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Behavior and Strength of Concrete Cylinders Confined by Reinforced Concrete Jacket and Ferro Cement Overlay

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***Abstract*-** Nowadays economy, serviceability, feasibility, time parameter, access to site, sustainability and extension of existing structure are prime concerns for the construction of any structure. So as to make these variables agrreeable, retrofitting or strengthening of existing structures draw interests of civil engineers and researchers everywhere throughout the world. Retrofitting is the modification of existing structures and/or structurally deficient members to make them more resistant to deflection and increased load and seismic activity by using the confinement effect of reinforced concrete, FRP, CFRP, ferrocement overlay, steel plate, etc. In this paper an attempt has been made to study the behavior and strength of concrete cylinders confined by the reinforced concrete jacket and ferrocement overlay. 45 concrete cylinders were cast and categorized into 4 groups. The first group of 9 specimens was confined with reinforced concrete confinement, second and third group of 9 specimens were retrofitted with one and two layers of ferrocement overlay respectively. No retrofitting techniques were applied to the remaining 18 specimens, categorized as fourth group. All cylinders were tested under axial compressive load. From the experimental investigation, it was found that between the two strengthening techniques, reinforced concrete confinement showed the higher capacity increase and one layer ferrocement overlay confinement showed the lower capacity increase with respect to the axial capacity of plain concrete (control) cylinders. The load-deflection responses of the strengthened specimens were also observed, which represent the ductility of confined cylinders over plain concrete cylinders and the failure mode after applying concentric axial loads was also investigated.

***Keywords*-** *Retrofitting; Concrete Jacketing; Ferrocement Overlay*

I. INTRODUCTION

Reinforced concrete is the commonly used material for the construction of structures which are designed in accordance to the specifications given in the standard codes to meet the service life [1][2]. During the service life if the loading conditions change due to purpose of use of the structure, this can result in non-performance of the structural elements for which it was designed earlier [3]. 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 [4][5]. 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 [6]. To restore the required strength of the deteriorated, defective, distressed structure, retrofitting is the solution [7]. Among all the retrofitting techniques, jacketing construction is the most preferred method of retrofitting that can be applied by confinement with reinforced concrete, FRP, CRP, ferrocement, external steel caging [8]. In comparison to the above, retrofitting with reinforced concrete and ferrocement confinement are the oldest and cost effective techniques used to strengthen the concrete structures [9]. Reinforced concrete (RC) jacketing is a strengthening technique most frequently used in seismic retrofitting [10]. From several investigations, it has been found that ferrocement is also an ideal material for retrofitting of structures because it improves crack resistance combined with high toughness, the ability to be cast into any shape, rapid construction with no heavy machinery, small additional weight, imposed and low cost of construction [11]. The objectives of this investigation are: to study the effect of concrete encasement and ferrocement overlay on the strength of plain concrete cylinders, compare the increase in strength gained by ferrocement and concrete confinement, to study the load-deflection response of concrete and ferrocement encasement on the strength of concrete cylinders and to investigate the failure modes under concentric loading [12][13].

II. METHODOLOGY

In order to investigate the retrofitting techniques a number of 45 plain concrete cylinders with three different compressive strength (f'_c) of 2,4 and 6 ksi, referred to as Control Cylinders, were cast and categorized into 4 groups. The first group of 9 specimens was strengthened with reinforced concrete confinement, second and third group of 9 specimens were retrofitted with one and two layers of ferrocement overlay respectively. No retrofitting techniques were applied to the remaining 18 specimens, categorized as fourth group.

A. Materials

AR 40 type cement of the brand “Seven Rings”, a mixture of 50% local sand (FM=1.5) and 50% of Sylhet sand (FM=2.6) as fine aggregate, Brick chips (absorption capacity=11.3%) of nominal size of 19 mm as coarse aggregate, and Mild Steel (yield strength, fy=72.5 ksi,8 mm diameter) as reinforcement and a 18 gauge woven wire-mesh with 0.5 inch openings was used for ferrocement.

B. Casting of Pure Concrete Cylinders (Control Specimen)

Plain concrete cylinders were cast in molds of inner diameter of 4 inches and a height of 8 inches. To achieve three different compressive strength of 2, 3 and 4 ksi, three different water cement ratios,obatined from following equation, recommended by ACI 211.1-91 was used [14][15].

$$\frac{w}{c} = 1.1734e^{-.0259f'c} \quad (1)$$

Where, w = weight of water to be used (kg)

C= weight of cement to be used (kg)

f'_c = required average compressive strength with sufficient increase in compressive strength (Mpa)

The slump values of 0.5 inch, 5 inch and 3.5 inch were used for compressive strength 2, 3 and 4 ksi respectively. No admixture was used for the casting of specimens. After casting all the specimens were properly cured for 28 days.

Figure 1. Casting of Control Specimens

C. Retrofitting:

1) Reinforced Concrete Confinement

The control concrete cylinders were provided with the reinforced concrete confinement of thickness 2 inches in which the additional concrete mix that was poured outside the control cylinders had f’c of 4 ksi, resulting in a total diameter of 8 inches and height of 8 inches. The cross and long section along with reinforcement are shown in Figure II. An overlapping of 2.5 inch for ties was used for ensuring proper confinement .

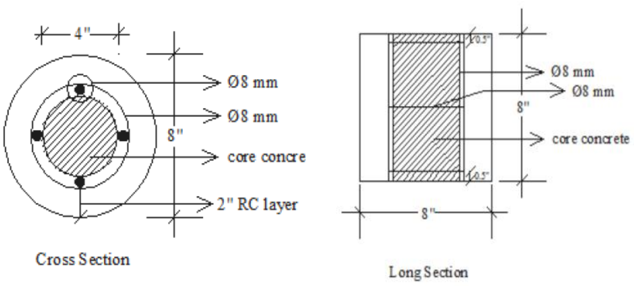

Figure 2. Detailing of the Section (Retrofitted by RC jacketing) [13].

The detailed procedure for preparing RC strengthened cylinder specimens is shown in Figure 3.

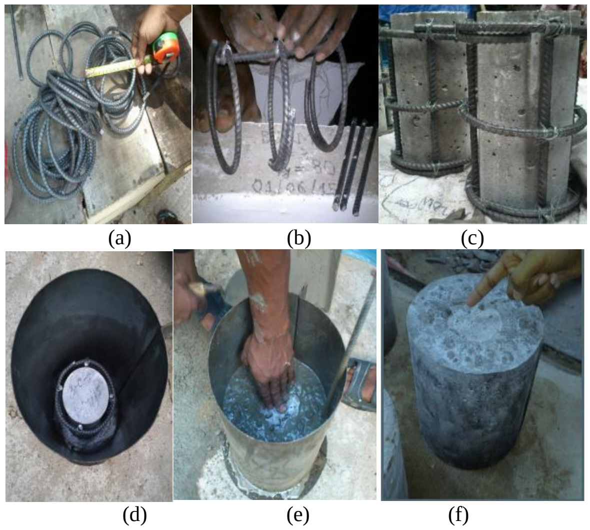

Figure 3. Preparation of Specimens for concrete confinement (a) Check for diameter of ties; (b)caging; (c) Encasement of plain concrete, (d) Plain concrete-reinforcement arrangement placement; (e) Pouring of concrete mix(f'_c=4ksi); (f) Resulting Strengthened Cylinder

2) Ferrocement Overlay (One and Two Layers)

18 gauge woven wire-meshes with 0.5 inch openings was employed as the reinforcing steel in case of ferrocemnt overlay. Cement ,sand mortar of ratio 1:3 and water-cement ratio of 0.4 was used.

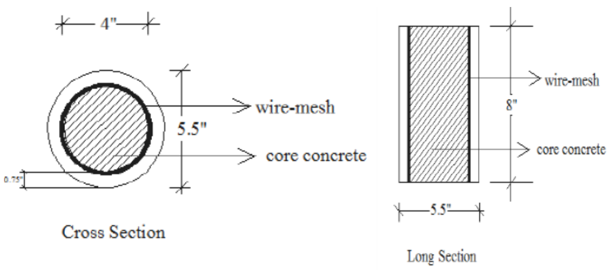

Figure 4. Detailing of the Section (Confined by one layer of ferrocement overlay) [10].

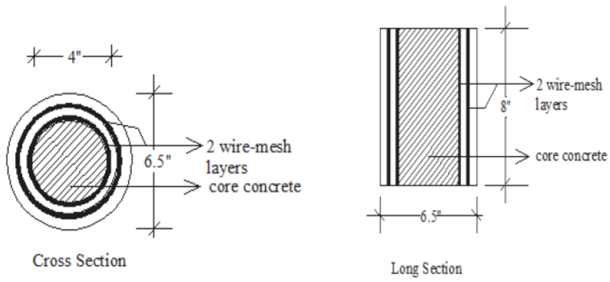

Figure 5. Detailing of the Section (Retrofitted by two layers of ferrocement overlay) [16].

The detailed procedure of providing with ferrocement overlay is shown in Figure 11. In case of Two layer ferrocement overlay**,** another ferrocement overlay of thickness 0.5 inch was applied onto the surface of one layer ferrocement overlaid specimen resulting in a total diameter of 6.5 inch approximately.

(a) (b) (c) (d)

Figure 6. Application of ferrocement overlay(a), (b) wrapping of wire-mesh; (d)drenching with cement suspension; (c) plastering; (e) finishing of specimens.

a) Experimental Setup:

TABLE I. SPECIMEN DESIGNATIONS AND THEIR DESCRIPTIONS [17].

Specimen Designation	Description
B2-1, B2-2, B2-3, B2-4, B2-5, B4-1, B4-2 , B4-3 , B4-4 , B4- 5, B4-6, B6-1, B6-2 , B6-3 , B6-4 , B6- 5, B6-6	Control concrete cylinders of dimension 4 inches diameter, 8 inches height. No confinement was applied.
C4B2-1, C4B2-2, C4B2-3, C4B4-1, C4B4-3, C4B4-3, C4B6-1, C4B6-2, C4B6-3	Concrete confinement with 2 inches thickness. 4-Ø8mm long. bars of fy= 500 Mpa.
F1B2-1, F1B2-2, F1B2-3, F1B4-1, F1B4-2, F1B4-3, F1B6-1, F1B6-2, F1B6-3,	Strengthened by one layer ferrocement overlay. (wire-mesh of openings of 0.5 inch)
F2B2-1, F2B2-2, F2B2-3, F2B4-1, F2B4-2, F2B4-3, F2B6-1, F2B6-2, F2B6-3,	Strengthened by two layer ferrocement overlay (wire-mesh of openings of 0.5 inch)

"F2B3-2", "F" and "B" stand for ferrocement and control concrete cylinders respectively. The digits after F stands for layers of ferrocement overlay and the digits after B indicate the concrete compressive strength and the number at the end of the designations indicates the number of one of the three similar specimens. In the designations of specimens confined with reinforced concrete jacketing such as C4B2-1, designates the specimen in the same manner as in case of ferrocement overlay except the "C" represents the reinforced concrete jacketing and the digit after it is the f'c of additional concrete mix out side the control cylinders.

b) Testing Machines

Control cylinders were tested using Digital Universal Compression testing machine of capacity 3000KN. Strengthened Cylinders were tested with analogous Universal Compression testing machine of capacity 3000KN. Universal Testing Machine of Tenious Olsen brand was used to obtain the ductile behavior of control and strengthened specimens.

c) Testing Procedures

After employing geotextile pads at the top and bottom of retrofitted specimens and aligning vertically and horizontally, concentric load was applied in a moderate rate until cracks occurred on cylinders.

III. RESULTS

TABLE II. TEST RESULTS OF SPECIMENS PROVIDED WITH REINFORCED CONCRETE CONFINEMENT

Designation	Max. Load (KN)	Avg. Max. Load (KN)	Load carried by plain Concrete (KN)	% Increase	Modes of Failure
C2B2-1	317	379	103	268	Shear Crack
C2B2-2	440				Spalling of Outer portion
C2B4-1	528	520	232	124	Shear Crack
C2B4-2	512				
C2B6-1	530	546	335	63	Splitting
C2B6-1	561				Shear Crack

TABLE III. TEST RESULTS OF SPECIMENS PROVIDED WITH ONE LAYER OF FERROCEMENT OVERLAY

Designation	Max. Load carried (KN)	Avg. Load (KN)	Load Carried by plain concrete (KN)	% Increase	Failure Modes
F1B2-1	154	147	103	44	Shear Crack
F1B2-2	168				
F1B2-3	118				
F1B4-1	247	227	232	12	Splitting
F1B4-2	273				Shear Crack
F1B4-3	160				Splitting
F1B6-1	261	231	335	0	Shear Crack
F1B6-2	246				Splitting
F1B6-3	187				

TABLE IV. TEST RESULTS OF SPECIMENS PROVIDED WITHTWO LAYERS OF FERROCEMENT OVERLAY

Designation	Max. Load (KN)	Avg. Load (KN)	Load Carried by plain concrete (KN)	% Increase	Failure Modes
F2B2-1	261	284	103	171	Shear Crack
F2B2-2	297				
F2B2-3	295				
F2B4-1	369	352	232	59	Splitting
F2B4-2	369				Shear Crack
F2B4-3	318				Splitting
F2B6-1	464	460	335	38	Shear Crack
F2B6-2	458				Splitting
F2B6-3	457				Splitting

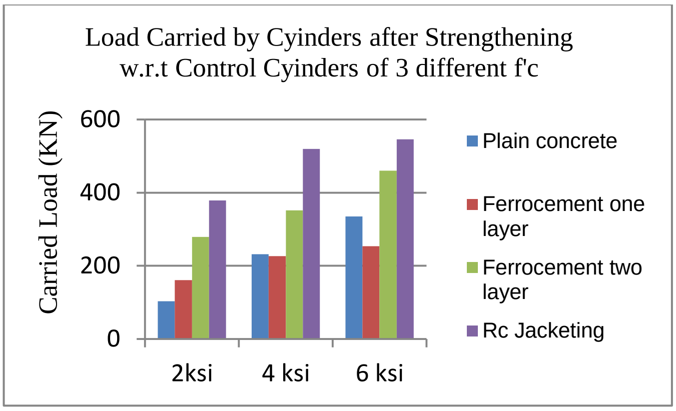

Figure 7. Comparison among the strengthened specimens after applying two different retrofitting techniques

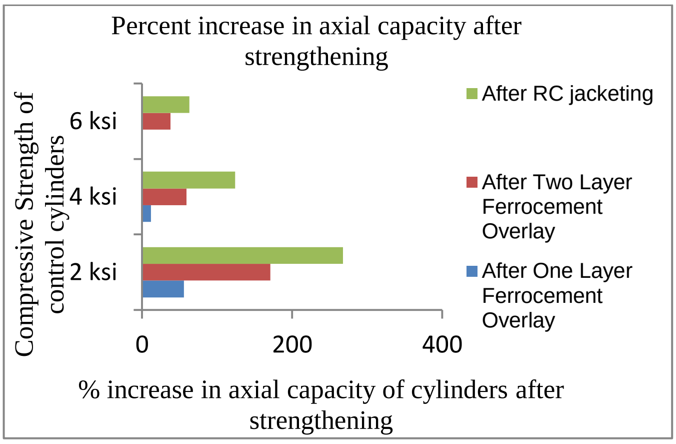

Figure 8. % increase in axial capacity

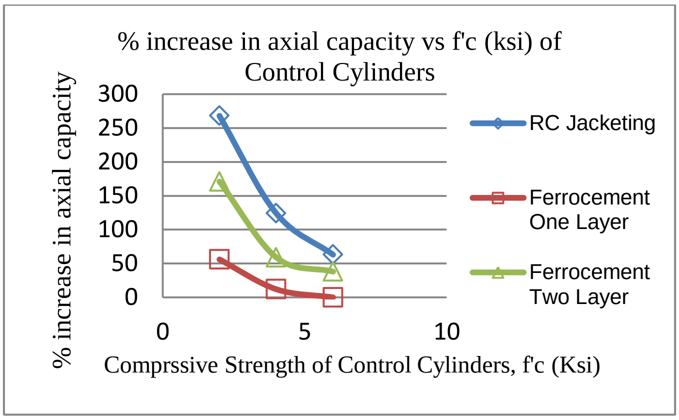

Figure 9. A trend to decrease in the capacity increase (%) with the increase of compressive strength of control specimens

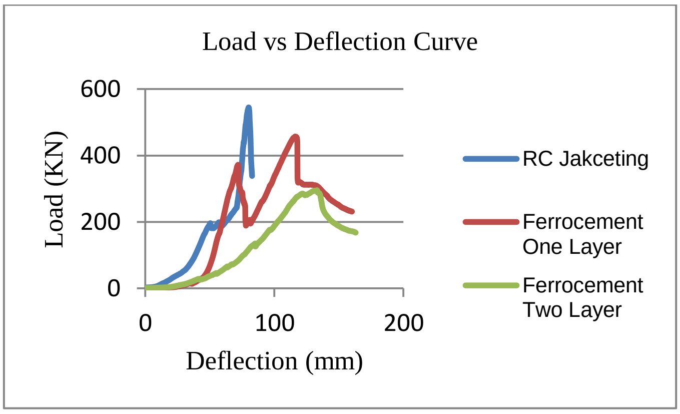

Figure 10. Typical Load vs Deflection Response

a) Modes of Failure:

(a) (b) (c)

Figure 11. (a) Shear Failure of Control Cylinder; (b)Shear Failure of RC Jacketed cylinder; (c) Spalling and Shear Failure of Ferrocement Strengthened Cylinder

IV. CONCLUSION

Within the limited scope of the investigation, it can be concluded that, all the confined cylinders exhibited a significant increase in axial capacity ,but a higher level of axial capacity increase (maximum 268%) has been achieved by using reinforced concrete jacketing. This was may be due to the contribution of reinforcing steel and additional outer concrete portion and confinement from transverse steel to the axial capacity of the cylinder.Also, a significant increase in axial capacity has been achieved by using two layers of ferrocement overlay, but it is less than that of RC jacketing.There is a trend to decrease in the percentage capacity increase with the increase of compressive strength of control specimens in the case of both RC jacketing and ferrocement overlay.The load-deflection responses represented greater ductility of RC jacketed cylinders and most of the strengthened cylinders exhibited shear (cone) failure.

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