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Behaviour of Ferrocement Encased RC columns under concentric Loading

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Abstract: In recent years, composite materials have gained significant attention for upgrading and rehabilitating concrete structures. Among the various strengthening methods, ferrocement jacketing has emerged as an effective solution for improving the performance of reinforced concrete columns. Since columns are the primary load-carrying elements in framed structures, any failure in these members can seriously affect the overall stability of the building and may even result in structural collapse. The present research examines the effectiveness of ferrocement jacketing in enhancing the strength of both square and circular reinforced concrete columns.

For square columns, two strengthening strategies were investigated. The first method involved providing reinforcement at all column corners, while the second focused on minimizing stress concentration by converting sharp edges into rounded corners. These approaches were further studied using two different jacketing configurations: (i) ferrocement jackets consisting of three wire mesh layers and (ii) jackets with a single mesh layer supplemented by two additional mesh layers at the corners.

For circular columns, the study evaluated the influence of varying confinement levels through the use of different numbers of galvanized iron wire mesh layers. The specimens were wrapped with single-layer, double-layer, and triple-layer ferrocement jackets to assess their effect on compressive strength enhancement.

A total of 27 specimens were prepared for the experimental program, including 15 square columns and 12 circular columns. After an initial curing period of seven days, the columns were retrofitted with ferrocement jackets and then cured for an additional 28 days. Once curing was completed, all specimens were subjected to concentric axial compression testing to determine their load-carrying capacities.

The experimental findings demonstrated a considerable improvement in structural performance due to ferrocement confinement. Square columns with rounded corners and three-layer ferrocement jacketing exhibited the highest enhancement, achieving an increase in load capacity of up to 82.29%. Likewise, the strengthened specimens identified as RFCS, RFCSC, and RFCRCC showed increases in capacity of 68.01%, 53.13%, and 58.20%, respectively. In the case of circular columns, the specimens CC1, CC2, and CC3 recorded improvements of 46.50%, 73.66%, and 132.51%, respectively, indicating that greater confinement through additional mesh layers significantly enhanced compressive strength.

Overall, the study confirms that ferrocement jacketing is an efficient and economical technique for strengthening reinforced concrete columns, particularly when proper corner treatment and adequate mesh confinement are provided.

I. INTRODUCTION

A. General

Reinforced concrete structures show excellent performance in terms of structural behavior and durability except for those zones that are exposed to severe environmental influences and high mechanical loading. Reinforced concrete is a commonly used construction material. RCC as a construction material has come into use for the last one century. In India RCC has been used extensively in the last 50 to 60 years. During this period we have created large number of infrastructural assets in terms of buildings, sport stadium, and bridges etc., which are lifeline for civilized society. These have been constructed with huge investment of resources. We can never dream of recreating such assets out of some degree of national resources. So it is essential to maintain them in functional condition.

The structures are constructed based on the specifications given in standard codes to meet the service life. As with time the codes are upgraded for different reasons, the structures which were constructed on the bases of old codes may have some deficiencies according to the upgraded codes. Change in use or higher loads and performance demands require modifications and strengthening of structural elements. Similarly a large stock of existing structures are deteriorated with use and time and might have passed their design life and require retrofitting and rehabilitation.

The structures are also susceptible to earthquake, flood, cyclone, environmental pollution, chloride attack, carbonation, inadequate design and faulty construction. The environmental stresses like humidity, air and water pollutants also cause corrosion and develop cracks leading to the failure of structural element. Replacement of damaged structural elements is difficult and cost intensive task and replacement of a particular structural element may lead to the integrity of the connecting members. Retrofitting of a damaged structural element is one of the best solutions instead of replacing it. Retrofitting is a process by which the strength or load carrying capacity of a structure or structural member is increased to a significant range.

Retrofitting may be carried out on a global basis by adding extra load resisting elements or it can be done on a local basis by retrofitting the existing structural elements. Global retrofitting of a RC structure can be done by the following methods:

1) Adding shear walls
2) Adding infill walls
3) Adding bracings
4) Adding wing walls
5) Wall thickening
6) Base isolation
7) Mass dampers

Local retrofitting is a technique in which an element of a structure is retrofitted and this can be carried out by following methods:

a) Jacketing of columns
b) Jacketing of beams
c) Jacketing of beam column joint
d) Strengthening of individual footing

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

- Confinement with external steel caging techniques
- Confinement with ferrocement
- Confinement with fibre reinforced polymers such as carbon fibres, glass fibre polymer etc.

Retrofitting with ferrocement confinement is the oldest and economical technique of retrofitting. Lots of research work has done on ferrocement confinement and it is found an effective technique to use ferrocement confinement for retrofitting of structural elements. The unique properties of ferrocement such as water proof, fire resistance, low self weight, durability and crack resistance makes it an ideal material for wider applications. Due to low cost and less skilled labour requirement in ferrocement construction, it is preferred in various rehabilitation projects.

B. Ferrocement Technology

The term ferrocement, also referred to as ferro concrete, is most commonly applied to a mixture of Portland cement and sand applied over layers of woven or expanded steel mesh and closely spaced small-diameter steel rods rebar. It can be used to form relatively thin, compound curved sheets to make hulls for boats, shell roofs, water tanks, etc. It has been used in a wide range of other applications including sculpture and prefabricated building components. It is a thin construction element with thickness in the order of 10-25 mm. It is a type of thin reinforced wall commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh (ACI Committee 549.-R97, 1997). It uses rich cement mortar with low water cement ratio usually 0.4 and small diameter wire mesh layers. Admixtures like silica fume, super plasticizers and non.-metallic fibres may be used for better results. This makes ferrocement structures high strength to weight ratio. Therefore, self-.weight of ferrocement structure is very less as compared to RCC. It requires no skilled labour for casting, and employs only little or no formwork. In ferrocement, cement matrix does not crack since cracking forces are taken over by wire mesh reinforcement immediately below the surface (Desai, 2011). A structure involving complex curvatures can be constructed in a reliable manner using ferrocement technology, giving free reign to architectural expression. Ferrocement construction technology is being popularized throughout the world in countries like Canada, USA, Australia, New Zealand, United Kingdom, Mexico, Brazil, the former USSR, Eastern European countries, China, Thailand, India, Indonesia, and in other developing countries due to its uniqueness and versality (Shannag and Ziyyad, 2007). Ferrocement is in great demand in construction industry due to its various applications in structural members like columns, beams, slabs, walls, floors, window and door frames, water and soil retaining structures etc. Ferrocement can be fabricated into any desired shape or structural configuration that is generally not possible with masonry, RCC, or steel. Based on these advantages, ferrocement can be effectively utilized for strengthening or retrofitting such as water tanks, boats, housing wall panels, roofs, form work etc.

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1) Constituents of Ferrocement

Ferrocement is a composite thin element which is constructed of building materials steel reinforcing mesh or wire mesh, cement, fine aggregate (sand) and water (ACI Committee 549R-97) and each of these materials are separately described in this section below.

a) Steel reinforcing mesh

Ferrocement uses layers of continuous small diameter steel wire weld mesh netting (metallic or non.-metallic) as reinforcement with high volume fraction of reinforcement (2 to 8%) and the specific surface of reinforcement is considerably higher for ferrocement than for RCC. Also, the reinforcing steel wire mesh has openings large enough for adequate bonding; the closer distribution and uniform dispersion of reinforcement, transform the otherwise brittle mortar into a high performance material distinctly different from reinforced concrete. Skeletal steel rods./wires/strands are used as spacer material and to form the skeleton of the shape of the structure to be built, around which the mesh layers are later attached (Naaman, 2000). The type of wire mesh available in market are square, expanded, hexagonal mesh as shown in fig. 1.1.

Fig. 1.1 Types of Wire Mesh

b) Cement

Portland cement is generally used in ferrocement. The type of cement should be selected according to the need or environment in which the structure is constructed. Mineral admixtures, such as flyash, blast furnace slag, or silica fumes, may be used to maintain a high volume fraction of fine filler material as well as to enhance the properties at wet and hardened state.

c) Aggregate

Only fine aggregate is used in ferrocement. Normally, the aggregate consists of well graded fine aggregate (sand) that passes a 2.34 mm sieve; and since salt.-free source is recommended, sand should preferably be selected from river.-beds and be free from organic or other deleterious matter. Good amount of consistency and compatibility is achieved by using a well-.graded, rounded, natural sand having a maximum top size about one-.third of the small opening in the reinforcing mesh to ensure proper penetration. The moisture content of the aggregate should be considered in the calculation of required water (Naaman, 2000).

d) Water

In ferrocement, the water used for mixing cement mortar should be fresh, clean and fit for construction purposes; the water of pH equal or greater than 7 and free from organic matter silt, oil, sugar, chloride and acidic material

e) Admixtures

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

2) Applications of Ferrocement

a) Structural applications of ferrocement

Ferrocement can be used in various structural members subjected to different type of stresses. As a compression member, hollow columns with horizontal stiffners can be cast in ferrocement. Columns or walls in concrete, RCC, stone or brickwork can be encased in ferrocement to increase their strength due to confinement. Members subjected to membrane stresses like shells, domes, pyramids can be cast in ferrocement very easily; and being a homogenous material, full section of member is utilized in resisting the membrane stresses. A greater use could be made of ferrocement in water-retaining constructions. Because of its very small crack widths under service load and it superior extensibility, ferrocement provides excellent leakage characteristics for applications in water tanks.

b) Roofing applications

Ferrocement is an economic alternative material for roofing. Flat or corrugated roofing system is quite popular.

c) Need for repair of RCC structures

Some major reasons for the deterioration of RCC structures are cracking (due to incorrectly made construction joints, poor compaction, segregation, poor curing and high water content) and spalling (due to corrosion in the reinforcement bars accelerated by a lack of adequate cover).

The cracks in the concrete may be developed due to wrong design of structure or due to poor quality of materials used, and this will facilitate internal corrosion of steel reinforcement used in RCC elements; the cracks in course of time deepens up due to increase in corrosion and subsequently, peeling of concrete cover or spalling of concrete takes place. Use of proper repairing materials and methods of damaged or deteriorated RCC structures is a necessity not only to serve the intended service life but also assure the safety of buildings (Masood et al. 2003). Ferrocement is generally used for repairing or retrofitting of structural members by jacketing techniques.

3) Ferrocement Confinement

Ferrocement confinement is done around defective circular or square/rectangular RCC columns in order to enhance the strength, ductility and energy absorption capacity of existing concrete columns. A jacketing layer of 30 mm is created around the RCC columns with ferrocement is done in order to increase its load carrying capacity. This confinement work also protects the existing reinforcement, provides water tightness and prevents ingress of the aggressive species to the surface of original concrete or steel surface. Ferrocement not only increases the performance/ function of structures but also enhances the appearance of the existing RCC structure. The repair in the structural elements using ferrocement can withstand for long years without cracking provided the mortar used is of proper proportion using good quality materials, and the wire mesh is of anti-corrosive coating type (Masood et al., 2003).

4) Advantages of Ferrocement Technology

- Ferrocement is an isotropic material up to 40% of the yield and its density is about 2750 kg/m3. RCC material is a heterogeneous material (density 2500 kg/m3) consists of voids and capillaries. Therefore, water and other gases easily entrapped in the concrete material which cause crack formation, spalling and corrosion of reinforcement. Moreover, the cracks formed over RCC structures are wide and deep whereas minute and shallow cracks are formed in the ferrocement structures. Structural members of ferrocement remain free of voids and capillaries hence remain corrosion resistant and water proof due to these properties.
- Ferrocement has high strength to weight ratio. Ferrocement is thin section high strength structural material highly waterproof, crack formation resistant, energy absorbing material. It is manufactured with high cement content, low water cement ratio around 0.4, wire mesh layers, light structural steel, admixtures mainly silica fume super plasticizers, non.-metallic fibres, particularly when ferrocement is cast-.in-.situ. Therefore self-.weight of ferrocement structure is very less as compared to RCC.
- Ferrocement is highly ductile, resilient, energy absorbing material. When put under load it develops cracks at a much higher value after the elastic limit. Because of this property a ferrocement structures frame will not collapse like RCC and therefore there will be least loss of life and property. Ferrocement structures do not collapse but get deformed. A large number of such structures as compared to RCC can be easy to repair. The debris formation will also be the less.

C. Column

Column is the most important element in a frame structure because it carries the load coming from beams and transfer that load to the foundation. So failure of this element may lead to the collapse of the whole frame structure. A reinforced concrete column is a structural members designed to carry compressive loads, composed of concrete with an embedded steel to provide reinforcement.
Retrofitting or reconstruction of the damaged column is the necessary task to prevent the further damage to the whole structure. So it is utmost important to increase the load carrying capacity and impart ductility to the concrete, which can be done by external confinement of column.

The strength of the column is greatly influenced by the length.

1) Classification of Columns

a) Classification on the basis of shapes

A column can be cast into various shapes. Generally used shapes are:

- Square
- Rectangular
- Circular
- Hexagonal
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b) Classification on the basis of slenderness ratio

Slenderness ratio is the ratio of length to diameter/ least lateral dimension. On the basis of slenderness ratio the columns are classified into two categories as:

- Short columns
- Long columns

If the value of slenderness ratio is less than 12, the column is considered as Short Column and if the value is greater than 12, it is considered as a Long Column. The short column has more load carrying capacity than the long column of the same cross section.

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

c) Classification on the basis of design

On the basis of design requirements columns can be categorized into two types:

- Spiral columns
- Tied columns

Spiral columns are cylindrical columns with a continuous helical bar wrapping around the column. The spiral acts to provide support in the transverse direction and prevent the column from barreling. Tied columns have closed lateral ties spaced approximately uniformly across the column. The spacing of the ties is limited in that they must be close enough to prevent barreling failure between them, and far enough apart that they do not interfere with the setting of the concrete.

2) Effective Length of the Column

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

Degree of end restraint of compression member	Symbol	Theoretical value of effective length	Recommended value of effective length
Effectively held in position and restrained against rotation in both ends		0.50 l	0.65 l
Effectively held in position at both ends and restrained against rotation at one end		0.70 l	0.80 l
Effectively held in position at both ends but not restrained against rotation.		1.00 l	1.00 l
Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position		1.00 l	1.20 l
Effectively held in position and restrained against rotation at one end, and at the other end partially restrained against rotation but not held in position		-	1.50 l
Effectively held in position but not restrained against rotation at one end, and at the other end restrained against rotation but not held in position		2.0 *l*	2.00 l
Effectively held in position and restrained against rotation at one end, but not held in position nor restrained against rotation at the other end		2.00 l	2.00 l

Where " l " is the unsupported length of the compression member.

Fig. 1.2 Effective Length of Compression Members (IS 456-2000)

D. Objectives

In recent years, strengthening of reinforced concrete elements, such as beams, columns etc., has given enormous emphasis as the failure of these elements could catastrophically fail the entire structure. In the past few decades, ferrocement has been used as restrengthening material for its better crack resisting properties. It is observed from the last thesis work that strengthening the square columns (sharp edges), with ferrocement jacketing increases the load carrying capacity of column, but maximum cracks during loading and after failure were observed at corners. To minimize these cracks at corners it is required to strengthen the corners or to reduce the stresses at corners by making them round.

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

1) To study the improvement in load carrying capacity and ductility of square columns after strengthening the corners with ferrocement jackets.
2) To study improvement in load carrying capacity and ductility of square columns by reducing the stress concentration at corners and strengthening them with ferrocement.
3) To study the effect of ferrocement confinement with different percentage of wire mesh in square columns.
4) To study the improvement in load carrying capacity of circular columns confined with different percentage of wire mesh (ie. one, two and three layer).
5) To study the first crack load and mode of failure.

II. CONCLUSION

From the experimental investigation of ferrocement jacketed RC square and circular columns under concentric load, the following concluding remarks could be made:

1) Ferrocement confinement improves the ultimate load carrying capacity of RC column.
2) Ferrocement confinement increases the ultimate axial deflection and lateral deflection of RC column.
3) Strengthening the square column by making the corners rounded is more effective than strengthening the column by keeping their edges sharp.
4) It is better to strengthen the square column with three layers of wire mesh than strengthening them with single layer of wire mesh and two extra layers of wire mesh at each corner.
5) It is concluded that type RFCRC and RFCRCC type ferrocement jacketing technique is better than RFCS and RFCSC respectively.
6) Crack patterns of tested square specimen also confirm that type RFCRC and RFCRCC type is more effective than RFCS and RFCSC respectively.
7) It is good to strengthen the circular column with three layers of wire mesh than that of two layers and one layer.
8) Crack patterns of tested circular column specimen also confirm that CC3 type of ferrocement jacketing technique is more effective than CC1 and CC2.

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