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Strengthening of Reinforced Concrete Column via Ferrocement Jacketing

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ABSTRACT

This work focuses on behaviors of reinforced concrete (RC) column encased by longitudinal steel and ferro cement under static axially loading. RC column specimens are encased by vertical steel reinforcements, wrapped by varying amount of wire mesh and then covered with cement mortar. The results show significantly improvement of strength and ductility of strengthened column over reference column without strengthening. Ductility is also significantly improved by the increase of the volume of wire mesh. ACI equation for prediction of strength of short axially loaded RC column can be applied to predict strength of both reference and strengthened column.

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1. Introduction

Structural building components in aged RC buildings need to be investigated and maintenances due to the deteriorations of concrete with time. Deterioration of concrete can be accelerated by aggressive environment and low quality of concrete as can be seen in Figure 1a. Low quality of concrete leads to high porosity which moisture can penetrate to concrete pore result in corrosion of steel in concrete. Spalling of concrete cover caused by rust from corrosion process has higher volume than original steel for about 4 times. Corrosion rates of steel increase rapidly with time if repair action is not performed. Reduction of concrete and steel area cause load

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carrying capacity of structural elements to decrease. Not only structural deterioration but also the need of changing functional use of building may cause increasing service load of building components.

(a) Corrosion of steel in concrete (b) Repair by nonshrink mortar and strengthening by steel jacketing

Figure1: Degradation of RC column and column strengthening.

RC column can be classified as the most important component of the building super structure since load from slabs and beams are both transferred to columns. Total collapse of RC building may occur due to change of service load and lack of column strength caused by deterioration. Repair and strengthening to increase load carrying capacity of column can be performed by distill degraded concrete, patch by nonshrink mortar and then strengthened by steel jacketing (Figure 1b) or encased by additional RC. Ferro cement jacketing is one of the alternate method of repair and strengthening of column which is low cost and easy to apply to existing column, as do-it-yourself (DIY). As describe above, behaviors of columns strengthened by additional steel reinforcement and encased by Ferro cement under static loading are studied in this work.

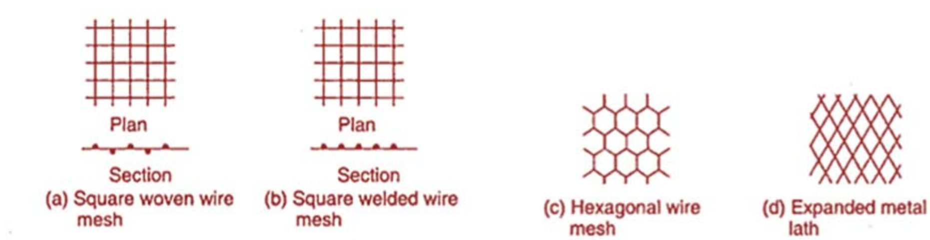

Figure 2: Example of steel wire mesh (Paul, 2013).

2. Ferrocement

ACI Committee 549, 1997 state that “Ferrocement is a type of thin wall RC, commonly constructed of hydraulic cement mortar, reinforced with closely spaced layers of continuous and relatively small size wire mesh (see Figure 2). The mesh may be made of metallic or other suitable materials.”

Advantages of ferrocement are high ductility, reduce number of cracks and crack width, high deformation capacity, improve impact resistance and toughness, good fire resistance, low permeability, low cost of maintenance and high strength to weight ratio.

3. Review of Literature

Ferrocement has great uses and applications (Naaman, 2000). There are many research on strengthening structural members by ferrocement.

Flexural analysis and behavior of ferrocement beam was studied by Balaguru et al. (1977). The study was able to predict ultimate flexural capacity and deflections and crack widths ferrocement beams under loading. The study also observed the load-deflection curves, crack distribution, and crack widths for ferrocement beams up to ultimate. From test measurement of stress-strain curves for mortar in compression (including the descending portion) and steel meshes in tension, an analytical model was developed to generate the nonlinear moment-curvature and load-deflection curves of ferrocement beams.

Moment capacity and cracking behavior of ferrocement beam in flexure was studied by Logan and Shaw (1973). Results of tests on ferro-cement beams was presented with data on initial cracking, crack widths and ultimate strength. Ferrocement beams were compared with conventionally reinforced concrete beam.

Strengthening of RC beams with ferrocement laminates was studied by (Paramasivam et al., 1998). The test can be observed on the effects of the level of damage of original beams prior to repair, and repeated loading on the performance of the strengthened beams. The study found that ferrocement is a practical method to strengthening and rehabilitation of reinforced concrete structures.

Flexural behavior of reinforced concrete beams with ferrocement thin plates reinforced with steel wire mesh was experiment by Shang et al. (2003). The test comprised 13 RC beams strengthened by steel wire mesh and 2 specimens without strengthening for comparison. The strengthening results of reinforced with three side (U shaped ferrocement put onto the tension face

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and two profile faces) and one side ferrocement had been analyzed. The study observed the performance of the tested beams, the modes of failure. Also, the test measured mid span deflection, crack width and strains of steel and wire mesh. The ferrocement can obviously increase the load bearing capacity and crack resisting capacity, and improve the bending stiffness of beam.

Many researches and discussions are about testing beams with ferrocement, but there are little researches on testing columns with ferrocement. Thus, this work will show behaviors of RC columns strengthened by ferrocement.

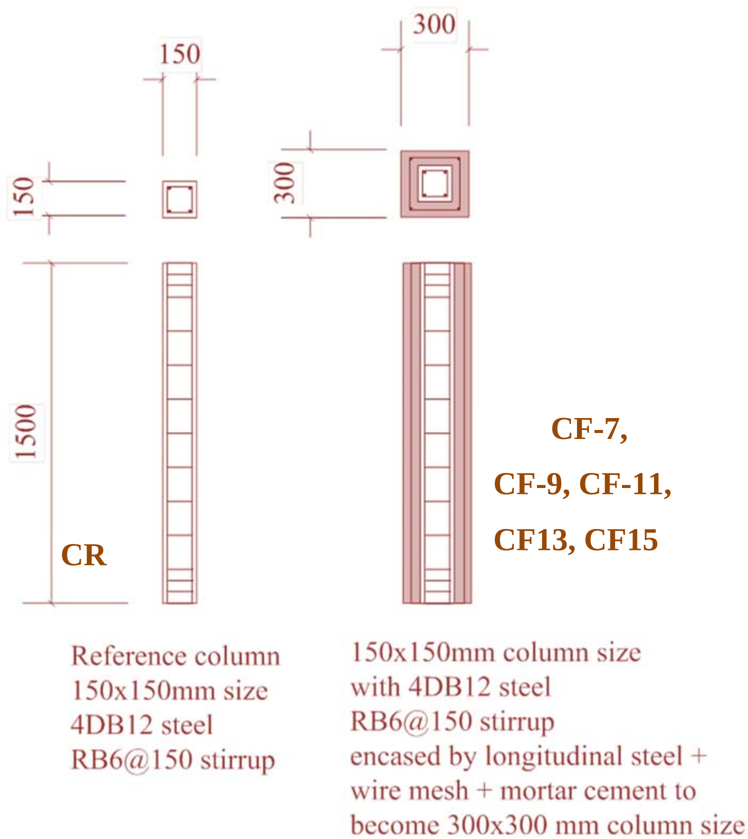

Figure 3: Details of test specimens.

4. Experimental Studies

This experiment has six tested columns, one being referenced specimen (CR) and five being tested columns encased by ferrocement (CF-7, CF-9, CF-11, CF-13, and CF-15). Referenced specimen CR is a 150x150x1500mm-size column reinforced by 4DB12mm longitudinal steels and RB6mm with stirrup spacing 150mm. All five columns strengthening with ferrocement ((CF-7, CF-9, CF-11, CF-13, and CF-15) have the same core column and reinforcement details as the referenced specimen CR. These columns are strengthened by additional longitudinal 4DB12mm steels, and wrapped by square welded wire mesh, and put with cement mortar in order have cross-sectional dimensions 300x300mm. The dimensions of all RC column specimen and reinforcement details are shown in Figure 3. The numbers 7, 9, 11, 13 and 15 refer to number of wrapping rounds of wire mesh around the existing column. Details of all test specimens are given Table 1.

Ordinary Portland cement is used both in mixing of mortar and concrete. Water to cement ratio (w/c) of mortar cement used in this work is 0.5. The average compressive strength of mortar from test is 21.7MPa. Average concrete strength and yield strength of steel from test are 11.5Mpa and 327.1MPa respectively.

Test set up of column specimens can be readily seen by the diagram shown in Figure 5. Load is applied to column statically or gradually increased by hydraulic jack. Load, strain and deformation of column can be captured by data logger and transfer to computer.

Table1: Details of reference and strengthened specimens.

Specimen name	Internal steel	External steel	No. of wire mesh round
CR	4 DB12	-	-
CF-7	4 DB12	4 DB12	7
CF-9	4 DB12	4 DB12	9
CF-11	4 DB12	4 DB12	11
CF-13	4 DB12	4 DB12	13
CF-15	4 DB12	4 DB12	15
Size of strengthened specimen		300x300mm	
Size of reference specimen		150x150mm	

Figure 4: Wrapping of wire mesh before applying mortar cement.

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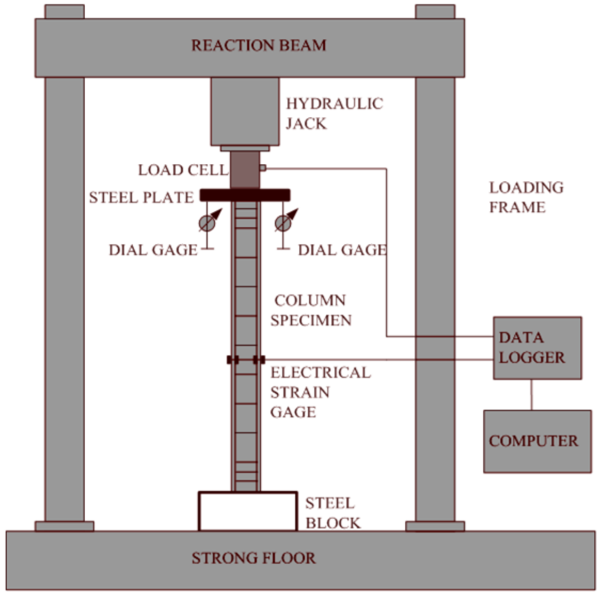

Figure 5: Test set up of column specimen.

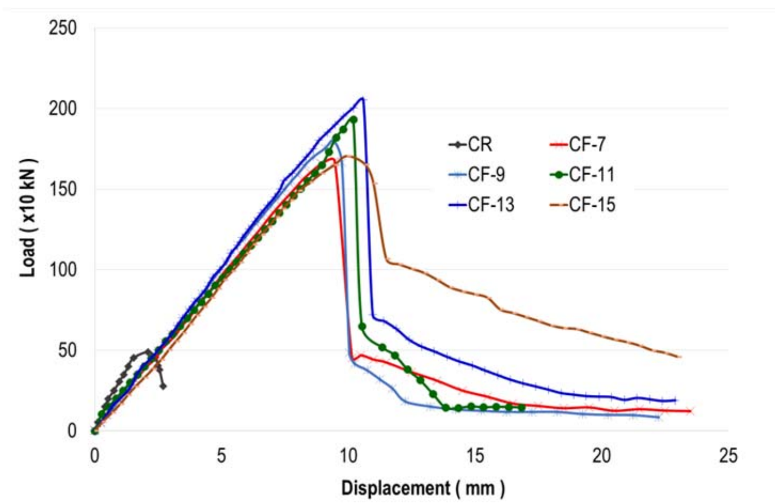

Figure 6: Relationship of load and displacement of test specimen.

5. Results and Discussion

Relationships of compressive load and displacement (contraction) of all test columns are given in Figure 6. It can be observed that significant improvement of static strength and ductility of all strengthened specimens over reference specimen CR. This is due to the additional area of column section both ferrocement and reinforcing steels. The deformation capacity prior to failure which indicates the ductility of column depends on the number of wrapping rounds of wire mesh. The result shows optimum number of wrapping round of wire mesh is 13 (specimen CF-13). Increasing of ductility is caused by the efficient confinement of wire mesh and mortar cement composite.

It can be said that ferrocement is equivalent to RC but its advantage is higher ductility due to the confinement of wire mesh composite with mortar cement. The prediction of nominal compressive load of column should be used the modified ACI equation as shown by Equation (1).

$$P_n = 0.85 f_c' A_c + A_s f_y + 0.85 f_{cf}' A_{cf} + A_{sf} f_y \quad (1)$$

where

P_n = Nominal loading capacity of column

f_c' =Concrete compressive strength

f_{cf}' = Compressive strength of cement mortar

f_y = Yield strength of steel

A_c = Gross area of concrete

A_{cf} = Area of cement mortar

A_{sf} = Area of additional steel

Nominal load carrying capacities of all test columns comparing to load prediction Equation (1) are exhibited in Figure 7. It can be seen that equation (1) can be applied to predict maximum nominal load carrying capacity both RC column and RC column strengthened by additional reinforcement and ferrocement.

Typical failure mode of reference column and strengthened column can be observed in Figure 8. It can be noticed that concrete core is prevented by ferrocement lead to increase of column ductility (*see* Figure 6).

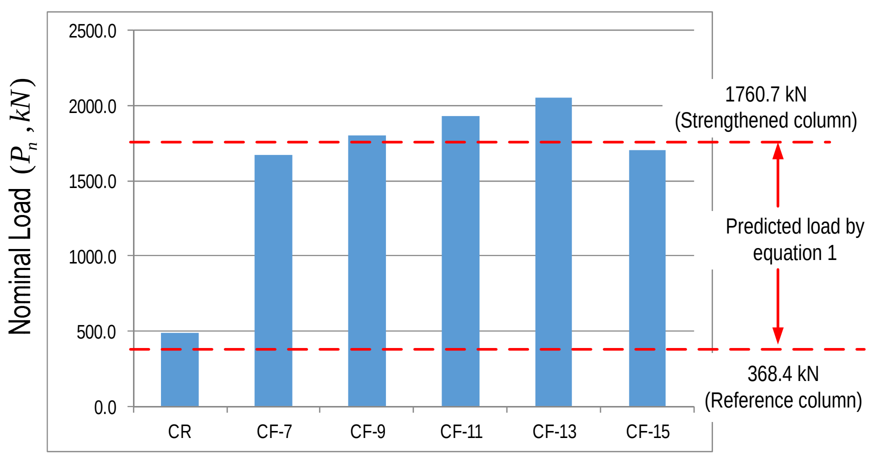

Figure 7: Nominal load (strength) of test specimens compared to load predictions Equation (1) (dotted line).

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Figure 8: Failure mode of test columns.

6. Conclusions

Behaviors under concentrically static loading of RC column strengthened by additional reinforcement and ferrocement are studied. The following conclusions can be made.

1) Strength of RC column can be significantly improved by additional steel and ferrocement.

2) Modified ACI equation can be used to predict static strength of both RC column and RC column strengthened by additional steel and ferrocement.

3) Concrete core can be prevented by ferrocement leading to high ductility of strengthened column.

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