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Effect of Ferrocement Confinement on RC Columns Under Axial Compression And Improvement

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Abstract

Retrofitting can be done by using the approach of local strengthening of structural elements or global strengthening of structure. Columns are the most important elements of structural system to carry vertical load and provide lateral resistance. Sometimes columns aren't strengthening enough due to inadequate shear reinforcements or splice length or bad construction workmanship. Column capacity can also be deteriorated by seismic action or fire. Hence, columns have to be locally strengthened using anyone of additional reinforced concrete layer, ferrocement jacketing or steel jacketing etc. Among them ferrocement jacketing is comparatively easy to install at site, cheaper and effective to increase load capacity. Ferrocement jacketing consists of different wire mesh layer at column with angle plate and sometimes with shear key to increase the column capacity. The gaps between installed ferrocement wire mesh layer and existing concrete surfaces are filled with mortar to ensure a continuous contact. Total six RC columns were prepared, among which one was kept as reference column & rest three were jacketed and tested under concentric axial load which showed improvement of additional 11%. 70% enhancement of capacity for corner mesh and 98% additional improvement for steel angle at corners has been identified.

Keywords: *RC Column; ferrocement; jacketing; compression; corner improvement.*

1 Introduction

1.1 Background of the Study

Columns have to be locally strengthened to ensure life safety using one of the following approaches, e.g. additional reinforced concrete layer, ferrocement jacketing, steel jacketing, FRP jacketing etc. (D. Sen & M. Begum, 2016). Reinforced columns capacity is lessened due to various reasons like overloading, corrosion of steel, earthquake, higher wind loads, fire, impact loads, etc. Therefore, the strengthening of deficient columns is necessary to increase the load carrying capacity and prevent spalling which can be achieved by confinement of column externally (M. Salih & C. Arunkumar, 2016). Several researchers conducted studies to evaluate the load carrying capacity of ferrocement wire mesh layers strengthened Reinforced Concrete (RC) columns. The main deficiency found in literature is the insufficient studies on the ferrocement strengthened RC columns with corner improvement by various technique, including improvement by using steel angle plate at corner which is subjected to axial loads. So, further studies are required on the behavior under axial load. To meet this need, an experimental attempt has been taken to investigate the behavior of ferrocement jacketed RC columns under axial loading with corner improvement and as well as changing the layer of ferrocement. Ferrocement is a thin construction element and uses rich cement mortar; no coarse aggregate is used; and the reinforcement consists of one or more layers of continuous/ small diameter steel wire/weld mesh netting. However, in his research, improved column using wire mesh layer at four corners was tested. So, the behavior of column with ferrocement wire mesh layer & angle plate at corner needs to be investigated. In this experiment, the column is improved using angle plates as well as wire mesh layer at four corners of the columns. These columns have been tested under axial compressive load to evaluate the behavior of improved ferrocement techniques.

1.2 Objectives of the Study

The primary objective of this study is to improve the durability, sustainability and cost reduction in building houses of rural and coastal areas. To obtain this objective special emphasis is given on:

i. Identifying the impact of ferrocement confinement due to axial loads on RC columns.
ii. Investigating the failure characteristics of ferrocement confined RC columns.
iii. Studying the effect of corner improvement of RC column by wire mesh & steel angles.
iv. Identifying the effect of shear key on ferrocement jacketed RC column.

2 Methodology

2.1 Investigations and identifications of materials specifications used for RC column construction

a) Cement: Standard Portland Composite cement branded as Shah cement has been used to construct all test columns.

b) Aggregate: Locally available brick chips of 0.75-inch downgrade and sand have been used as coarse aggregate and fine aggregate respectively. Properties of aggregates, necessary for the mix design have been determined from the laboratory tests and are presented in the Table 1 and gradation in Figure 1.

Table 1. Properties of Coarse and Fine Aggregate

Property	Test Method	CA	FA
Bulk Sp. Gravity (OD)	ASTM C127	1.80	2.60
Bulk Sp. Gravity (SSD)	ASTM C127	2.07	-
Aprnt. Sp. Gravity (OD)	ASTM C127	2.48	2.68
Absorption Capacity (%)	ASTM C127	15.27	1.11
Dry Rodded Unit Weight	ASTM C29	1550	1590
Fineness Modulus (FM)	ASTM C136	6.49	-

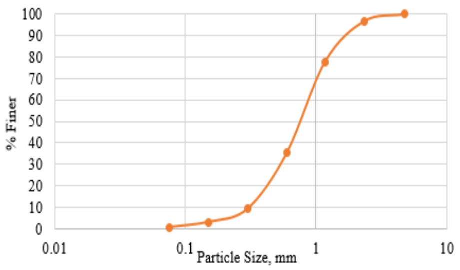

Figure 1. Gradation Curve of Fine Aggregate

c) Reinforcement: 10mm and 8mm diameter deformed bars branded as ASRM 300 have been used as long and tie reinforcements respectively. As well as 50x50x5mm angles branded as "VSL Xsuper 345" has been used in this study. Properties of the steel reinforcements and angle have been shown in the Table 2.

Table 2. Properties of steel elements of retrofitted RC columns

Properties	10mm φ Rebar	8mm φ Rebar	Angle
Yield stress (MPa)	409	576	449
Yield strain (mm/mm)	0.00204	0.00288	0.00224
Ultimate stress (MPa)	556	647	624
Ultimate strain (mm/mm)	0.19	0.02	0.19

d) Ferrocement Wire mesh: (50mm x 75mm) opening wire with 0.8mm diameter has been used as ferrocement wire mesh for retrofitting. Properties of wire mesh have been shown in table 3.

Table 3. Properties of wire mesh

Gauge	**Dia (mm)**	**Cross sectional area (mm^2)**	**Wire mesh type**	**Mesh opening (mm^2)**	**Yield strength (Mpa)**	**Ultimate strength (Mpa)**
20	0.86	0.581	Woven square	(8.5 × 12.5)	401	448

e) Concrete mix design: The main focus during mix design was to make a relatively low strength concrete. Locally available materials have been used to make the concrete mix. Properties of all materials are given in the previous section. Relation between water/cement ratio and average compressive strength of concrete was established in ACI 211.1-91. Based on ACI recommendations a trial mix was designed with a selected water/cement ratio and slump test was performed. The aggregates were sieved and put into saturated surface dry condition overnight.

Selected Cement: Fine Aggregate: Coarse Aggregate Content (by volume) – 1:2:3

Trial Mix w/c ratio: 0.69 by weight.

The cement was weighed and the water was carefully added in the mixer. Slump test was performed on the mixed concrete. The obtained result from the slump test was 7 inches. The trail mixed concrete was then placed in a cylinder and the cylinder was tested after 28 days. The concrete compressive strength was found to be 1.5ksi, which is acceptable for our specimens.

Figure 2. Trial Mix Slump test being performed

2.2 Preparation of Test Specimens and strengthening

Six half scale RC columns measuring 150x150x1500mm have been constructed. Among them, five columns have been retrofitted by using wire mesh of (3x2) opening per inch and of 20 gage wire were used. In addition, angle plate (50mm x 50mm x 5mm) and shear key also has been used. Wire mesh layers have been bonded with the sides of RC column with cement mortar. Each mortar layer was of approximately 19mm. In order to improve the corner additional wire mesh and angle were used at corner of few columns. In order to avoid local shear failure strength of top (150mm) and bottom (150mm) of column were much greater than that of the middle portion. 10mm diameter longitudinal reinforcement along with 8mm diameter ties at an interval of 150mm has been embedded in RC core. After 28 days of curing, bodies of hardened columns, except C1 have been chipped off to get uneven surface. Ferrocement wire mesh were attached in round throughout the column specimen with each specified before in Table 4. Cement mortar is used as a binding material between RC column surface and wire mesh layer. Details of the column retrofitting technique using ferrocement wire meshes have been described in Table 4 and 5 and illustrated in figure 3.

Table 4. Model Specimen Configurations after Retrofitting

Column Designation	Cross Section Dimension (mm)	Height (mm)	Reinforcement details		Retrofitting Details	
			Longi-tudinal Bar	Stirrup	Wire Mesh configuration	No of wire mesh layer
C1	152 x 152	1524	4 No. #10 mm	#8 mm tie bar @150 mm c/c	None	None
C2	190 x 190	1524			(8.5mm x 12.5mm) opening with 0.8mm diameter wire	Single Layer & at corner double layer
C3	190 x 190	1524				Single Layer
C4	190 x 190	1524				Double Layer
C5	190 x 190	1524				Double Layer & shear key
C6	190 x 190	1524				Single layer with (50mm× 50mm×5mm) angle plate at corner

Table 5. Model Specimen Configurations Before Retrofitting

Column Designation	Cross Section Dimension (mm^2)	Height (mm)	Reinforcement Details		Percentage of Reinforcement ρ%
			Longitudinal Bar	Stirrup	
C1	152 × 152	1524	4 No. #10 mm	#8 mm tie bar @ 150 mm c/c	1.20%
C2	152 × 152	1524			
C3	152 × 152	1524			
C4	152 × 152	1524			
C5	152 × 152	1524			
C6	152 × 152	1524			

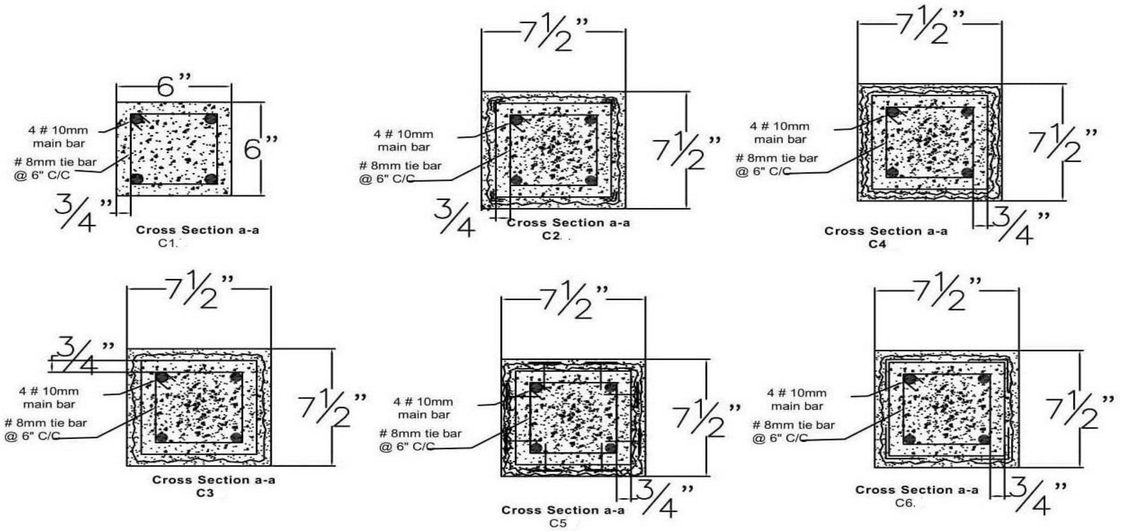

Figure 3. All Column Cross sections accumulated

2.3 Test Set Up

The test was carried in the Universal Testing Machine located at the Structural Materials Laboratory (SM LAB) of Civil Engineering Department, BUET. The specimens were placed of capacity 2000kN between the upper cross-head and the fixed cross head. Specimens were loaded at a rate of 3 mm/min and the load displacement data were recorded by a careful data-acquisition software. Data recorded by the machine included time, load and the position of the machine head which was used to find the deflection. Moreover, the load at which crack appeared and the width of the crack were also recorded.


Figure 4. TINIUS OLSEN MACHINE and RC column set up

3 Experimental Results and Discussions

a) Load Capacity, effect of corner improvement and deflection: Reference Column (C1) was tested to find its ultimate axial load carrying capacity. From the test result we found that the capacity of this column is 294 KN. The 1st crack was appeared at 136 KN. The ductility of this column was poor. It shows brittle in nature. From the test result we found that the capacity of the column C3 is 325 KN. The 1st crack was appeared at 186 KN. The capacity of the C2 column is 511 KN. The 1st crack was appeared at 206 KN. The column was more ductile since it's shown more deflection before ultimate failure. The capacity of the column C4 is 498 KN. The 1st crack was appeared at 202 KN. The ductility of this column is relatively higher. Column C5 was retrofitted with Using double wire mesh layer with shear key @ 6"c/c in longitudinal direction and @3" c/c in horizontal distance between two shear key. From the test result we found that the capacity of this column is 450 KN. The 1st crack was appeared at 198 KN. The column is more ductile and it deflect more before failure took place. The capacity of the column C6 is 580 KN. The 1st crack was appeared at 286 KN. From the graph, we can see that, the highest load bearing capacity is for column with single wire mesh layer and angle plate at corner. Its load bearing capacity is 580 KN which is 98% higher than reference column. Angle at the corner of single wire mesh layer is the reason for resisting higher load. The increased magnitudes of loading are obtained as 11%, 53%, 70% and 74% for C3, C5, C2 and C4 respectively. From the table 6, we can see that column with double wire mesh layer have the highest axial deflection of 15.3 mm at ultimate load bearing capacity. Reference column has a deflection of 8.6 mm. So column with double wire mesh layer has a 78% higher deflection than reference column. The increased magnitudes of deflection are obtained as 25%, 42%, and 9% for C2, C4 and C6 respectively. Only Column with single wire mesh layer has a negative increment of 23% having a value of 6.6 mm. It is due to the load may have experienced this column was subjected to some eccentricity.

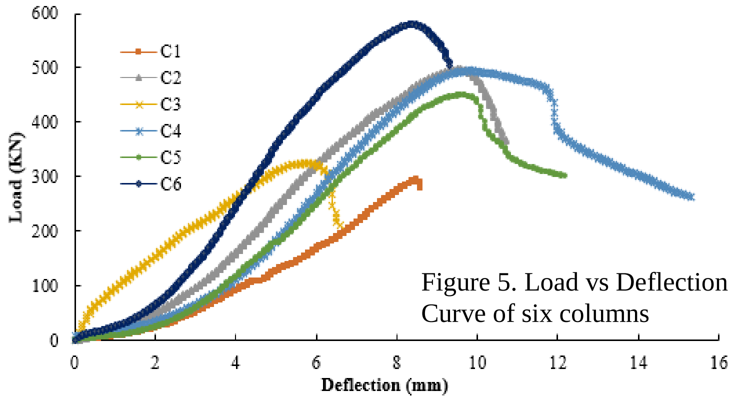

Figure 5. Load vs Deflection Curve of six columns

Table 6. Axial deflection of each column and their increment

Column Designation	Axial Deflection (mm)	% Increment of axial deflection
C1	8.6	0
C2	10.7	25
C3	6.6	-23
C4	15.3	78
C5	12.2	42
C6	9.3	9

b) Effect of shear key: Core Column is very weak in its capacity. Different kind of retrofitting have performed in order to increase its capacity using ferrocement wire mesh as well as added shear key to the column. From the Figure 6, we can see that the capacity of core column is 294 KN and column with double wire mesh layer is 511 KN. The capacity of column with improving corner using double wire mesh with including shear key in all face is 450 KN.

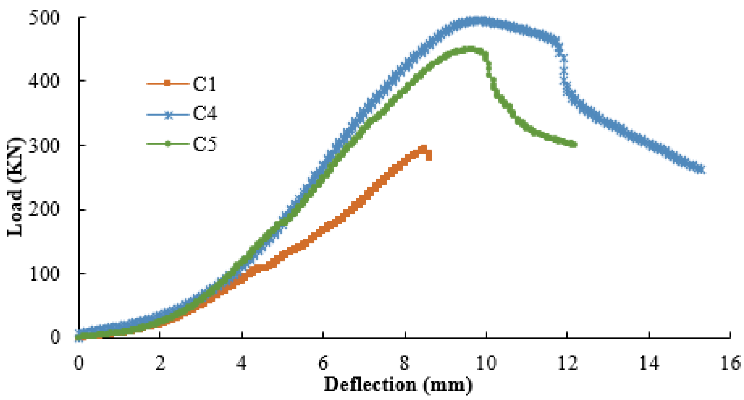

Figure 6. Load vs Deflection Curve of column C1, C4 & C5

c) Major failure pattern: The axial shortening increased in a linear manner till failure would occur in the column. In order to distribute the load uniformly to the column jute fiber was used in top and bottom of every column. Overall summary of failure patterns is listed below with maximum crack width.

Table 7. Summary of failure pattern and maximum crack width

Column	Major Failure Pattern	Max Crack Width (mm)	First Cracking Load (KN)
C1	Shear failure	0.9	136
C2	Shear failure	1.5	206
C3	Shear failure	1.0	186
C4	Compression failure	2.1	202
C5	Compression failure	1.7	198
C6	Shear failure	0.8	286

C1	C2	C3	C4	C5	C6

Figure 7. Failure pattern of six columns

Conclusion

This paper presents a brief overview on the axial capacity of the ferrocement jacketed RC column. Double layers' column capacity is 58% greater than single layer capacity. column with double wire mesh layer has increased its ductility up to 78% with compare to the reference column. Corner improvement using wire mesh, increases capacity up to 53% & developed more ductility. Corner improvement with steel angle increase the capacity up to around two times comparing with reference column. It was observed that failures for the columns retrofitted with shear keys were mainly governed by compression failure. Hence, the ferrocement confined RC columns have shown improved ductility at failure as compared to the unconfined RC column.

References

Desai, J.A. (2011), Corrosion and Ferrocement, Proceedings of the National Conference on Ferrocement, FS 2011, 13-14 May 2011, Pune, India,pp.45-52.

Prem Pal, Dr. Manik Kumar, Dr. S.K. Kaushik, "Effect of Wire Mesh Orientation on Strength of Beams Retrofitted using Ferrocement Jackets.", IJE, Vol-2, Issue-1, pp-9.

BNBC: Bangladesh National Building Code‖, an acronym for Bangladesh National Building Code, Volume 2, Part 6, Structural Design", chapter 12, Ferrocement structures", pp. 6-703 to 6-711, 2015.

Wu, Y. F., Liu, T., and Oehlers, D. J. (2006). "Fundamental Principles that Govern Retrofitting of Reinforced Concrete Columns by Steel and FRP Jacketing", Advances in Structural Engineering, 9(4), 507–533.

Reinhorn, A.M. and Prawel, S.P.Seismic retrofit of structural masonry using a ferrocement overlay", Proceedings of the Third North American Masonry Conference, 1985.

Belal, M.F., Mohamed, H.M., and Morad, H.A., (2015), "Behavior of Reinforced Concrete Columns Strengthened by Steel Jacket", HBRC Journal, 11, 201-212.

A.B.M.A. Kaish, M. Jamil (2015), "An approach to improve conventional square ferrocement jacket for strengthening application of short square RC column", Materials and Structures, DOI 10.1617/s11527.

M. Salih & C. Arunkumar (2016), "Strenghtening of Reinforced Concrete Column using Jacketing Technique", ICEIS-2016.