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Repair and Rehabilitation of RC Short Square Columns using Improved Ferrocement Jacketing

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Abstract: Strength of columns is an important factor which determines the performance of reinforced concrete framed structures subjected to various types of loads. Hence repair and strengthening of weak/damaged columns using various jacket schemes is attracting much attention. Due to its efficient cost-performance ratio, ferrocement jacketing is becoming an attractive option of retro fitting. Rehabilitation efficiency of improved jacketing scheme was studied and for this purpose, fully damaged as well as partially damaged columns were chosen.

Keywords: *Ferrocement, rehabilitation, square, short columns*

1. Introduction

Reinforced concrete (RC) structures often suffer damages due to overloading, natural disasters (like earthquake, tsunami, cyclone, flood, etc.), fire, various environmental effects (like corrosion), change in building usage, etc., before reaching their intended design life. These damages may cause failure of structural elements. If proper attention is not paid in this regard, entire structure could fail to carry its design load and catastrophe could happen. Failure of the most authoritative structural element such as column may lead to total collapse of a frame-structured building as it is the only structural element that conveys the total vertical loads of the building to the ground.

This member could lose its strength and stiffness due to damages occurring in its service life. Therefore repair or reconstruction is necessary in case of noticeable crack, so that they can carry loads and transmit them to the ground. One of the state-of-the-art methods used to carry structural loads by partially damaged column is the restrengthening of the column. Replacement of structurally weak concrete, fiber-wrap technique and external jacketing are normally used to restrengthen the RC columns according to their application. Replacement of structurally weak concrete requires removal of deteriorated concrete and casting of new concrete in the same place. Restrengthening of RC column using external jacketing is based on the well-established fact that the lateral confinement of concrete core substantially enhances its compressive strength and ultimate axial strain.

In developing countries ferrocement jacketing can be an effective restrengthening tool for RC columns as its raw materials are readily available. Application of this jacketing to RC column is very easy and needs no skilled labour.

Due to uniform distribution of reinforcement, it has many improved engineering properties such as tensile and flexural strengths, toughness, fracture and crack control, fatigue resistance and impact resistance. Low material cost, special fire and corrosion protection features makes it an ideal means of jacketing. Studies have shown that ductility of ferrocement jacketed column is higher than that of FRP (Fibre Reinforced Polymer) confined column. In circular RC column subjected to axial compression, the concrete core is uniformly confined by the external jacketing and the behaviour of such uniformly confined concrete core with different confining materials has been studied extensively. Among all jacketing techniques used to restrengthen square RC column, square jacketing is the most time saving and a low cost solution. Square jacketing provides confinement pressure only at the corners, thus only a portion of the cross section gets effective confinement. [9]

Some of the investigations have been carried out to reduce the stress concentration at the corners using FRP restrengthening technique in square RC columns. Jacketing with rounded column corner gives certain degrees of confinement by reducing stress concentration at corners of the square RC column [9]. This type of jacketing could be a representative of improving strength of existing substandard column and improving load carrying capacity of previously cast column that requires vertical extension of existing structure and for other anticipated phenomena.

2. Experimental Programme

The following sections deals with the details of the experimental programme used in this study.

2.1. Preliminary Investigation

The preliminary experimental investigation consists of test on constituent materials and mix proportioning. Cement used in all mixes was Portland Pozzolana Cement conforming to IS specification [4]. Commercially available M-Sand passing through 4.75 mm sieve was used as fine aggregate. The physical properties of M-Sand was tested as per IS specifications [5]. Specific gravity and fineness modulus of M-Sand used were 2.46 and 2.9 respectively. The size of crushed aggregate used in this test was 12.5 mm and below. The properties of fine and coarse aggregate conformed to the IS specification [6]. Specific gravity of the coarse aggregate used was 2.74. Potable drinking water available in the college water supply system was used for casting as well for curing of the test specimens. HYSD bars of 8 mm and 6 mmdiameters of yield strength 420 N/mm^2 and 486 N/mm^2 respectively were used for the study. The woven wire mesh used for ferrocement jacketing was of 0.6 mm diameter and yield strength 374 N/mm^2. The design of M_{30} mix was done as per IS specification [7]. The properties of all ingredients of concrete were determined and mix proportion was arrived at. After mix design and trial mixes, optimum mix was found as 1:1.41:2.65 with a w/c ratio of 0.44. It yielded a 28 day compressive strength of 43 N/mm^2. The specimens for the study were prepared with optimum mix and cured for 28 days. The mix for ferrocement jacketing used was in the ratio 1:2 by weight of cement and river sand respectively with water-cement ratio of 0.45. The 28 day compressive strength of the same was 43 N/mm^2.

2.1.1. Design and detailing of specimens

The dimensions of the square column specimens used for the test was of 140 mm x 140 mm sides and 1.2 m height. The dimensions and reinforcement details of the specimen are shown in Figure 1.

2.1.2. Casting and testing of specimens

RCC concrete columns of square cross section were prepared with M_{30} mix. After curing of the column specimens, first set of square columns were modified by rounding their corners to approximately 20 mm radius and strengthened using ferrocement jacketing (SAJ) and second set of columns were strengthened using conventional ferrocement jacketing (SCJ) and the third set of column specimens were subjected to axial compressive loading so that complete failure was observed and the corresponding ultimate load was recorded. The remaining square columns were loaded to 80%, 60% and 40% of this ultimate load. Cover spalling was observed for fully damaged specimens only and these damaged portions were repaired using concrete of appropriate grade and properly cured for 7 days. These fully and partially damaged columns were then rehabilitated using improved ferrocement jacketing technique.The columns were strengthened with ferrocement jacket as detailed in Table 1. Control column specimens (SC) and all the jacketed specimens were tested under axial load. Figure 2 shows the schematic diagram of the test setup. The axial displacements were noted at each load step till failure of the specimens. From the load-deformation plot, displacement ductility, axial stiffness and energy absorption capacity were calculated. The failure modes of the specimens were also observed. The properties of the control, improved jacketed and rehabilitated specimens were compared and the test results are as shown in Table 2.

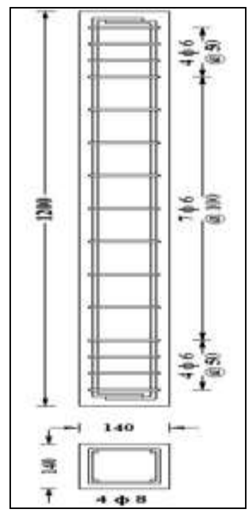

Figure 1 *Reinforcement detailing of column specimens*

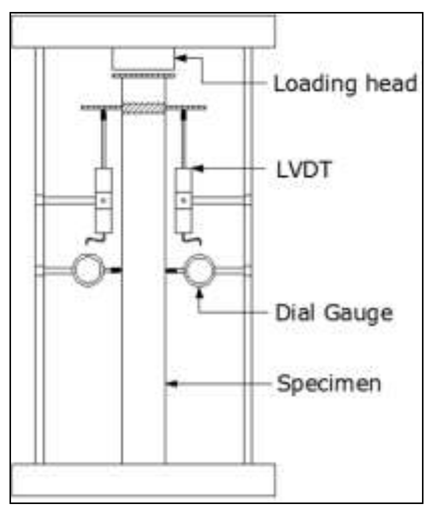

Figure 2*Experimental test setup*

Table 1: *Specimen details and designation*

Specimen designation	Details	
SC	Square column specimen without jacketing	Control
SCJ	Conventionally jacketed square column specimens	Retrofitted
SAJ	Square improved jacketed specimens with 20mm radius rounded corners	
R - 40	Rehabilitation of specimen loaded to 40% of ultimate load	Rehabilitated
R - 60	Rehabilitation of control specimen loaded to 60% of ultimate load	
R - 80	Rehabilitation of control specimen loaded to 80% of ultimate load	
R- 100	Rehabilitation of control specimen loaded to 100% of ultimate load	

3. Results and Discussions

3.1. Load- displacement behavior

The improved jacketed specimens (SAJ) were found to have better load carrying capacity compared to the conventional jacketed specimens (SCJ) which is mainly due to the better confinement offered by rounding of corners.

The load- axial displacement curves for comparing the performance of rehabilitated specimens with that of control specimens are as shown in Figure 3. Fully damaged columns on rehabilitation with improved ferrocement jacketing technique showed ultimate load and deflection comparable to that of control specimens. In other words, the damaged columns regained their original load- deflection behaviour due to the effective confinement offered by the ferrocement jacketing. Partially damaged columns on rehabilitation showed higher values of ultimate load and displacement when compared to that of control specimens. This is clear significance of the fact that rehabilitating the partially damaged column specimens not only helps in regaining the initial strength, but also to improve the load-deflection response.

3.2. Energy Absorption Capacity

Energy absorption capacity is calculated as the area under the load- deflection plot up to the ultimate load. It can be observed that an increase in energy absorption was observed for all the retrofitted specimens when compared to the control specimen who is mainly due to the fact that the provision of jackets delayed the failure of specimens by a considerable margin compared to the control specimens, which resulted in better energy absorbing capacity.

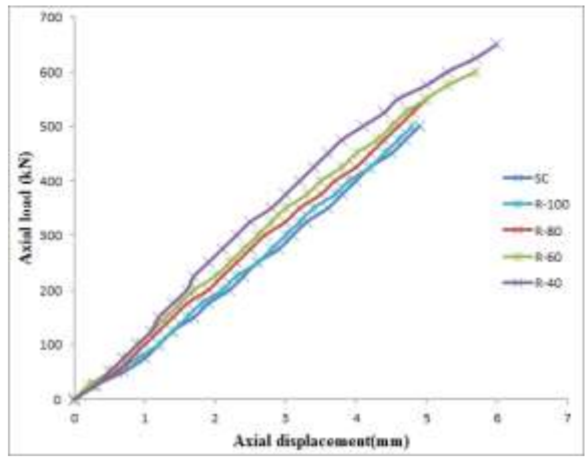

Figure 3 *Load - axial displacement graph for control and rehabilitated specimens*

The fully damaged control specimens on rehabilitation regained its actual energy dissipation capacity signifying the effectiveness of the jacketing scheme. It was also found that as the intensity of damage imparted was increased, their respective energy dissipation capacities decreased proportionally. Among the rehabilitated specimens, R-40 specimens in which only 40% of the ultimate load was applied as preload had performance comparable to that of SAJ. This signifies that the columns under service loads benefits the most and shows superior performance compared to the columns which had already undergone significant damage and repaired using the same jacketing scheme.

3.3. Axial Stiffness

It was found that after jacketing the fully as well as partially damaged specimens, the initial axial deflection was reduced which resulted in an improvement in axial stiffness of these specimens. It was also found that the axial stiffness varies inversely with the pre-loading intensity. The increase in axial stiffness is a crucial factor which helps in lowering the deflection at yield which in turn has direct effect on the ductile behavior of the specimens.

Table 2: *Results of tested specimens*

Specimen designation	Ultimate Load (kN)	Energy Absorption Capacity (kN)	Axial Stiffness (kN/mm)	Displacement ductility
SC	500	1178	111.1	1.09
SCJ	650	2310	142.8	1.74
SAJ	725	2850	147.8	2.20
R - 40	650	2148	142.8	1.50
R - 60	600	1817	125.0	1.43
R - 80	550	1333	117.6	1.25
R- 100	500	1140	113.6	1.07

3.4. Displacement Ductility

Displacement ductility factor is defined as the ratio of the displacement at ultimate load to the displacement at yield load. The ductility factor of jacketed specimens was found to be more than that of corresponding control specimens. The ductility factor for improved jacketed specimens (SAJ) was more than that of conventional jacketed specimens (SCJ). This is due to the stiffer behavior which leads to a lower value of yield displacement and improved confinement which leads to a higher value of ultimate displacement in the case of improved jacketed specimens.

From the results it was seen that repairing the damaged control columns using the proposed jacketing scheme either improved or helped in regaining the initial ductile response of the control columns. This can be attributed to the fact that the provision of jackets improved the stiffness of the damaged control columns, thereby reducing the yield displacement. It was also found that the presence of jacketing prevented the abrupt failure of the damaged columns thereby showing an improvement in ultimate displacement. Both these factors summed up to provide better ductile response for the rehabilitated specimens compared to that of the control specimens.

3.5. Crack Patterns and Failure Modes

It was observed that the fully as well as partially damaged column specimens after jacketing showed ductile mode of failure unlike the control specimens (Fig.4). So it can be seen that repairing the damaged columns using the proposed jacketing scheme was very effective in delaying the onset of failure and prevented the columns from acatastrophic mode of failure which was found in the control specimens. Fig.5 shows the failure modes of rehabilitated specimens.

4. Conclusions

i. Rounding of column corners prior to jacketing resulted in an improved jacketing scheme which considerably better performance had compared to that of the conventional square jacketed specimens.

ii. The fully damaged control specimens regained its original strength and stiffness after being rehabilitated with advanced jacketing scheme.

iii. As the magnitude of damage induced decreased, the rehabilitated specimens showed performance comparable to that of the retrofitted specimens.

iv. Rehabilitation of square columns using advanced ferrocement jacketing scheme is most benefited by the columns under service loads compared to those which had already undergone significant damage.

Figure 4 *Failure patterns of control and retrofitted specimens*

Figure 5 *Failure patterns of rehabilitated specimens*

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