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A Comparative Study on the Use of Single and Double Layer Ferromesh Confinement in the Form of Strips on the Behaviour of Short RCC Columns

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The structural behavior of columns is a critical aspect of building safety hence enhancing their strength and ductility is essential for ensuring safety and resilience. This research experimental study determines the use of ferromesh as confinement reinforcement in short reinforced concrete (RCC) columns to study their axial load carrying capacity and axial and lateral behavior. In this research experimental scheme total five types of column specimens were casted, each consisting of three samples. The first type, a control column, was reinforced with four longitudinal bars (10mm diameter) and conventional confinement reinforcement (6mm diameter). The remaining four types were deviation of the control column, confined with the help of ferromesh in different configurations: with 100mm wide ferromesh strips with 100mm c/c spacing over the control column in single and double layer of ferromesh, and the other longitudinal bars wrapped with ferromesh strips only in single and double layer strips of 100mm, spaced at 100mm c/c as confinement were used.

All column specimens were subjected to axial load testing on a 100-ton Universal Testing Machine (UTM), with axial and displacement measurements recorded using BAUMERS sensors associated to a dedicated data logger system. Load versus axial and lateral displacement curves were examined.

The results exhibits that the use of 100 mm wide ferromesh strips in addition to conventional r/f as confinement reinforcement can significantly enhance the column behaviour. Among the different configurations, the column confined with a double layer of 100mm wide ferromesh strips with conventional rings performed the best, showing better lateral and axial displacement control. The findings suggest that ferrocement is a highly efficient, cost-effective method for enhancing the structural performance of RC columns, offering considerable improvements in stiffness, and ductility.

Keywords: Concrete, Ferrocement, Column, Axial & Lateral displacement, Ductility.

1. Introduction

Columns are among the most critical structural elements in any building, primarily responsible for transferring loads from the superstructure to the foundation. Beyond their load-bearing capacity, ductility—the ability of a column to undergo significant deformation before failure—plays a crucial role in column performance. Enhancing the ductility of columns has become a focal point of structural engineering research, leading to the development and study of various techniques aimed at achieving this goal.

Confined concrete has been studied for its improved properties under axial loads, mainly its ability to improve strength, ductility, and stress-strain behaviour. Transverse reinforcement, hydrostatic pressure, and the interaction between the concrete core and reinforcement play's a significant role in influencing these properties. The basic purpose of transverse reinforcement in reinforce columns is to preventing the longitudinal bars from buckling, improving shear strength and confining the concrete core in order to improve ductility as well as durability [7]. Experimental data also proved that confined concrete shows evidence of higher strength and ductility compared to unconfined concrete [48, 63, 65]. In 1928, Richart et al. carried out a study which shows the relationship between transverse reinforcement and improved strength, confirming that passive confinement pressure from transverse reinforcement gives uniform lateral support [11, 13]. The stress strain behaviour of confined concrete differs significantly from those of plain concrete. It was also observed the stress-strain behavior for confined concrete normally shows a bilinear or trilinear pattern, with improved peak stress and strain values. When considered to axial compression, transverse strains produce lateral pressure that improves the overall confinement effect. Such relations are influenced by the Poisson's ratio and the arrangement of transverse reinforcement [19]. This was also proved by Saatcioglu (1987) that proper detailing of longitudinal and transverse reinforcement enhances its ductility and strength [18]. Further to this researcher has also proved that the volumetric ration and spacing of transverse reinforcement influence on confinement effectiveness [15, 16, 17].

Among these methods, the use of ferrocement has emerged as a promising solution for improving both the strength and ductility of reinforced concrete (RC) columns. Ferrocement is a specialized form of reinforced concrete characterized by layers of closely spaced wire mesh or small-diameter bars embedded in a rich mortar mix [1]. Numerous studies have demonstrated the effectiveness of ferrocement reinforcement in strengthening damaged RC columns and restoring their load-bearing capacity [2]. By confining columns with ferrocement, researchers have found not only enhancements in overall strength but also significant improvements in ductility, enabling the columns to deform more extensively without failing [3].

As axial loads on a column increase, its ductility tends to decrease due to the P-Δ effect. To counteract this decline, a higher degree of confinement reinforcement is required, which can be efficiently provided through ferrocement[4]. The key to achieving greater strength and ductility lies in increasing the amount of confinement reinforcement [5]. Ductility, defined as the ratio of ultimate load to yield load, decreases with higher axial loads and concrete strength but increases with greater confinement reinforcement [6]. One common cause of column failure is inadequate confinement [10]. Fukumoto discussed how the variability in steel properties such as yield strength can reduce the structural ductility factor [8]. Various materials have been explored for confining RC columns, including geopolymer jackets, carbon fiber, plastic mesh, and steel wire mesh. While carbon fiber offers the highest strength, it comes at a higher cost; conversely, plastic mesh and steel wire provide economical alternatives [14]. Ferrocement has also proven effective in enhancing the strength, serviceability, and ductility of masonry walls. The effectiveness of ferrocement reinforcement is influenced by factors such as mortar quality, thickness, bond strength between the wall and ferrocement, and the gauge of the wire used [9]. While several strengthening methods exist—such as reinforced concreting, steel straps, fiber-reinforced polymers, steel plates, and ferrocement jackets—ferrocement stands out as a cost-effective and high-performing option [12].

Ferrocement jacketing has shown outstanding performance in improving the ductility and energy absorption capacity of RC columns. Mourad et al. (2007) tested ferrocement-jacketed columns under axial compression and found that the load-carrying capacity increased by 28% to 78%, depending on the degree of pre-loading and the confinement configuration [20]. Tests performed by Benzaid et al. (2008) showed that the stiffness of ferrocement jackets considerably impacts their confinement pressure and, their ability to enhance axial and radial strain capacity [23]. The studies showed that ferrocement jacketing gives a ductile failure mode, which is suitable for seismic retrofitting [21,22].

In this experimental study, fifteen one-third-scale columns were categorized into five groups, each containing three column specimens. The columns were cast with different configurations of confinement reinforcement, and their performance was assessed in terms of axial strength, axial-lateral displacement, and ductility.

2. Experimental program

This experimental study involved testing fifteen short square column specimens, each with a cross-sectional size of 150mm x 150mm and a height of 960mm. The longitudinal reinforcement in all columns consisted of four 10mm diameter bars, while 6mm diameter bars were used as stirrups for confinement reinforcement. Additionally, a 2mm diameter welded wire mesh, with 75mm x 75mm grid spacing, was employed as in single and double layer confinement reinforcement in certain specimens. The fifteen columns were divided into five distinct groups, with each group containing three specimens, as outlined below:

- C-I: Control Specimen: The control columns with measured cross sectional dimension as 150mm x 150mm with the height of 960mm. All these columns were reinforced with four bars of 10mm diameter as longitudinal bar and 6mm diameter rings for confinement reinforcement

- C-II: Columns Confined with 6mm rings and single layer of 100mm ferromesh strips: In this group, columns remained the same dimensions (150mm x 150mm, 960mm height) and longitudinal reinforcement as of the C-I type specimens. Along with the 6mm stirrups, the columns were wrapped with a welded wire mesh with 100mm wide strips in single layer at distance of 100mm. The mesh had a grid spacing of 75mm x 75mm and with 2mm thickness, 100mm mesh strip acted as an additional layer of confinement reinforcement.

- C-III: Columns Confined with single layer of 100mm ferromesh strips only: In this group, the columns were similarly sized (150mm x 150mm, 960mm height) and contained the same four 10mm diameter longitudinal bars. However, instead of using traditional stirrups, the confinement reinforcement was provided solely by wrapping the column with a 2mm thick welded wire mesh of 100mm wide strips, having a 75mm x 75mm grid spacing with single layer.

- C-IV: Columns Confined with 6mm rings and double layer of 100mm ferromesh strips: In this group, columns remained the same dimensions (150mm x 150mm, 960mm height) and longitudinal reinforcement as of the C-I type specimens. Along with the 6mm stirrups, the columns were wrapped with a welded wire mesh with 100mm wide strips in double layer with distance of 100mm. The mesh had a grid spacing of 75mm x 75mm and with 2mm thickness, 100mm mesh strip acted as an additional layer of confinement reinforcement.

- C-V: Columns Confined with double layer of 100mm ferromesh strips only:: In this group, the columns were similarly sized (150mm x 150mm, 960mm height) and contained the same four 10mm diameter longitudinal bars. However, instead of using traditional stirrups, the confinement reinforcement was provided solely by wrapping the column with a 2mm thick welded wire mesh of 100mm wide strips, having a 75mm x 75mm grid spacing with double layer.

Table 1 summarised the detailed provision of each short RCC square column specimen used in this study. By altering the patterns of confinement and ratio of reinforcement volume across the various column types, the load carrying capacity, axial-lateral displacement, crack patterns, and ductility were assessed to analyse the impact of each configuration.

2.1. Material properties

The concrete mixture for all column specimens was prepared using Ordinary Portland Cement (OPC), coarse aggregate (CA) with a maximum size of 20mm, and fine aggregate consisting of properly washed sand. The oven-dry bulk specific gravities of the coarse and fine aggregates were 2.68 and 2.60, respectively. Tap water was used in the mix, and the concrete mix design followed a ratio of 1:2.836:2.96 (cement: sand: aggregate), with a water-to-cement (w/c) ratio of 0.46. The reinforcement used for all columns was Fe-500 grade steel.

2.2. Preparation of specimen

The skeletons of all columns were prepared using the required longitudinal bars and confinement reinforcement, according to the specific column types. A mild steel (MS) mould, custom-fabricated to the column dimensions (150mm x 150mm x 960mm), was used for casting. To facilitate easy de moulding and prevent adhesion, the internal surfaces of the mould were thoroughly coated with oil. The longitudinal bars and confinement reinforcement were carefully placed within the mould, and wooden spacers of 13mm thickness were positioned at the edges to ensure consistent concrete cover. During the pouring of concrete, a mechanical vibrator was employed to ensure uniform compaction and eliminate voids within the column structure. Once cast, the columns were demoulded after 24 hours and left to cure. The columns were tested after 90 days. Fig. 1(i), (ii), (iii), (iv), and (v) illustrate the column cages for each type before insertion into the mould, while Fig. 1(vi) shows the MS mould used for preparing the columns.

(i) (ii) (iii) (iv) (v) (vi) (vii)

Figure 1: - (i) type I column skeleton; (ii) type II column skeleton; (iii) type III skeleton; (iv) type IV column skeleton; (v) type V column skeleton; (vi) MS fabrication mould in which column were casted; (vii) Spirit level check to assure vertical alignment of column.

Table 1. Description of different types of column used in the experiment.

Description of Column	longitudinal R/f	Tranverse R/f	Layer of ferromesh	Number of columns
C -I	4 - 10mm dia.	6mm rings	---	03
C –II	4 - 10mm dia	6mm rings along with 100mm strips of ferromesh	Single	03
C –III	4 - 10mm dia	Ferromesh 100mm strips as confinement r/f	Single	03
C- IV	4 - 10mm dia	6mm rings along with 100mm strips of ferromesh	Double	03
C- V	4 - 10mm dia	Ferromesh 100mm strips as confinement r/f	Double	03
Total				15

2.3. Instrumentation and setup

As the 90 days curing is over, all these column specimens were kept in a dry place for testing. To perform the test all these column were tested on 100 ton Universal Testing Machine. During the test, before applying the load, the vertical alignments of all columns were assured using spirit level in order to ensure its vertical position as shown in figure 1 (vii) above. Further to this in order to get a flat surface on top & bottom supports, plaster of paris layer was used. Similarly to prevent the column from local or premature failure at supports, both supports were clamped using 6mm thick mild steel plate.

Precise BAUMER sensors were used in order to catch the axial and lateral displacement of the column when subjected to gradual load using Universal Testing Machine (UTM). BAUMER sensors used were of very high precision, it has accuracy of 0.001mm. In order to get the lateral displacement of the tested column, theses BAUMER sensors were placed at mid height of all four surface of the column, while to get the axial displacement BAUMER sensor was placed focused on the bottom crosshead of the UTM.

These entire BAUMER sensors, collecting the reading of axial and lateral displacement of the columns were connected to a devoted data logger system. This devoted data logger system was so placed near to load reading display, that while capturing the video through digital camera, the readings of load and axial and lateral displacement readings displayed on data logger system can be seen in a single screen.

Below figure 2 shows the complete test setup, showing the exact positions for the BAUMER sensors and the devoted data logger system in reference to the column specimen. Figure 3 givea detailed view of the data logger system used during the tests.

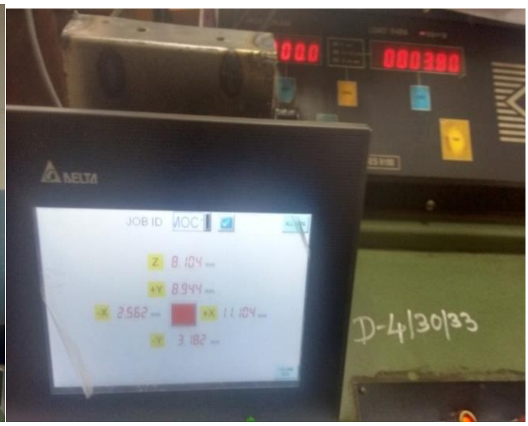

Figure 2: Test setup

Figure 3:Devoted data logger

3. Discussion of test results

In this experimental process, various data were collected and analyzed to assess the behaviour of the column specimens. This section highlights the main observations and result related to load carrying capacity, displacement, and overall behaviour of the columns.

3.1. Load carrying capacity

Following table 2 represents the load carrying capacities of all column specimens tested. Based on the recorded results, the following observations were made:

Table 2 Types of column used

Column Description	Confinement R/f	Layer of jacket	Load carrying capacity (in kN)
C -I	6mm rings	---	658
C –II	6mm rings along with 100mm wide strips of ferromesh	Single	675
C –III	Ferromesh 100mm wide strips as confinement r/f	Single	625
C - IV	6mm rings along with 100mm wide strips of ferromesh	Double	675
C – V	Ferromesh 100mm wide strips as confinement r/f	Double	675
Total			NA

From the above table it was observed that the load carrying capacity of the column ranges from 625kN to 675kN. It was also observed that when single layer of 100mm feromesh strips is used a slight enhancement in load carrying capacity was observed in addition to conventional rings and in absence of the rings there is not much difference in the load carrying capacity of the column compared to C-I type of column. It was further observed that when double layer of 100mm strips of ferromesh used with rings or without rings the load carrying capacity enhanced slightly to 675kN.

3.2. Axial displacement

A graph drawn between axial loads applied Vs axial displacement. It was observed that all columns indicate initially linear increase which proves elastic behaviour for all column specimens. due to additional ferromesh strips of 100mm wide wrapped on column specimen along with conventional rings higher stiffness was observed in column C2 and C4. In consideration to axial load carrying capacity C3 observed as lowest. While the other ie C1,C2 and C5 exhibits comparable axial load carrying capacity but vary in displacement.

It was also observed that C5 indicates maximum axial displacement before load drop; it means highest ductility. While C3 has demonstrated steep decline indicating brittle failure.C4 gives a gradual load drop after yield, showing ductile failure. The failure of C3 indicates insufficient reinforcement.

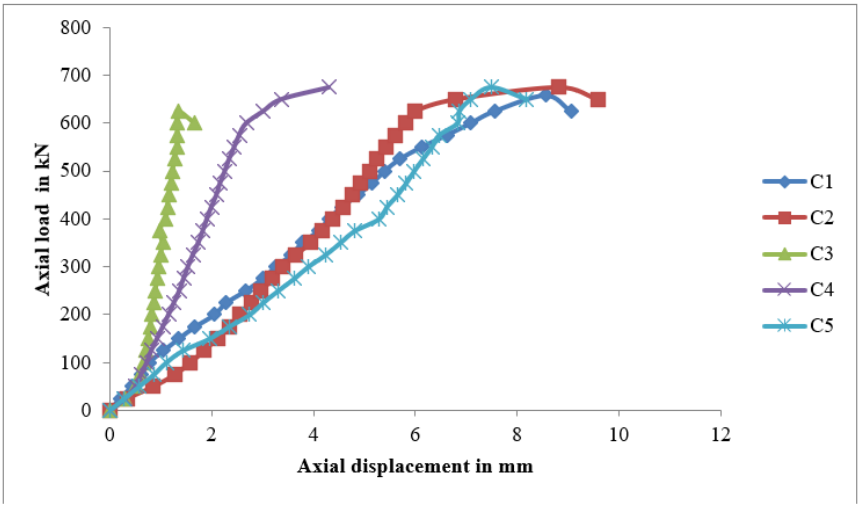

Figure 4 Axial displacements Vs. Axial Load

3.4 Lateral displacement

In the graph of lateral displacement Vs axial load it can be observed that all column specimens show initial linear displacement with axial load, this indicates stability during the initial loading phase.

Column C3 demonstrates premature lateral instability. Column C4 shows the minimum lateral displacement at maximum load, means high stability. Additional confinement in C4 helps in reducing lateral deformation and improving stability and load capacity. In opposite to this inadequate reinforcement in C3 shows early lateral instability and reaches to failure. While C5 exhibits maximum lateral displacement it means susceptibility towards buckling.

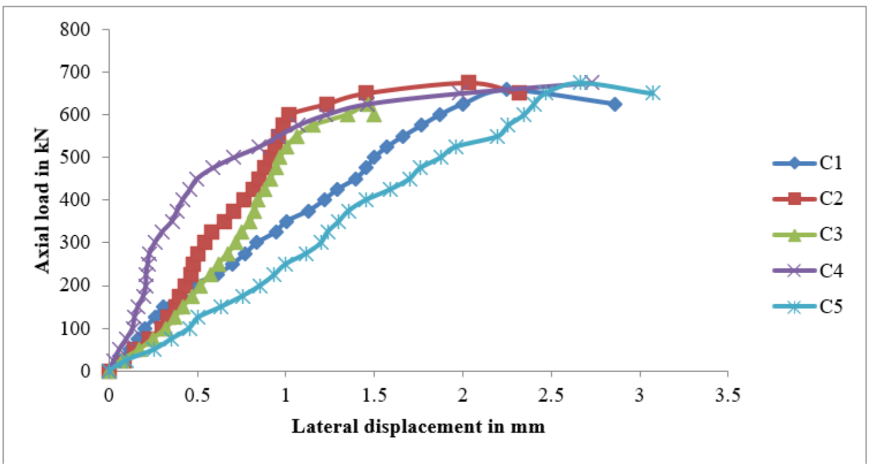

Figure 5 Lateral displacements Vs. Axial Load

4. Conclusion:

Based on above results following conclusion can be drawn.

1. Use of only double layer of feromesh strips of 100mm width column (C5 type) provides high energy absorption means high ductility but need to enhance lateral stability.

2. Due to lack of confinement reinforcement when used only single layer of ferromesh strips of 100mm width, ie C3 type, shows a need for better design in order to prevent failure and instability.

3. Among all above double layer of feromesh strips of 100mm width column with conventional rings (C4 type) demonstrate best performane with minimum lateral displacement and balanced ductility, results in making it the most effective way of providing confinement in column.

4. This research shows that providing hybrid confinement techniques ie combining traditional and new reinforcement (like ferromesh) are significant for enhancing the behavior of reinforced concrete columns.

5. Considering the advantages of feromesh like low cost, easy to use, can be used in column as confinement reinforcement along with conventional rings.

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