# *Strengthening 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 jacketing schemes is attracting much attention. Due to its efficient cost-performance ratio, ferrocement jacketing is becoming an attractive option of retrofitting. For retrofitting square short columns, conventional square jacketing is most widely adopted but it results in excessive stress concentration and hence improved jacketing technique with rounded column corners need to be implemented. In this study, the ultimate load carrying capacities were experimentally determined and hence the efficiency of confinement offered by square conventional and advanced jacketing schemes were compared. In some cases providing jacketing throughout the length of the column is uneconomical and not completely necessary from performance point of view. By observing the failure patterns of control column specimens, five different partial jacketing schemes were adopted in which only selected areas of the columns were jacketed. Out of this, the schemes that were effective both in terms of performance as well as economy were redeemed as suitable alternative to full jacketing scheme.***

***Keywords*— short; square; column; ferrocement; jacket**

## I. 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.

## II.EXPERIMENTAL PROGRAMME

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

### *A. 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 mm diameters 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 $N/mm^2$.

### *B. 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 Fig.1.

### *C. Casting and Testing of Specimens*

RCC concrete columns of square cross section were prepared with $M_{30}$ mix. After curing of the column specimens, some of the square columns were modified by rounding their corners to approximately 20 mm radius. The columns were strengthened with ferrocement jacket in different patterns as detailed in Table I. Control specimens and the jacketed specimens were tested under axial load. Fig.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. Partial jacketing technique was also applied on the modified columns and compared with the results of fully jacketed modified columns. The properties of the control and strengthened specimens were compared.

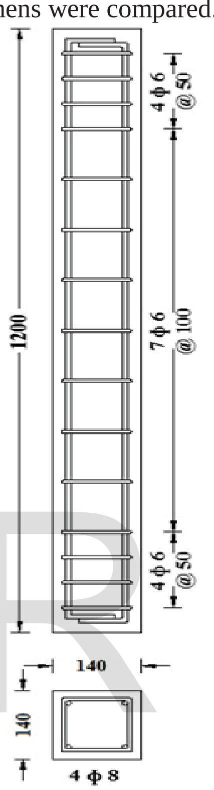


Fig. 1. Reinforcement detailing of column specimens

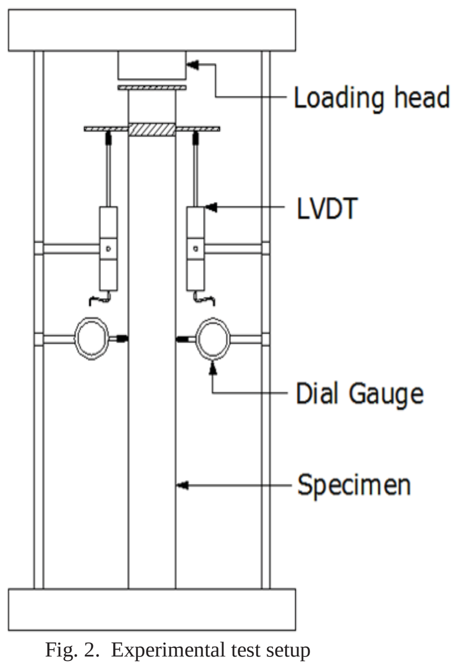


Fig. 2. Experimental test setup

TABLE I. SPECIMEN DETAILS AND DESIGNATION

| Specimen Designation | Details | Dimension (mm) |
|---|---|---|
| SC | Square control | 140 x 140 |
| SCJ | Square conventional jacketed | 140 x 140 |
| SAJ | Square advanced Jacketed | 20mm radius rounded corners throughout |
| E-30 | Jacket only on top and bottom 1/4th distance | Corner rounding only where jacketing is applied |
| C-30 | Jacket only on middle 1/4th distance | Corner rounding only where jacketing is applied |
| E-40 | Jacket only on top and bottom 1/3rd distance | Corner rounding only where jacketing is applied |
| C-40 | Jacket only on middle 1/3rd distance | Corner rounding only where jacketing is applied |
| C-60 | Jacket only on middle 1/2 distance | Corner rounding only where jacketing is applied |

## III.RESULTS AND DISCUSSIONS

The test results of control specimens, fully jacketed specimens as well as partially jacketed specimens are presented and compared in terms of load-displacement graphs, energy absorption capacity, axial stiffness, displacement ductility factor and failure modes. The observations made during the course of the test are briefly described in the following sections. The test results are summarized in Table 2.

### *A. Load-Displacement Behaviour*

The load- displacement behavior of the column specimens are shown in Fig 3. From the load-displacement curves it can be seen that the jacketed specimens SCJ, SAJ, E-30 and E-40 have better load carrying capacity compared to the respective control specimens. This is mainly due to the confinement provided by the tight winding of the wire mesh and high strength of the mortar used in ferrocement jackets. The advanced 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.

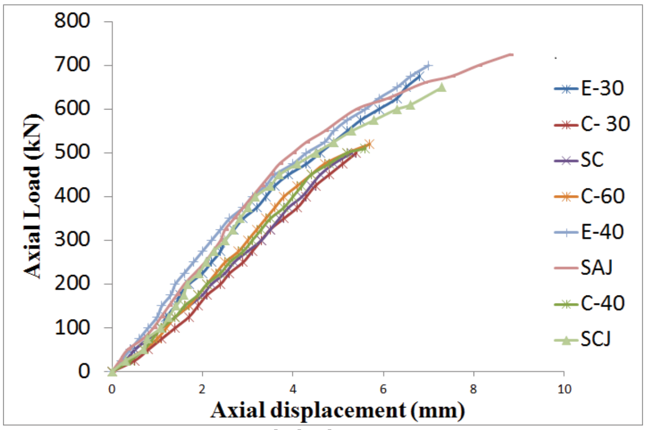


Fig. 3. Load- displacement curve

It was also found that the load carrying capacity of end jacketed specimens i.e., E-30 and E-40 was comparable with that of fully jacketed specimens (SAJ). But the load carrying capacity of centrally jacketed specimens i.e., C-30, C-40 and C-60 was not satisfactory.

### *B. 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 fully jacketed specimens when compared to the respective control specimens which 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. The energy absorption capacity of the partially jacketed specimens is a clear significance of the fact that strengthening the columns at their potential failure zones alone helps a great deal in improving the same and is comparable to that of fully jacketed specimens. It was also found that jacketing the central portion of the column alone, did not show any significant improvement in its energy absorption capacity when compared to the control specimens.

### *C. Axial Stiffness*

From the load-deflection curve it can be seen that, the jacketed specimens have higher slope during the initial phases of loading which signifies better axial stiffness for the same. 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. For the partial jacketing schemes, it was observed that the end jacketed specimens had better axial stiffness compared to the centrally jacketed ones. This may be due to the fact that the former had regions undergoing maximum deflection effectively confined thereby preventing excessive deflections of the specimens at earlier stages of loading.

TABLE II. TEST RESULTS OF COLUMN SPECIMENS

| *Column* **Designation** | *Ultimate Load (kN)* | *Gain* | *Energy Absorption Capacity (kNmm)* | *Gain* | *Axial Stiffness* **(kN/mm)** | *Gain* | *Displacement ductility factor* | *Gain* |
|---|---|---|---|---|---|---|---|---|
| SC | 500 | 1 | 1178 | 1 | 111.1 | 1 | 1.09 | 1 |
| SCJ | 650 | 1.3 | 2310 | 1.96 | 142.85 | 1.28 | 1.74 | 1.59 |
| SAJ | 725 | 1.45 | 2850 | 2.42 | 147.8 | 1.33 | 2.2 | 2.02 |
| E30 | 675 | 1.35 | 2493 | 2.12 | 118 | 1.06 | 1.57 | 1.44 |
| E40 | 700 | 1.40 | 2583 | 2.19 | 125 | 1.13 | 1.67 | 1.53 |
| C30 | 500 | 1 | 1285 | 1.09 | 100 | 0.9 | 1.15 | 1.06 |
| C40 | 510 | 1.02 | 1510 | 1.28 | 100 | 0.9 | 1.22 | 1.12 |
| C60 | 520 | 1.04 | 1588 | 1.35 | 111.1 | 1 | 1.29 | 1.19 |

### *D. 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 advanced 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 advanced jacketed specimens. From the results of the partially jacketed specimens, it was observed that the end jacketed specimens offered better ductile response compared to that of the centrally jacketed specimens. The end jacketed specimens had lower values of yield displacement and higher values of ultimate displacement which in turn played a major role in improving the axial stiffness of the same. When it comes to centrally jacketed specimens, the critical portions were not jacketed and hence the displacement at yield was comparable to that of control specimens. It was also found that the failure in these specimens occurred at the non-jacketed regions making the ultimate displacement of these specimens close to that of control specimens. As a result no noticeable improvement in the displacement ductility factors was observed for these specimens.

### *E. Failure Modes*

The major drawback of SCJ specimens is that they have stress concentration towards the corners. This was substantiated by the failure patterns of the same in which the specimens failed by crack formation at corners and eventually the mortar cover in that region fell off, followed by breakage of wire mesh. The major objective of SAJ specimens were to reduce the stress concentration at corners and the failure patters showed that the cracks occurred only on the centre of the faces. Due to effective confinement offered throughout the cross section, the mortar cover did not fall off from any portion of the jacket. When it comes to the partially jacketed specimens, it was seen that the end jacketed specimens (E-30, E-40) failed by cracking of the jacketed portions alone. In other words, the portions devoid of jacketing remained intact even after the occurrence of failure. This clearly signifies that jacketing the critical regions alone is sufficient to enhance the behavior of the control columns under extreme loading conditions. The added advantage is that the provision of the partial jacketed schemes is highly economical due to the savings in raw materials as well as labour. In the centrally jacketed specimens (C-30, C-40, C-60), the critical regions of failure were left unjacketed. Hence the failure of these specimens was analogous to that of control specimens. Though the jacketed specimens remain intact in these positions, there was no significant improvement in the failure mode i.e. the failure was sudden and catastrophic, similar to that of the control specimens. Fig. 4, Fig. 5 and Fig. 6 shows the failure patterns of the control, fully jacketed and partially jacketed specimens respectively.


Fig. 4. Failure patterns of square control specimen


Fig. 6. Failure patterns of partially jacketed specimens


Fig. 5. Failure patterns of fully jacketed specimens



## IV. CONCLUSIONS

- Ultimate load carrying capacity for advanced jacketed square columns improved by 1.45 times compared to that of control specimens whereas the improvement was only 1.30 times for conventionally jacketed specimens
- Compared to the control specimens, the energy absorption capacity for advanced jacketed specimens were improved by 145% but for conventionally jacketed specimens, the improvement was only 95%
- A slight improvement in axial stiffness was noticed for advanced jacketed specimens when compared to conventionally jacketed specimens
- Displacement ductility factor for advanced jacketed specimens improved by 102% compared to control specimens but for conventionally jacketed specimens, the improvement was only 60%
- Failure of conventionally jacketed specimens caused due to spalling of concrete from the corners, signifying stress concentration at corners
- Failure of advanced jacketed specimens was by crack formation at the center of faces, signifying absence of stress concentration at the corners
- The end jacketed specimens had ultimate load, axial stiffness, energy absorption capacity and displacement ductility comparable to that of advanced jacketed specimens whereas the performance of centrally jacketed specimens did not show any significant improvement when compared to that of control specimens
- In the end jacketed specimens, the ones which had jackets extending up to one-third of the column length from both ends was found to have slightly better performance when compared to those having jackets extending up to one-fourth of column length, which signified improvement in performance of the specimens by a slight margin with increase in length of jacketing
- Failure of end jacketed specimens was by formation of cracks in the jacketed portion, when the unjacketed portions remained intact
- Failure of centrally jacketed specimens was analogous to that of control specimens, i.e., failure occured at the top and bottom unjacketed portions and the jacketed portions remained intact

## References

[1] Campione, G., Colajanni, P., La Mendola, L., and Spinella, N. (2007), "Ductility of reinforced concrete members externally wrapped with fiber-reinforced polymer sheets", Journal of Composites for Construction, Vol. 11, No .3, pp. 279-290.

[2] Chaallal, O., Shahawy, M., and Hassan, M. (2003), "Performance of axially loaded short rectangular columns strengthened with carbon fiber-reinforced polymer wrapping", Journal of Composites for Construction, Vol. 7, No. 3, pp. 200-208.

[3] Hwang, S. K., and Yun, H. D. (2004), "Effects of transverse reinforcement on flexural behaviour of high-strength concrete columns", Engineering structures, Vol. 26, No. 1, pp. 1-12.

[4] IS 1489 (Part I):1991, Portland Pozzolana Cement Specification (Third Revision)

[5] IS 2386 (Part IV):1963, Methods of Test for Aggregates for Concrete.

[6] IS 383(Part III):1970, Specification for Coarse and Fine Aggregates from Natural Sources for Concrete. (Second Revision).

[7] IS 10262 : 2009, Concrete Mix Proportioning – Guidelines (First revision)

[8] Jirawattanasomkul, T., Dawei, Z., and Ueda, T. (2013), "Prediction of the post-peak behavior of reinforced concrete columns with and without FRP-jacketing", Engineering Structures, Vol. 56, pp. 1511-1526.

[9] Kaish, A. B. M. A., Alam, M. R., Jamil, M., Zain, M. F. M., and Wahed, M. A. (2012), "Improved ferrocement jacketing for restrengthening of square RC short column", Construction and Building Materials, Vol. 36, pp. 228-237.

[10] Kazemi, M. T., and Morshed, R. (2005), "Seismic shear strengthening of R/C columns with ferrocement jacket", Cement and Concrete Composites, Vol. 27, No.7, pp. 834-842.

11. Kumutha, R., Vaidyanathan, R., and Palanichamy, M. S. (2007), "Behaviour of reinforced concrete rectangular columns strengthened using GFRP", Cement and concrete composites, Vol. 29, No. 8, pp. 609-615.

12. Li, B., Lam, E. S. S., Wu, B., and Wang, Y. Y. (2013), "Experimental investigation on reinforced concrete interior beam–column joints rehabilitated by ferrocement jackets", Engineering Structures, Vol. 56, pp. 897-909.

13. Mirmiran, A., Shahawy, M., Samaan, M., Echary, H. E., Mastrapa, J. C., and Pico, O. (1998), "Effect of column parameters on FRP-confined concrete", Journal of Composites for Construction, Vol. 4, pp.175-185.

14. Mourad, S. M., and Shannag, M. J. (2012), "Repair and strengthening of reinforced concrete square columns using ferrocement jackets", Cement and Concrete Composites, Vol. 34, No. 2, pp. 288-294.

15. Promis, G., Ferrier, E., and Hamelin, P. (2009), "Effect of external FRP retrofitting on reinforced concrete short columns for seismic strengthening", Composite structures, Vol. 88, No. 3, pp. 367-379.

16. Takiguchi, K., and Abdullah (2003), "An investigation into the behavior and strength of reinforced concrete columns strengthened with ferrocement jackets", Cement and Concrete Composites, Vol. 25, No. 2, pp. 233-242.

17. Teng, J.G., Chen, J.F., Smith, S.T., and Lam, L. (2002) "FRP strengthened RC structures". West Sussex (UK): Wiley