieve dry surface conditions. 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. The medium and short column having slenderness ratio ($\lambda = 3, 6, 12$) Concentric compressive load was applied on all the specimens. Lateral deflections were measured at mid height using two LVDTs (Linear Variable Differential Transducer) on circumference of the column specimens. LVDTs had an accuracy of 0.01mm. Test setup and mode of loading are shown in Fig 3.5.

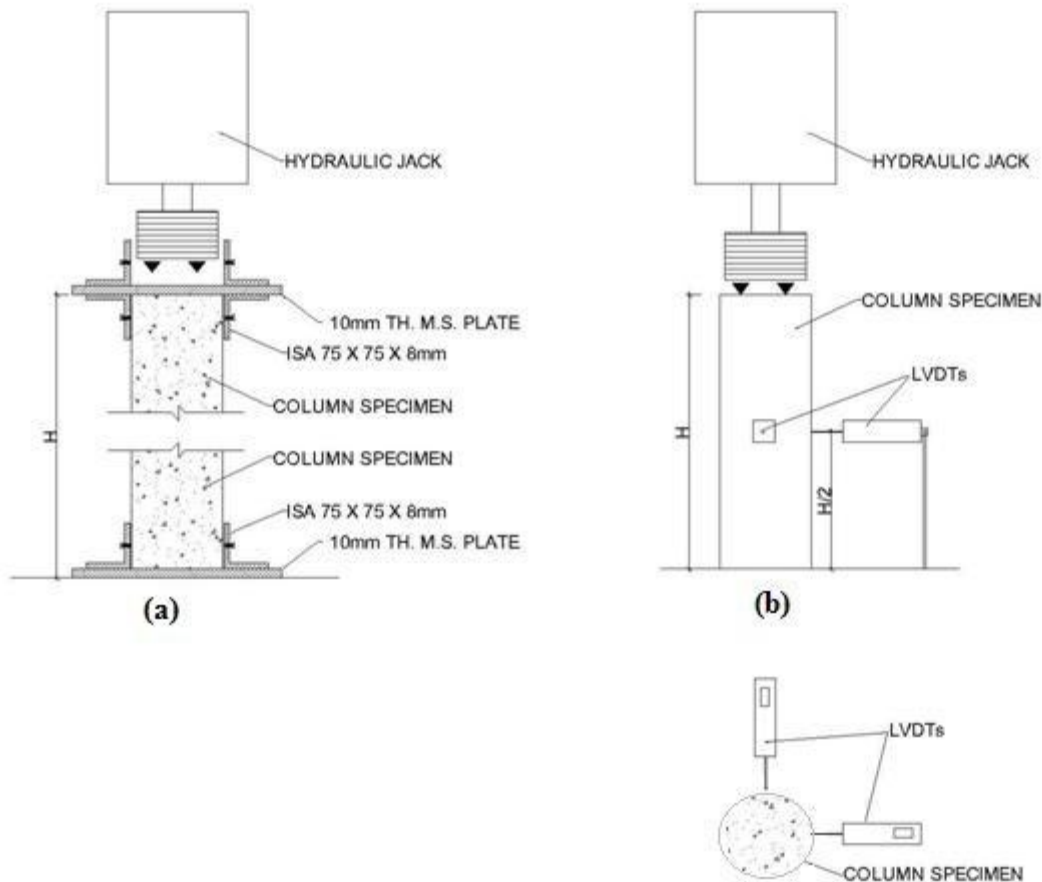


Fig. 3.5 Detail of Test Setup (a) Test setup for type LC (b) Mode of Loading and Position of LVDTs and Plan of Position of LVDTs



(a)



(b)



(c)



(d)

Fig. 3.6 Detail of Test Equipment (a) Control Equipment for Loading Jack; (b) Loading Jack of 600 KN Capacity; (c) Typical Test for long Columns($\lambda=13$); (d) Test Setup for medium($\lambda=7$); and short type Columns($\lambda=3$).

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 presented in this chapter. The average load-displacement graphs of six unconfined control concrete specimens (type CS, CM and CL with $\lambda=3, 6$ and 12 respectively), Eighteen specimens No-loaded / Pre-loaded(80%) confined with Polymer Ferrocement (one layer of Polymer mortar wire mesh in type RFCS1, RFCM1 RFCL1, Pre- loaded one layer of polymer mortar wire mesh in type RFPCS1, RFPCM1 RFPCL1 with $\lambda=3, 6$ and 12 respectively) and Eighteen specimens No-loaded / Pre-loaded(80%) confined with Polymer Ferrocement (two layers of wire mesh in type RFCS2, RFCM2 ,RFCL2 and Pre-loaded two layers of polymer mortar wire mesh in type RFPCS2, RFPCM2 and RFPCL2 with $\lambda=3, 6$ and 12 respectively) were prepared. All specimens were tested under concentric mode of loading. Load vs. displacement values, crack pattern and ultimate load capacity were recorded and analyzed.

4.2 SHORT COLUMN WITH $\lambda=3$

Columns in which the strength is governed entirely by the strength of materials and the geometry of the cross-section are called pedestals. The columns having λ less than 3 are called short column. 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 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, $\lambda=3$)

In the initial stages of loading, some low level cracking was initiated which may be due to micro cracking of concrete. When the load reached at 102 KN some cracking and spalling of the surface of the concrete at bottom and near the middle width was observed. At a load of 145 KN, cracks were observed starting from the top of the column. As the load reached the ultimate value of 180 KN, the column failed in a compression, the total column was crushed at peak load. The maximum horizontal displacement was 3.8mm. The graph of load vs. mid height displacement is shown in Fig. 4.1 and Fig. 4.2 describes the detail of column during initial and final phases of loading.

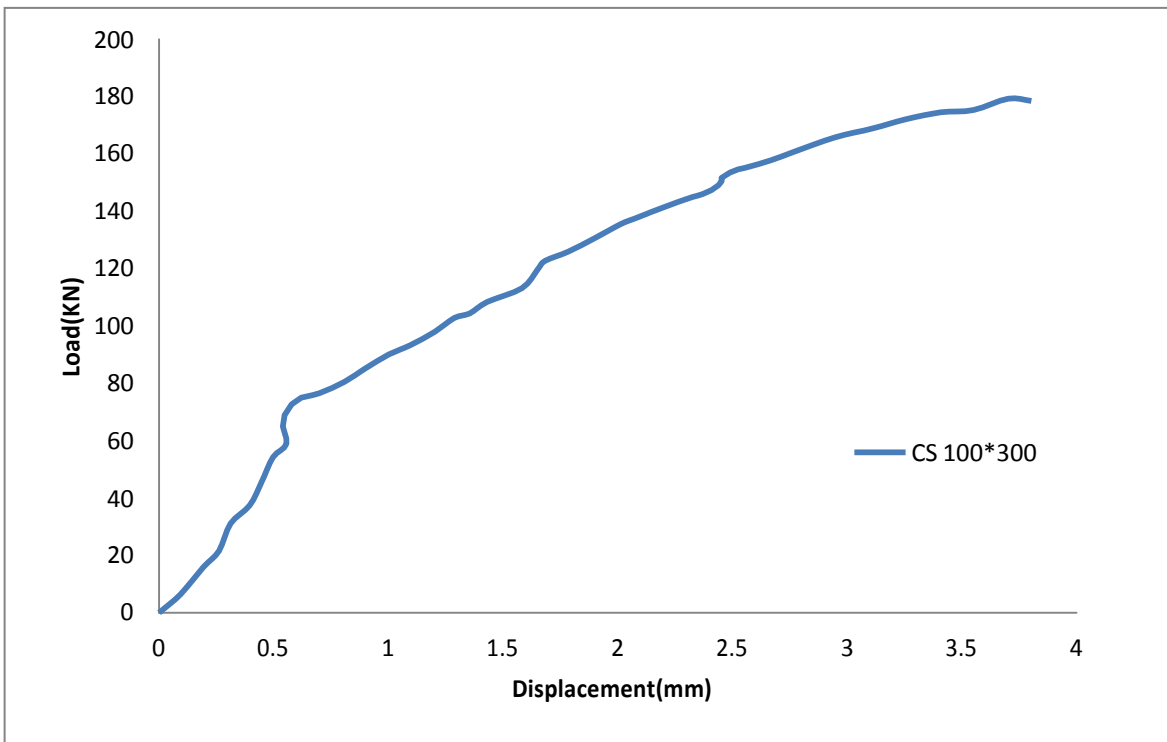


Fig. 4.1 Load vs. Displacement of Control Column (CS, $\lambda=3$)



Fig. 4.2 Detail of column during initial and final phases of loading

4.2.2 Column confined with one layer SBR Ferrocement wire mesh (RFCS1, RFPCS1, $\lambda=3$)

The confinement by wire mesh increased the value of load and resulted in a decrease in the lateral deformation. The failure crack in RFCS1 was observed at a load of 275.4 KN and in RFPCS1 cracks were observed at a load of 246.6 KN. The cracks were vertical with spalling of the mortar layer from the wire mesh layer. The de-lamination of the mortar layer was also observed.

The confinement increased the ultimate load capacity to almost 53.1% in RFCS1 and 37% in RFPCS1 as compared to control column CS. The maximum displacements were 2.35mm and 2.18mm in RFCS1, RFPCS1 respectively. The load vs. mid height displacement graph and column at initial and final stages of loading is shown in Fig. 4.3, and Fig. 4.4 respectively.

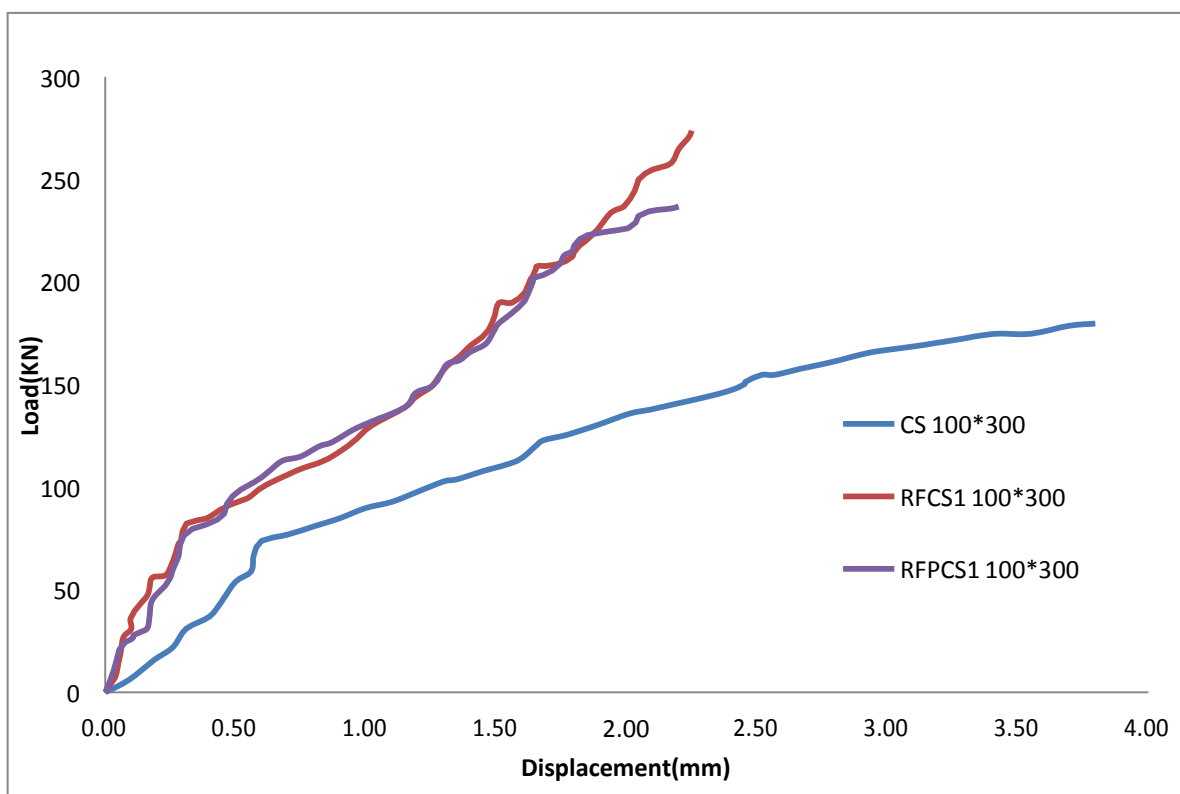


Fig. 4.3 Load vs. Displacement of RFCS1, RFPCS1 ($\lambda=3$)

As the graph shows the variation of load against displacement, it can be observed that the load carrying capacity of the sample with 1 layer wire mesh is more than that of control sample. It can also be determined that the displacement is decreased when the sample is confined with 1 layer wire mesh.



Fig. 4.4 Detail of column during final phases of loading

4.2.3 Column confined with two layer of SBR Ferrocement wire mesh (RFCS2, RFPCS2, $\lambda=3$)

In these set of columns Pre-loading was applied which was 80% to the peak load of control sample. The columns were pre-loaded with a load of 145 KN. In the early stages of loading, the behavior of the specimens was similar to those with one layer of wire mesh wrapping. The failure of the concrete samples occurred at a load of 306 KN(RFCS2) and 286.2 KN(RFPCS2) respectively.. The maximum displacement was 2.3mm and 2.05mm in RFCS2, RFPCS2 respectively 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 displacement graph and Fig. 4.6 shows the loading stages of the specimen.

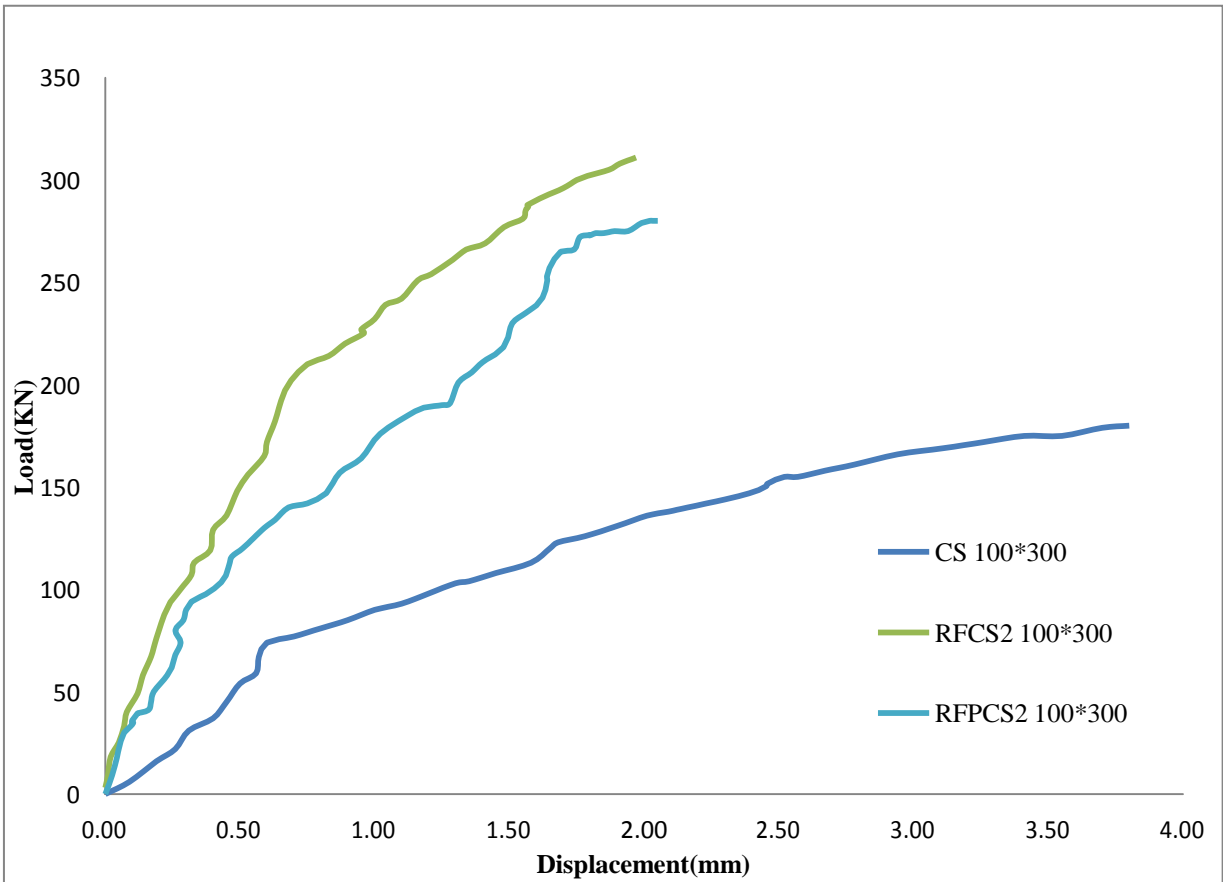


Fig. 4.5 Load vs. Displacement of RFCS2, RFPCS2 ($\lambda=3$)



Fig. 4.6 Detail of column during final phases of loading

4.2.4 Comparison of CS, RFCS1, RFCS2 and RFPCS1, RFPCS2 ($\lambda=3$)

Test results show that after SBR Ferrocement confinement, columns results in a tremendous increase in the ultimate load capacity and first crack load and reduction in the lateral mid-height displacement as compared to the control column. The effect of pre-loading reduces the amount load capacity.

The crack pattern was similar in the confined specimens as all specimens failed by the delamination of the mortar layer from the wire mesh. This indicates that confinement may also reduce initial cracking. Fig. 4.7 shows the comparison of load vs. mid height displacement values of five column specimens; CS, RFCS1, RFCS2 and RFPCS1, RFPCS2.

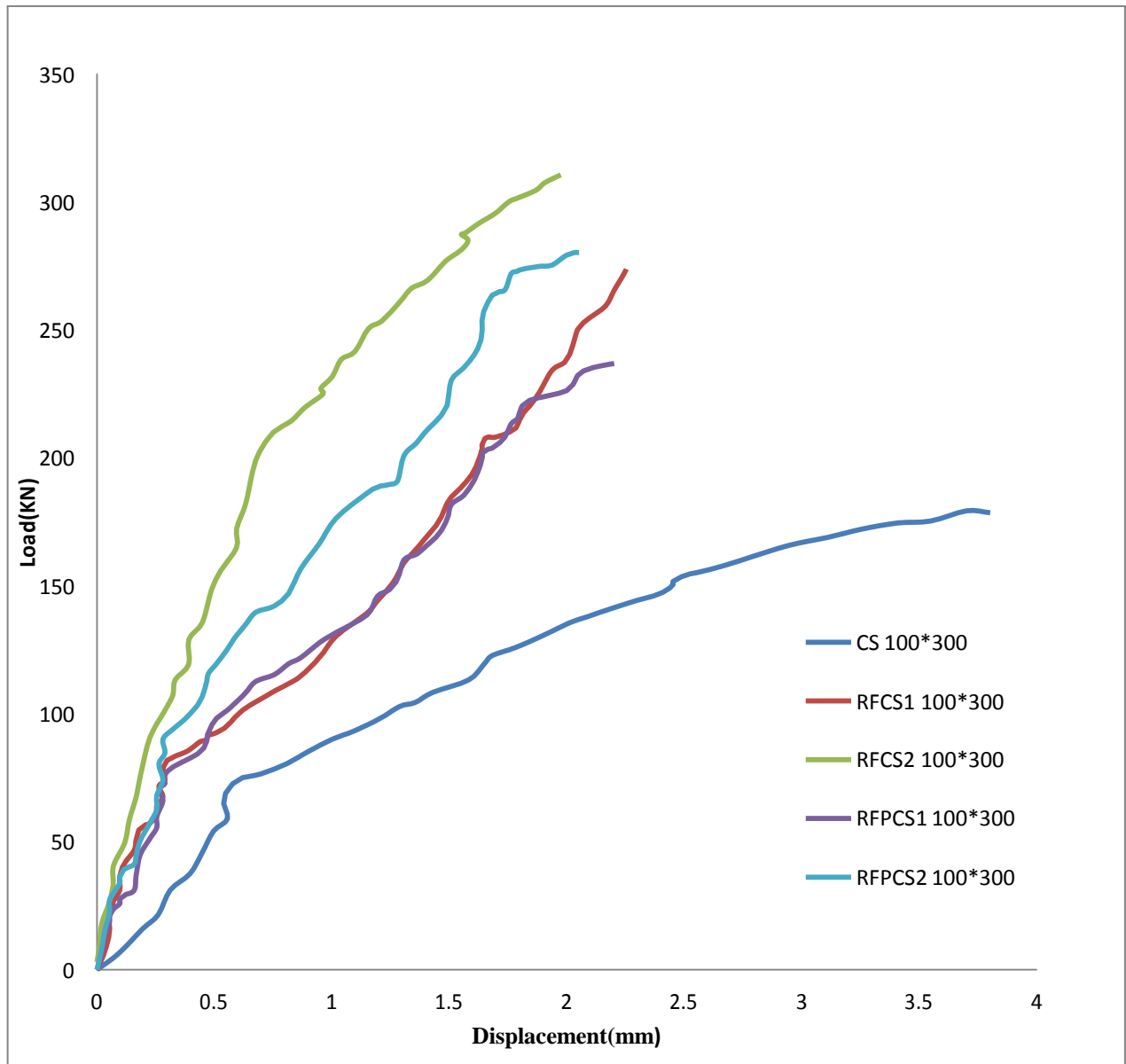


Fig. 4.7 Comparison of Load vs. Displacement of Control and Confined Columns (CS, RFCS1, RFCS2 and RFPCS1, RFPCS2, $\lambda=3$)

4.3 MEDIUM COLUMN WITH $\lambda=6$

4.3.1 Control column (CS, $\lambda=6$)

As the load was applied, the specimen continued to deform. The first crack was observed at a load of 135 KN. The failure occurred at an ultimate load of 154 KN. The compression failure was observed. The spalling of concrete was observed. The maximum displacement was 6.25mm. The load vs. mid height displacement graph is shown in Fig. 4.8 and detail of crack pattern and the column at final loading are shown in Fig. 4.9.

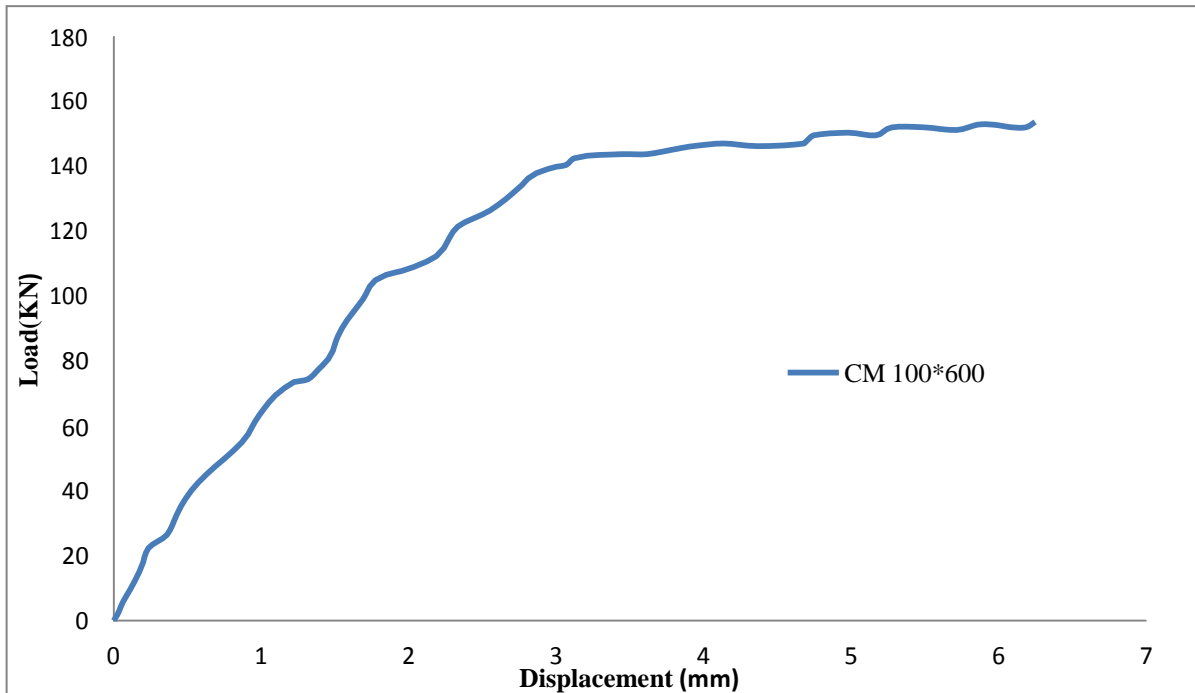


Fig. 4.8 Load vs. Displacement of Control Column (SC, $\lambda=6$)



Fig. 4.9 Detail of column during final phases of loading

4.3.2 Column confined with one layer of SBR Ferrocement wire mesh (RFCM1, RFPCM1, $\lambda=6$)

As the load increased, the column shows sign of cracking. The first crack in RFCM1 was observed at a load of 202 KN and in RFPCM1 cracks were first observed at a load of 190 KN. The mortar layer of Ferrocement was separated from the wire mesh with compression failure of the column near the base. The wire mesh continued to confine the column till the failure of the concrete occurred at a load of 225.3 KN(RFCM1) and 203 KN(RFPCM1) respectively. The maximum displacements were 5.6mm and 5.3mm in RFCM1 and RFPCM1 respectively. The load vs. mid height displacement plot is shown in Fig. 4.10 and the detail of crack pattern, column before and after loading are shown in Fig. 4.11.

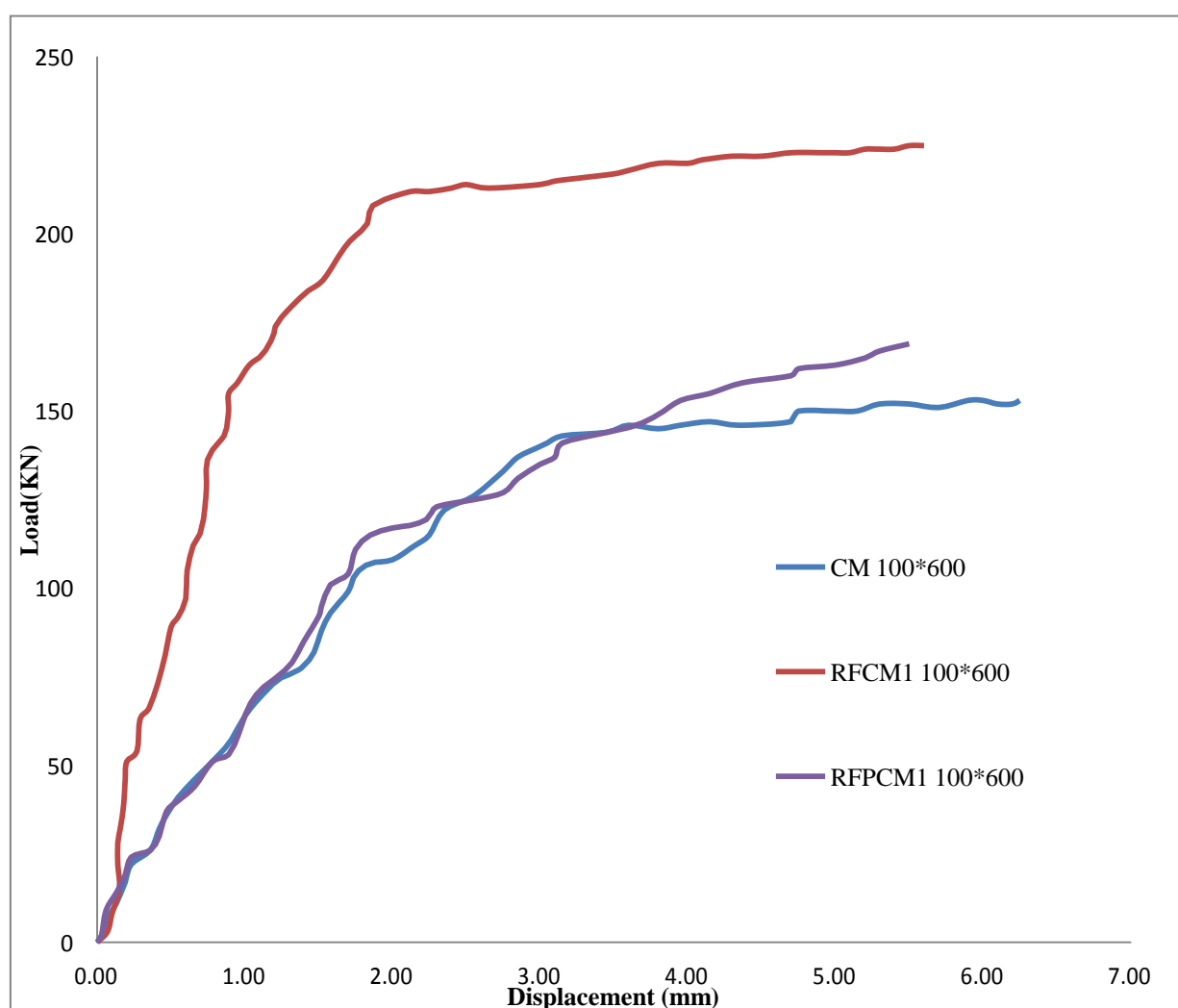


Fig. 4.10 Load vs. Displacement of RFCM1, RFPCM1 ($\lambda=6$)



Fig. 4.11 Detail of column during final phases of loading

4.3.3 Column confined with two layer of SBR Ferrocement wire mesh (RFCM2, RFPCM2 , $\lambda=6$)

In these set of columns Pre-loading was applied which was 80% to the peak load of control sample. The columns were pre-loaded with a load of 123 KN. As the load increased the column shows sign of cracking. The mortar layer of Ferrocement was separated from the wire mesh with compression failure of the column near the base. The wire mesh continued to confine the column till the failure of the concrete occurred at a load of 250 KN(RFCM2) and 239.16 KN(RFPCM2) respectively.

The maximum displacement were 5.1mm and 4.9mm in RFCM2, RFPCM2 respectively The load vs. mid height displacement graph is shown in Fig. 4.12.1 and Fig. 4.12.2. The details of column before and after loading are shown in Fig. 4.13.

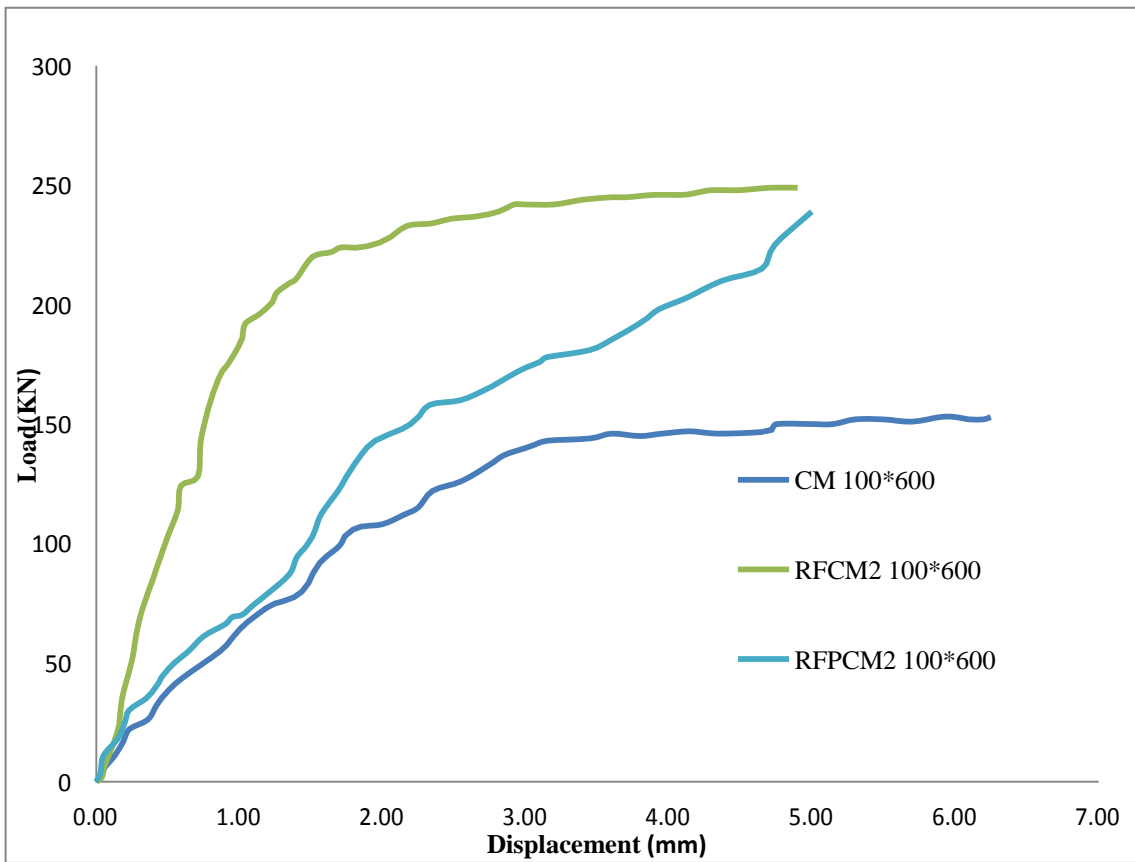


Fig. 4.12 Load vs. Displacement of RFCM2, ($\lambda=6$)



Fig. 4.13 Detail of column during final phases of loading

4.3.4 Comparison of CM, RFCM1, RFCM2 and RFPCM1,RFPCM2 ($\lambda=7$)

It is clear from the graph in Fig. 4.14 that the Ferrocement confined specimens can withstand higher load values and show lower displacement response. The mode of failure of all the specimens is compression. Crushing of mortar is accompanied by de-lamination of mortar from the wire mesh 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. However, the extent of load capacity was affected to a lower percentage in case of two layer wire mesh. The effect of slenderness ratio is also observed. The load carrying capacity decreases as the slenderness ratio " λ " increases.

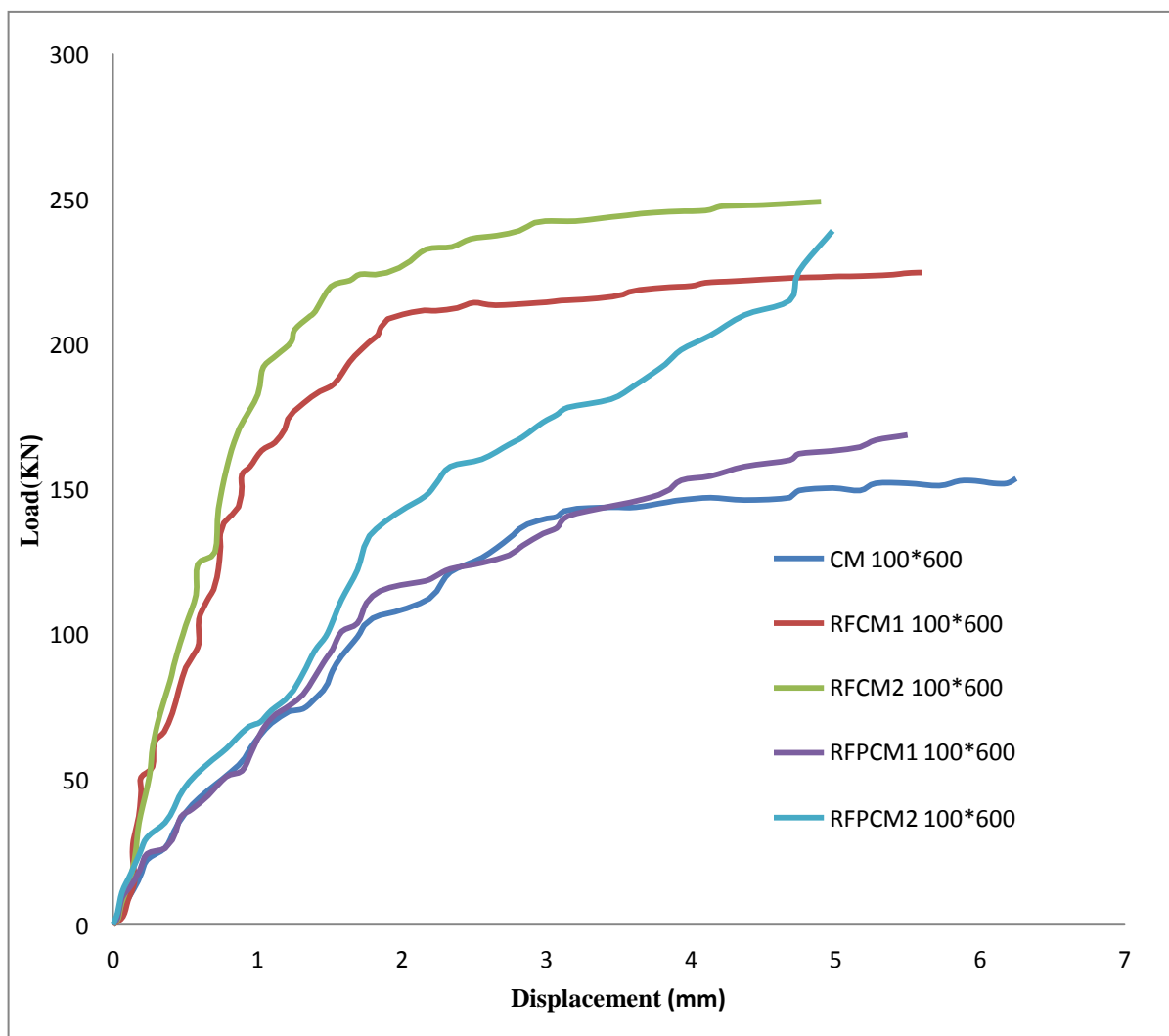


Fig. 4.14 Comparison of Load vs. Displacement of Control and Confined Columns (CM, RFCM1, RFCM2 and RFPCM1, RFPCM2, $\lambda=6$)

4.4 LONG COLUMN WITH $\lambda=12$

4.4.1 Control column (CL, $\lambda=12$)

The column, due to its slenderness ($\lambda=12$) showed more displacement at a lower load. There was a significant increase in mid-height displacement as load increased to higher values around 160KN. The first crack was observed at a load of 110 KN. The column failed at a load of 132 KN. The maximum displacement was 17.8mm. The Fig. 4.15 shows the load vs. displacement response of the CL sample.

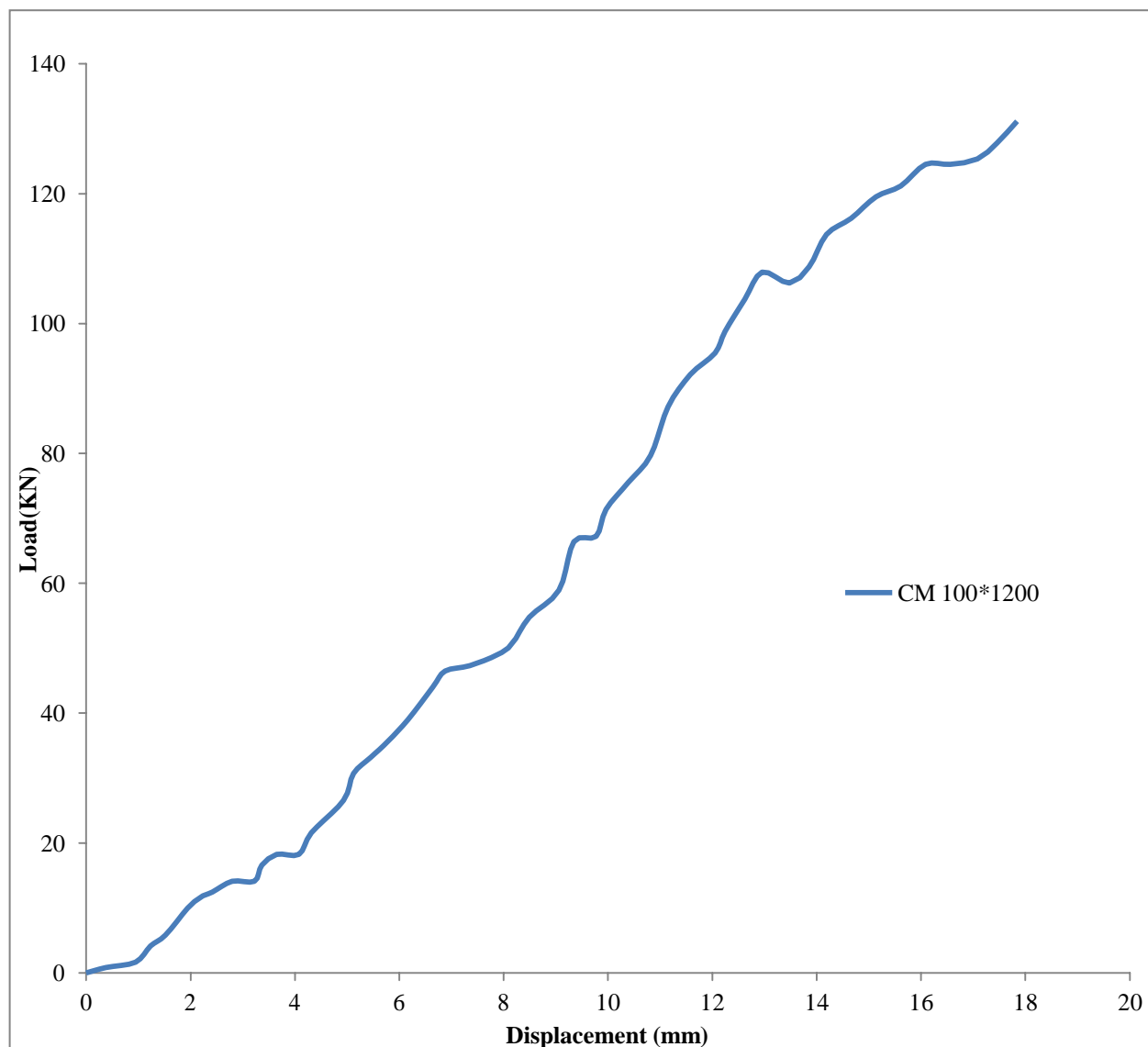


Fig. 4.15 Load vs. Displacement of Control Column (CL, $\lambda=13$)



Fig. 4.16 Detail of column during final phases of loading

4.4.2 Column confined with one layer of SBR Ferrocement wire mesh (RFCL1, RFPCL1, $\lambda=12$)

After application of the load the column shows sign of cracking. The mortar layer of Ferrocement was separated from the wire mesh with compression failure of the column near the base. The wire mesh continued to confine the column till the failure of the concrete occurred at a load of 184.5 KN(RFCL1) and 171.6 KN(RFPCL1) respectively. The maximum displacements were 12.9mm and 12.2mm in RFCL1 and RFPCL1 respectively. Fig. 4.17 shows the load vs. displacement behavior of the column RFCL1 and RFPCL1 respectively.

As the behavior shows decrease in the load carrying capacity, this is because of the slenderness ratio of the column. As the slenderness increases the load carrying capacity decreases.

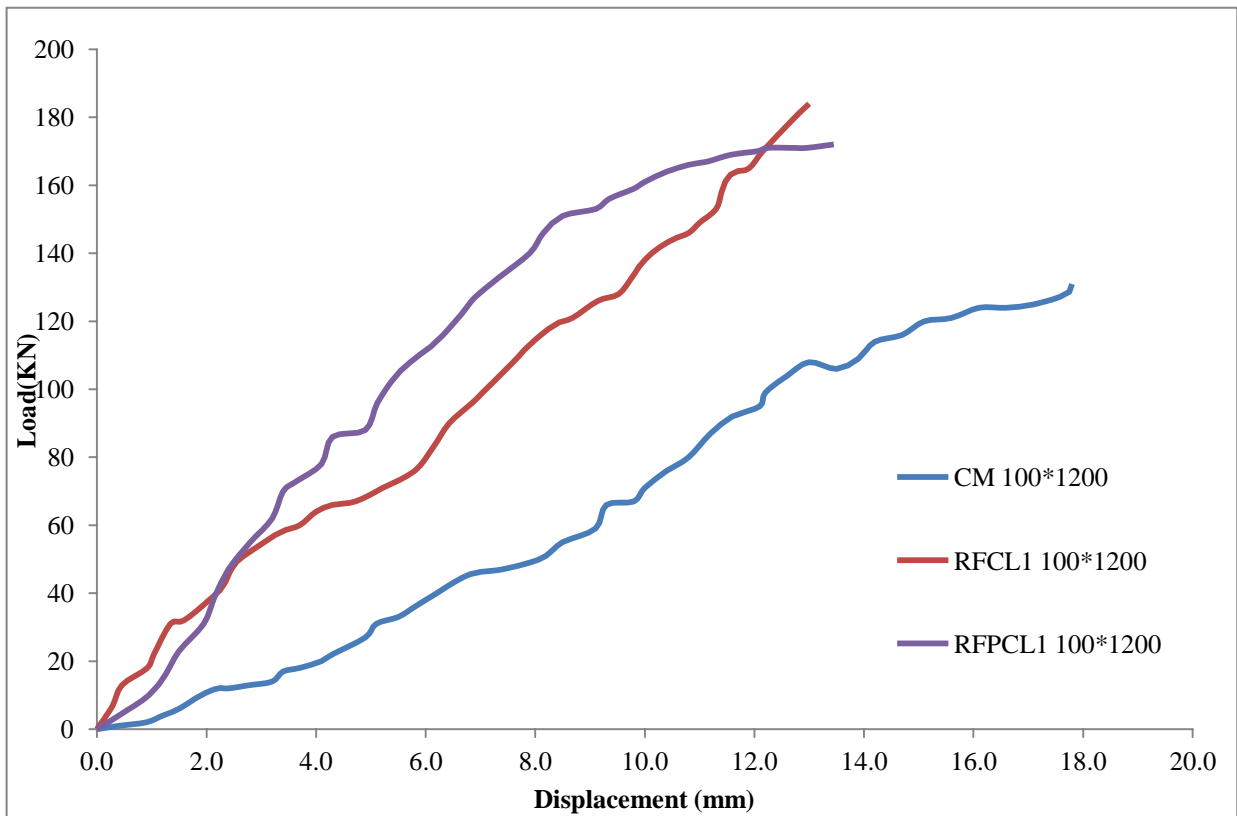


Fig. 4.17 Load vs. Displacement of RFCL1, RFPCL1 ($\lambda=12$)



Fig. 4.18 Detail of column during final phases of loading.

4.4.3 Pre-Loaded Column confined with two layer SBR Ferrocement wire mesh (RFCL2, RFPCL2 , $\lambda=12$)

In these set of columns Pre-loading was applied which was 80% to the peak load of control sample. The columns were pre-loaded with a load of 105.6 KN. As the loading started the behavior of the specimen was similar to the previous samples with one layer of Ferrocement wire mesh. The failure of the concrete samples occurred at a load of 199.3 KN(RFCL2) and 187.5 KN(RFPCL2) respectively. The maximum displacement was 11.05mm and 10.39mm in RFCL2 and RFPCL2 respectively. Fig. 4.19 shows the load vs. displacement graph of the column and Fig. 4.20 shows the details during different phases of loading

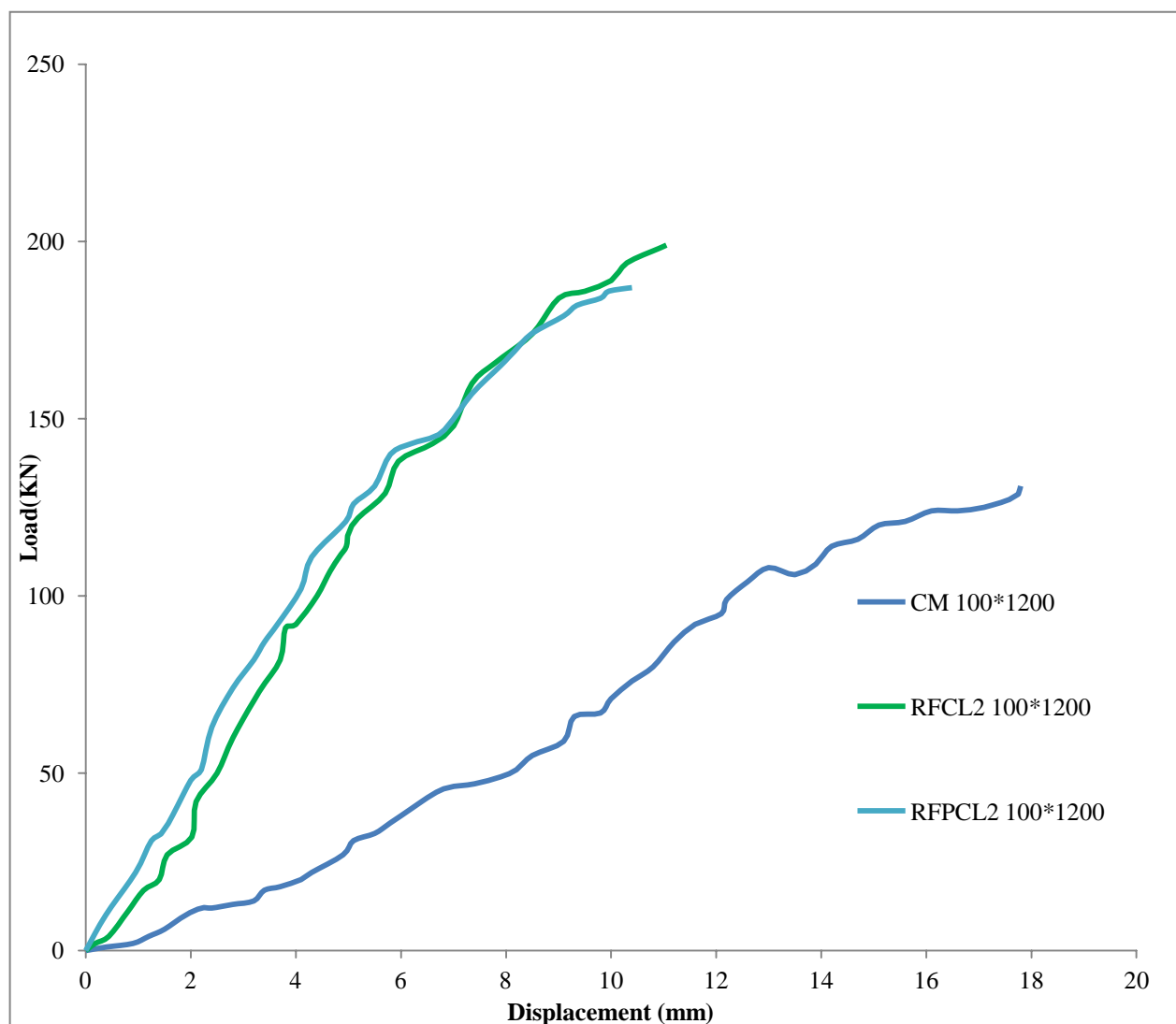


Fig. 4.19 Load vs. Displacement of RFCL2, RFPCL2 ($\lambda=12$)

4.4.4 Comparison of CL, RFCL1, RFCL2 and RFPCL1,RFPCL2 ($\lambda=12$)

In case of the unconfined control column CL, both of the Ferrocement confined columns behaved in a similar manner under the load-displacement criteria. The confinement reduced the displacement in case of RFLC1 and RFPCL1 reinforced with one layer wire mesh as well as RFCL2 and RFPCL2 reinforced with two layers of wire mesh.

The Comparison of Load vs. Displacement of Control and Confined Columns CL, RFCL1, RFCL2 and RFPCL1, RFPCL2, $\lambda=12$ is shown in Fig. 4.20.

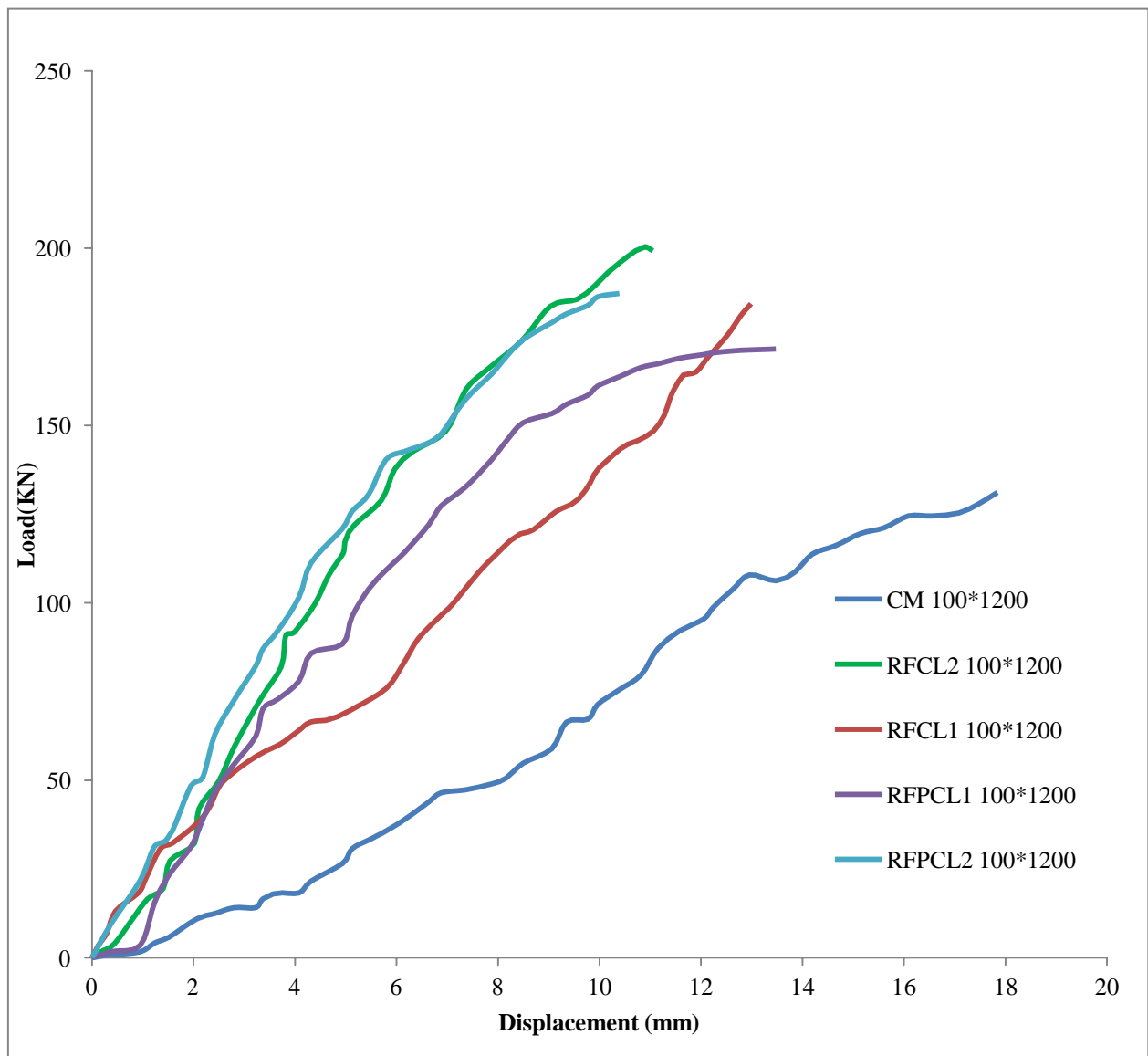


Fig. 4.20 Load vs. Displacement of Control and Confined Columns (CL, RFCL1, RFCL2 and RFPCL1, RFPCL2, $\lambda=13$)

4.5 OVERALL COMPARISON OF TEST RESULTS OF COLUMNS

Comparative analysis of control columns and Ferrocement confined columns with different slenderness ratio, wire mesh and SBR layers is given in Table 4.1. shows the comparison between the slenderness ratio and Ferrocement confinement on the load carrying capacity of the column. The column, due to its slenderness ratio ($\lambda=12$) shows more displacement than that of other sample groups.

4.5.1 Effect of slenderness ratio on ultimate load capacity.

There is an increase in the ultimate load carrying capacity of confined columns RFCS1, RFPCS1 and RFCS2, RFPCS2 as compared to the control column CS. The ultimate load capacity of the control columns CM ($\lambda=6$) and CL ($\lambda=12$) is also lower than the control column CS ($\lambda=3$), which clearly indicates the effect of slenderness ratio. The percentage increase with one layer of wire mesh in RFCS1 ($\lambda=3$), RFCM1 ($\lambda=6$) and RFCL1 ($\lambda=12$) is 53%, 46.3% and 39.8% respectively in comparison to the control columns of the same slenderness ratio. The percentage increase with one layer of wire mesh in Pre-Loaded columns RFPCS1 ($\lambda=3$), RFPCM1 ($\lambda=6$) and RFPCL1 ($\lambda=12$) is 37%, 31.8% and 30% respectively. This shows that the confinement of columns using one layer of wire mesh is less effective in Pre-Loaded column. The percentage increase with two layer of wire mesh in RFCS2 ($\lambda=3$), RFCM2 ($\lambda=6$) and RFCL2 ($\lambda=12$) is 70%, 62.1% and 51% respectively. The percentage increase of Pre-loaded column with two layer of wire mesh in RFPCS2 ($\lambda=3$), RFPCM2 ($\lambda=6$) and RFPCL2 ($\lambda=12$) is 59%, 55.3% and 42.1% respectively

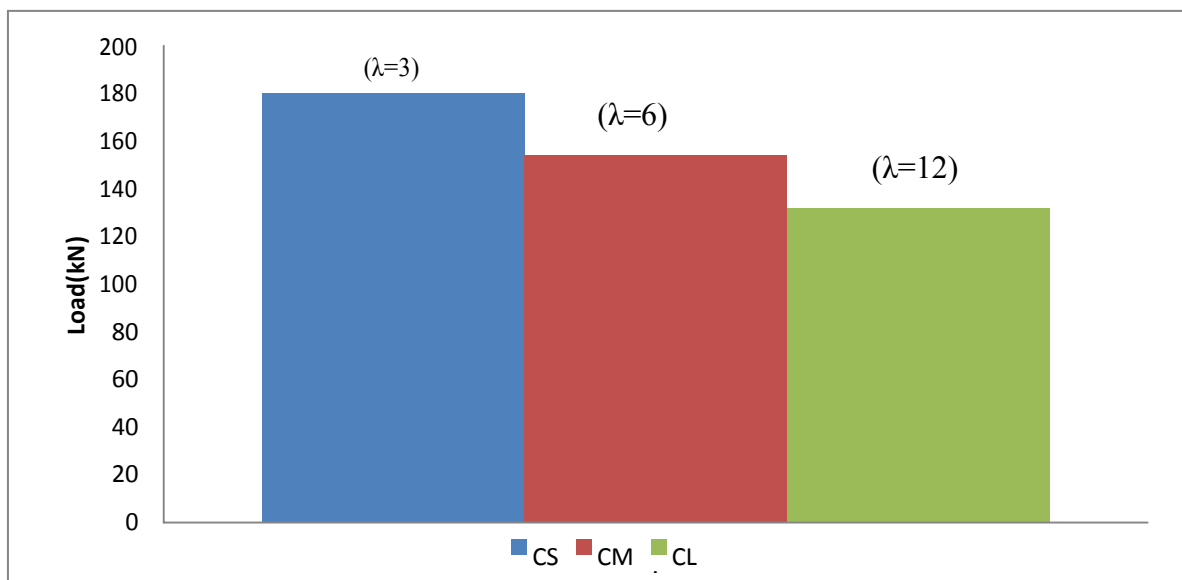


Fig. 4.21 Effect of slenderness ratio on control column

Table 4.1 Test Results of Control, Ferrocement and SBR Confined Columns

Specimen	Slenderness ratio	Number of wire mesh	Pre-loading level	Avg. Ultimate load (KN)	Percentage Increment in ultimate load
CS	3	-	-	180	-
CM	6	-	-	154	-
CL	12	-	-	132	-
RFCS1	3	1	NIL	275.4	53.1
RFCS2	3	2	NIL	306	70
RFPCS1	3	1	80%	246.6	37
RFPCS2	3	2	80%	286.2	59
RFCM1	6	1	NIL	225.3	46.3
RFCM2	6	2	NIL	249.6	62.1
RFPCM1	6	1	80%	202.9	31.8
RFPCM2	6	2	80%	239.1	55.3
RFCL1	12	1	NIL	184.5	39.8
RFCL2	12	2	NIL	199.3	51.2
RFPCL1	12	1	80%	171.6	30
RFPCL2	12	2	80%	187.5	42.1

4.5.2 Effect of initial damage level and no. of wire mesh on retrofitted columns.

The displacement during compression was also reduced due to Ferrocement confinement. There was an increase in load carrying capacity of both no-loaded and pre-loaded columns as compared to control specimen. In case of short columns with slenderness ratio ($\lambda=3$), load capacity is considerably increased, to 275.4kN (RFCS1), 246.6kN (RFPCS1) and 306kN (RFCS2), 286.2(RFPCS2) as compared to that of control column CS, 180kN.



Fig. 4.22 Effect of initial damage level and no. of wire mesh on column ($\lambda=3$)

Similar pattern was observed with other column specimens of different slenderness ratio. The medium column with slenderness ratio, $\lambda=6$, showed increase in load carrying capacity of column i.e. 225.3kN (RFCM1), 202.9kN (RFPCM1) and 249.6kN (RF CM2), 239.1kN (RFPCM2) when compared to that of control column CM, 154 kN.

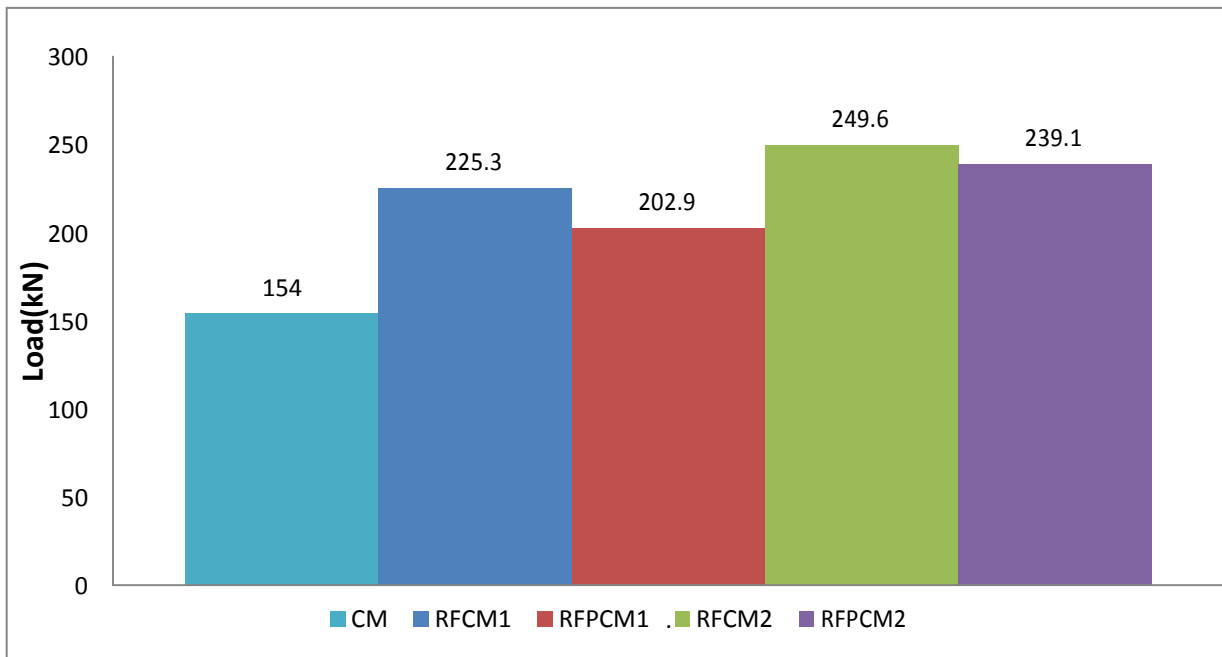


Fig. 4.23 Effect of initial damage level and no. of wire mesh on column ($\lambda=6$)

Similarly long column with slenderness ratio $\lambda=12$, exhibited the increase in load carrying capacity to 184.5kN (RFCL1), 171kN (RFPCL1) and 199.3kN (RFCL2), 187.5kN (RFPCL2) when compared with that of control column CL, 132kN. All the categories of the columns show similar pattern, i.e. load carrying capacity increased with number of wire mesh confinement. The test results also show that in pre-loaded columns load carrying is increased as compared to control columns but there is a decrease in load carrying capacity as compare to non-loaded columns.

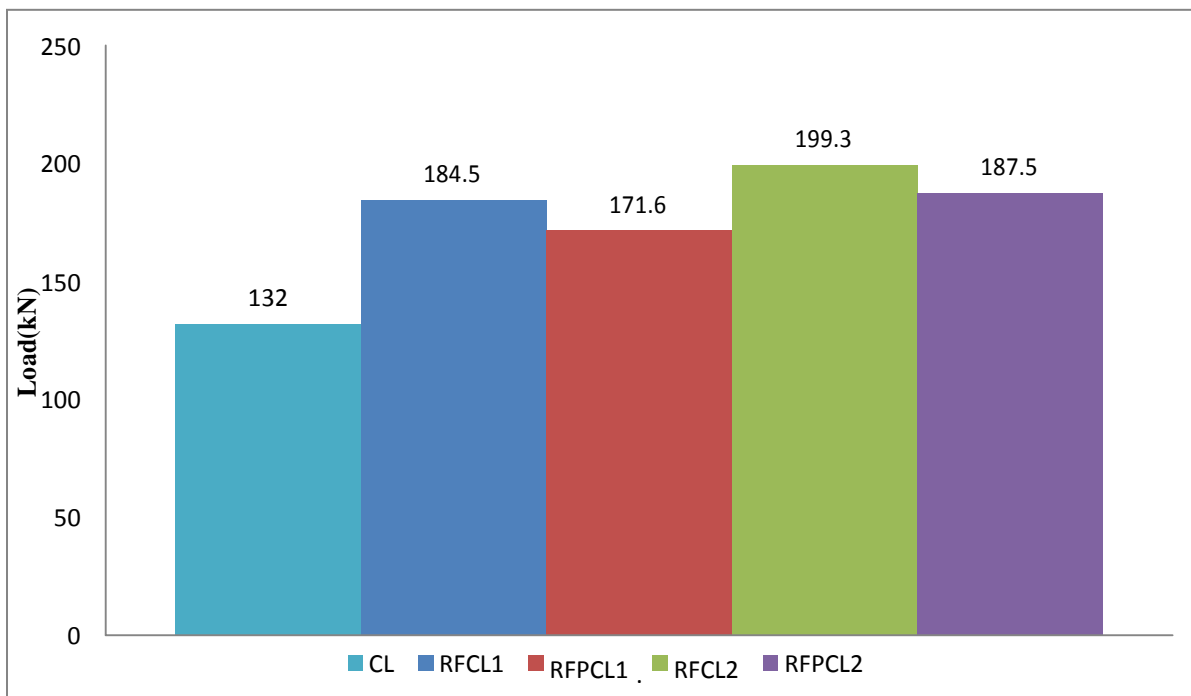


Fig. 4.23 Effect of initial damage level and no. of wire mesh on column ($\lambda=12$)

CHAPTER 5

CONCLUSION

This experimental study is carried out to analyze the behavior of No-Loaded and Pre-loaded (80%)RCC columns with different slenderness ratio and SBR ferrocement confinement on the strength of the columns. Based on test results, the following conclusions are obtained:

1. Ferrocement confinement significantly increased the ultimate load carrying capacity of columns. Further, increase in load carrying capacity of No-loaded column confined with SBR Ferrocement is above that of Pre-loaded columns confined with SBR Ferrocement.
2. With the increase in slenderness ratio of columns the strength provided by SBR Ferrocement confinement decreases. In short column ($\lambda=3$) confinement with one layer of wire mesh increased the strength up to 70% as compared long column ($\lambda=12$) which exhibited an increase in load carrying capacity of only 51%, the similar pattern was followed by Pre-Loaded SBR Ferrocement columns with the decrease 59% to 42.1%.
3. As the number of wire mesh increased , load carrying capacity increased from 53.1% to 70% in no-loaded column ($\lambda=3$) and 37% to 59% in pre-loaded column ($\lambda=3$). Similar trend was seen in long column ($\lambda=12$) load carrying capacity increased from 39.8% to 51.2% in no-loaded column and 30% to 42.1% in pre-loaded column.
4. Lateral deflections are significantly minimized with SBR Ferrocement confinement up to first layer of wire mesh but there is marginal decrease with second layer.
5. The cracking behavior of short column is different from both medium and long column, In short column total height of column takes load, whereas in long and medium column there is local failure, this is due to the effect of slenderness ratio of the column.
6. The load is significantly evenly distributed over the span of short column ($\lambda=3$) therefore there is no local failure as a result column is crushed as whole. In medium column there is a local failure from top and bottom of column. In long column the bottom is crushed and spalling of concrete can be seen at mid height.
7. In case of Pre-Loaded columns there is a decrease in deflection , this may be caused due to the load applied to achieve Pre-Loading which does not allow the column to deflect as much as No-Loaded column.

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