

RETROFITTING OF R.C SQUARE COLUMNS BY MICRO-CONCRETING AND CFRP CONFINEMENT- AN EXPERIMENTAL STUDY

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Abstract- There is different techniques to increase existing column capacities; however, such techniques differ in their advantages and disadvantages. In this research work, it is intended to study the effectiveness of an alternative technique involving micro-concreting (around square specimen to obtain circular) for increasing existing column capacity without much increase in section dimensions under axial compressive load using 200 T compression testing machine. The objectives of this research are to understand the behavior of R.C square, R.C square micro-concreted to circular (SMC) & R.C integral circular specimens subjected to axial compression & to compare the effect of CFRP confinement on the above three types of column specimens by means of an experimental investigation. Totally, 16 short reinforced concrete column specimens, 10 unconfined and 6 confined, subjected to axial compressive loading were considered for the experimental study. Here SMC represents specimens obtained using modified method of retrofitting the square columns by micro concreting. It is confirmed that confinement by CFRP is an effective method of retrofitting for enhancement of ultimate load carrying capacity & ductility of column and concluded that the degree of enhancement of ultimate axial load carrying capacity due to CFRP confinement of SMC specimens & integral circular specimens is more than that of similar confinement of R.C square column specimens. Performance (in terms of ultimate axial load, & ultimate axial strain) of CFRP confined reinforced SMC specimen is better than corresponding R.C square column specimen & is equal to that of equivalent integral circular column specimen.

Index Terms- RC Square column, R.C square micro-concreted to circular (SMC), CFRP, Ductility.

I. INTRODUCTION

Natural disasters such as hurricanes, tornadoes, tsunamis, and earthquakes and accidental impacts can damage or make structures in-deficient in a matter of seconds. On the other hand, saltwater, de-icing chemicals, and freeze-thaw cycles can cause structural deterioration over a longer period of time. The majority of older buildings and bridges were constructed according to older design codes. These structures are vulnerable during extreme events and need to be retrofitted to meet the current codes and standards. Advanced composite materials are generally used in the industrial fields like aerospace, marine and automotive industries due to their excellent engineering

properties such as high strength, high stiffness, high durability, low density, high fatigue endurance, low thermal coefficient, corrosion resistance and good strength-to-weight ratio (Pendhari et al., 2008). Understanding of the CFRP-confining effectiveness in different cross sections of concrete column is essential to the proper strengthening of RC columns through the wrapping of FRP sheets. The use of confinement increases the lateral pressure on the member which results in more ductility and higher load capacity. Confinement is less effective for rectangular and square than circular shape RC columns due to the confining stresses that are transmitted to the concrete at the four corners of the cross-section. This phenomenon is presented in Figure 1.1, where confinement effectiveness is shown as grey shaded area for various column shapes. Confinement effectiveness improves with the increase in the corner radius.

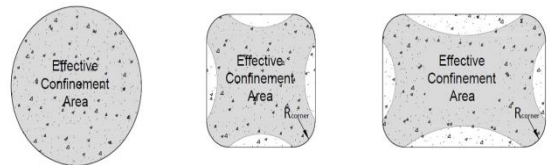


Fig 1.1: Effective confinement areas in circular, square and rectangular columns.

It is seen that even after rounding of the corners of the jacketed square columns the enhanced compressive strength of jacketed square columns is limited compared to the jacketed circular specimens (Stephen Pessiki et al 2001). So a modified technique for effective FRP confinement of square/rectangular columns was used. In this technique, the square columns are modified into circular columns by micro-concreting (without rounding off the columns) such that the diameter of circular column is equal to the diagonal of the original square column, followed by external wrapping with FRP fabric so as to obtain high compressive strength. It was shown that for R.C square concrete column specimens, this technique resulted in ultimate load carrying capacity higher than that of FRP jacketed square columns (with round corners) and nearly equal to that of the FRP jacketed circular specimens of same radius. In the above scheme, as the circular edges replace the straight edges, unconfined concrete area as shown in Fig-1.2 is converted into effective confinement area.

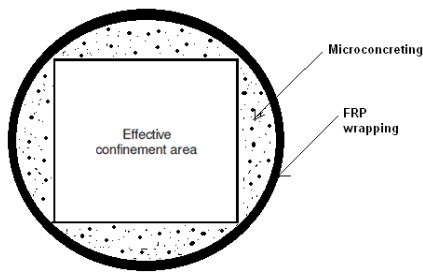


Fig-1.2. CFRP wrapped SMC (Square Micro-concreted to Circular) specimen

Hence there will be uniformity of confinement in modified square sections and hence the concrete area can be effectively utilized in confinement. Effectiveness of the above technique for R.C square specimen is investigated in the present study and such column specimens are termed as SMC (Square Micro-concreted to Circular) specimens.

II. LITERATURE REVIEW

Lei-Ming Wang, Yu-Fei Wu (2008) undertook compressive testing to investigate the effect of corner radius on the strength and ductility of FRP-confined concrete columns. A series of tests on 108 carbon FRP (CFRP) confined short concrete columns of dimensions 150 × 150 mm in cross section and 300 mm in height but with different corner radii were conducted. The primary variables in the investigation were the corner radius, transverse jacket stiffness (thickness of the CFRP), and concrete grade. The compression tests were conducted using a FORNEY testing machine with a maximum load capacity of 2500 kN. The test results demonstrated that the corner radius ratio is in direct proportion to the increase in confined concrete strength. Furthermore, it was revealed and explained that confinement provided by a jacket with sharp corners is insignificant in increasing the strength of columns but significant in increasing the ductility of columns.

Abbas S. Al-Ameeri, et.al. (2013).In this work, the behavior of reinforced concrete columns under biaxial bending is studied. This work aims at studying the repairing of columns by using carbon fiber reinforced polymer (CFRP). The experimental work includes investigation of six reinforced concrete columns (150*150*500mm) tested under several load conditions. Variables considered in the test program include; effect of eccentricity and effect of repairing material (Epoxy and Sika repair). Test results are discussed based on load – lateral deflection behavior and ultimate load. The CFRP reinforcement enhances the behavior of damaged columns. Using of Epoxy material was more significant than effect of the Sika repair material.

Ahmed Shaban Abdel-Hay(2014)This study is carried out to investigate the overall behavior of R.C square columns with poor concrete at upper part, strengthened with CFRP. The wrapped part of column was the upper part only. An experimental program was undertaken testing ten square columns 200 · 200 · 2000 mm. One of them was a control specimen and the other nine specimens were strengthened with CFRP. The main parameters studied in this research were the compressive

strength of the upper part, the height of the upper poor concrete part, and the height of CFRP wrapped part of column. The experimental results including mode of failure, ultimate load, concrete strain, and fiber strains were analyzed. The main conclusion of this research was, partial strengthening of square column using CFRP can be permitted and gives good results of the column carrying capacity.

III. PROPERTIES OF MATERIAL USED IN THE INVESTIGATION

3.1 Cement

The Cement used for casting of the concrete columns was chosen conforming to IS code which is local available. The properties of cement are given in table.1.

Specific gravity	3.1
Initial setting time	70 minutes
Final setting time	430 minutes
Compressive strength	• /mm ²

3.2 Coarse Aggregate:

The coarse aggregate used is crushed stone of 12 mm down size. The laboratory analysis yielded the results of specific gravity and fineness modulus are 2.70 & 2.12 respectively.

• Fine Aggregate:

Fine aggregate used in experimental programme Natural River sand collected from local source. The specific gravity of sand is 2.62. The fineness modulus of sand is 3.52 and its conforming to zone II grading of I.S 10262-1982.

• Micro-Concrete

Micro-concrete is a dry ready mix cementitious based composition formulated for use in repairs of areas where the concrete is damaged & the area is restricted in movement making the placement of conventional concrete difficult. It is supplied as a ready to use dry powder which requires only addition of clean water at site to produce a free flowing non shrink repair micro concrete. Fig 3.1, shows the image of micro-concrete.



Fig 3. 1 Image of Micro-concrete

The properties of which as supplied by manufacture as follows:

Aspect	Grey powder
Water/powder ratio, by weight	0.15
Fresh wet density	2300-2400 kg/m ³
Compressive strength (ASTM C109, 7cm cube)	30 MPa at 1 Day 60 Mpa at 7 Days 75 Mpa at 28 Days
Flexural strength (ASTM C78)	8 MPa at 28 Days
Modulus of elasticity	25 N/mm ²

• **CFRP**

The properties of carbon FRP sheets, as listed in Table.3, were provided by a standard manufacturer and used for wrapping the column specimens. The fabric was unidirectional with non-structural weaves in the secondary direction to hold the fabric together. For each revolution of the FRP sheets, an overlap of 100 mm & 130 mm for square and circular column specimens respectively were used to ensure proper confinement and to avoid de-bonding of CFRP overlaps.

Fibre orientation	Unidirectional
Modulus of elasticity	285 kN/mm ²
Tensile strength	3500 N/mm ²
Density of fibre	1.8 g/cm ³
Ultimate elongation %	1.5
Thickness	0.30 mm

• **Mix Proportions**

Grade of concrete used for casting of columns was M15. By having the properties of cement and aggregates the mix design was carried out to calculate the quantities of materials and water-cement ratio to obtain strength of 23.6 N/mm² (target strength) as per I.S 10262-1982. The mix proportions selected out of trial mixes are given in table 4, corresponding to the average cube compressive strength of concrete at 28 days in the experimental study is equal to 25.6 n/mm.²

• **Description of Test Specimens**

- Unwrapped R.C square specimens, SR0
- R.C square specimen wrapped with 1 layer of CFRP, SR1.
- R.C square specimen wrapped with 2 layers of CFRP, SR2.
- Unwrapped R.C square micro-concreted to circular specimen, SMC0.
- R.C square micro-concreted to circular specimen wrapped with 1 layer of CFRP, SMC1
- R.C square micro-concreted to circular specimen wrapped with 2 layers of CFRP, SMC2.
- Unwrapped Reinforced equivalent circular specimens, CR0.
- Reinforced equivalent circular specimens wrapped with 1 layer of CFRP, CR1.

- Reinforced equivalent circular specimens wrapped with 2 layers of CFRP , CR2.

IV. EXPERIMENTAL PROGRAMME

• **Casting of Specimens and Curing**

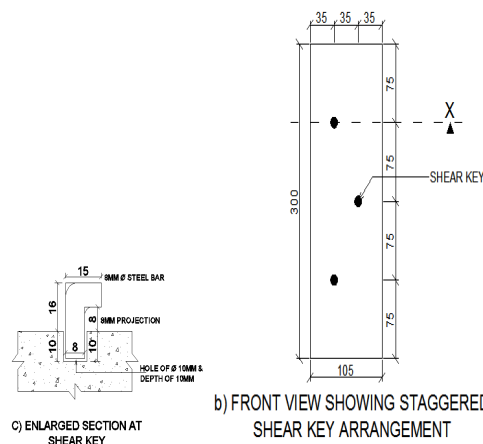
The constituent materials were measured in weighting machine in dry condition and fed into the concrete mixer by adding water content (admixture was mixed in water). The mix was then allowed to rotate for a period of 2 minutes. After ensuring uniform mixing, concrete was dumped and put into moulds. After placing the concrete into moulds, compaction was done thrice by vibrator to eliminate the voids. The specimens were de-moulded, numbered and transferred into fresh water tank for curing period of 28 days.

• **Micro-Concreting**



This was required for SMC specimens

- Surface Preparation For SMC Type Specimens Before Micro-Concreting.



After curing of square columns, appropriate shear keys were provided to bring about integral action between existing concrete and new micro-concrete. 10 mm diameter holes were drilled with the help of drilling machine by keeping staggered spacing equal to 150 mm and are separated by 35 mm horizontally as shown in the Fig-5.1 (a) and (b). For Shear keys mild steel bar of diameter 6 mm is used and bent into L shape, the dimensions of which are as shown in the Fig-5.1(c). Shear keys are anchored into holes by using an anchoring material which consists of two parts, filler and resin. Filler and resins were mixed thoroughly in 4:1 proportion. The grout should be poured steadily into the prepared dust free

holes. The anchor bar is then pressed into the hole to the required depth.

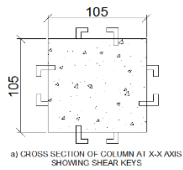


Table 4. Mix Proportions

Materials	Cement (kg/m ³)	Water (lts/m ³)	F.A (kg/m ³)	C.A (kg/m ³)
Quantity	250	145	839	1219
proportion	1	0.58	3.35	4.87

The external surface before applying epoxy bonding material, was hacked to obtain rough surface and was treated with epoxy bonding material for having better bond between old concrete and new micro-concrete then epoxy bonding material was applied as shown in Fig 5.2.



For each batch, 75 Kg of micro-concrete was weighed and placed in tilting drum mixer. The optimum water required for pourable concrete is 3.5 liter per 25 kg of micro-concrete. Water required for 75 kg is 10.5 Kg in which 80 % of water was added initially into the mixer by keeping the mixer running slowly. Process of mixing was continued for 3-4 minutes until a lump free mix is obtained. Remaining water was added while continuing the mixing until the desired consistence is achieved. The mixed micro-concrete was poured into form work until all the gaps were filled up and 3 cubes of 100 mm size were also cast for determination of compressive strength. Formwork was demoulded after 1 day. The specimens were left for curing for 7 days.

V. CFRP WRAPPING

5.3.1 Application of saturant and CFRP sheet.

On the next day, the two-part epoxy saturant was mixed thoroughly in accordance with the manufacturers specifications and a thin layer of it was applied to the surface of the specimen by using flexible Nylon brush as shown in Fig5.3 (a). The CFRP sheet was then carefully wrapped around the specimen with the

fibers oriented in the hoop direction, forming one or two layers of CFRP as show in Fig 5.3 (b).



- **Capping of Test Specimens**

In order to have uniform distribution of applied compressive stress, the end surfaces are made smooth, perfectly perpendicular to the longitudinal axis of the column and this process is called as capping. The capping is done using a cementitious grouting material which has a high compressive strength (55-65 MPa), so that it should not fail before the column.



Fig- 5.2 Capping of Column Specimens

All specimens were mounted in a Compressive Testing Machine of 200 T capacities as shown in Fig-4.15 (a) & (b) and loaded under a monotonic uni-axial compression load upto failure.



Fig 5.3 Under axial compression testing of column specimens

VI. RESULTS AND DISCUSSIONS

The results presented in the form of tables (table 5.1, table 5.2 & table 5.3) & graphical representations (fig 5.1 to fig 5.22) are presented in the following order

- Load deformation behaviour,
 - Axial Stress axial strain behaviour,
 - Failure pattern.
- **Effect Of Confinement Of CFRP On Square R.C Column Specimens**
 - **Load Deformation Behaviour (SR0, SR1, SR2):**

The load deformation variation of SR1 & SR2 column specimens are compared with SR0 specimen in fig5.1. Initially the load-deformation behaviour of all specimens coincide & is linear but deviate later. Though SR1 & SR2 specimens are expected to be slightly stiffer than SR0 specimens, this did not occur in the present experiment study. However, CFRP confinement contributes to appreciable increase in both ultimate load carrying capacity & ultimate axial deformation. During initial stages of loading, the load is carried by concrete and steel upto yielding of concrete and steel, and load is transferred to CFRP which confines the concrete. Because of this confinement of CFRP wrapping on the column, ultimate load carrying capacity of specimens wrapped with 1 & 2 layers of CFRP resist 1.35 times & 1.75 times higher load than that of unwrapped specimen. Ultimate deformation of SR1 & SR2 specimens increased by 1.37 and 2.91 times respectively that of unwrapped specimen, showing that CFRP confinement contributes not only to increase in load carrying capacity but also increases the ductility of specimens

Fig 5.1 Load-deformation behaviour of R.C square column specimens confined with 1 & 2 layers of CFRP

- **Stress Strain Behaviour:**

Fig 5.2 compares the stress strain behaviour of R.C square column specimens wrapped with 1 & 2 layers of CFRP with unwrapped specimen. Stress-strain behaviour of specimens is exactly similar to load deformation behaviour, because of the same area of cross section of all specimens. The ultimate axial stresses of specimen wrapped with 1 & 2 layers are 1.35 times & 1.75 times higher than that of unwrapped specimen. The ultimate axial strain of specimens wrapped with 1 & 2 layers of CFRP are found to be 1.37 times & 2.9 times that of unwrapped specimen, which are same as that of deformation. This shows how the compressive strength & ductility of R.C column specimens are further enhanced by the increase in the degree of confinement.

Fig5.2 Stress-strain behaviour of RC square column specimens confined with 1 & 2 layers of CFRP

- **Effect Of Micro Concreting By Modified Method Of Square R.C Column Specimens.**
- **Load Deformation Behaviour (Smc0, Cr0, Sr0):**

The load deformation behaviour curves of unwrapped square micro-concreted to circular (SMC0) specimen, CR0 specimen & R.C square column specimen (SR0) are compared as shown in fig 5.4. The load deformation behaviour of SMC0 specimens depicts to be more stiffer than CR0 & SR0 specimens, both of which exhibit the same load deformation

behaviour till the failure of SR0 specimen (fig 5.4). Specimens SMC0 & CR0 record significant increase (1.71 times SR0) in ultimate load. This is because of the higher area of cross section of the two specimens. The ultimate load carrying capacity of SMC column specimen is found to be 1.71 times higher than that of R.C square column & comparable with CR0 specimen.

- **Stress Strain Behaviour**

Fig 5.5 compares stress-strain behaviour of SMC0, CR0 & SR0 specimens. The stress strain behaviour curves of SR0 & SMC specimens are similar almost upto 3/4th strength and deviate later. The strain developed in these specimens is almost half of that of CR0 specimen. However SR0 specimen can absorb slightly higher strain of 1.18 times that of SMC0 specimen. CR0 specimen resists 1.49 times & 1.23 times higher strain than SMC0 & SR0 specimens respectively.

Fig 5.3 Load deformation behaviour of SR0 , SMC0 & CR0 specimens

Fig 5.4 Stress-strain behaviour of SR0 , SMC0 & CR0 specimens

- **Effect of CFRP Wrapping On SMC Specimens.**
- **Load Deformation Behaviour (SMC0,SMC1, SMC2):**

The load deformation behaviour curves of Square micro concreted to circular specimens confined with 1 & 2 layer of CFRP (SMC1, SMC2) are compared with corresponding unconfined specimen (SMC0) in fig5.7 . During initial stages of loading, load deformation curves for all coincide & are linear upto 200kN and then curves deviate, showing non-linearity.

Fig 5.5 Load deformation behaviour of SMC0 , SMC1 & SMC2 specimens

Because of high confinement of CFRP wrapping on SMC column, ultimate load carrying capacity of specimens wrapped with 1 & 2 layers takes 1.31 times & 2.15 times higher load than that of unwrapped specimen. Ultimate deformation of SMC columns wrapped with 1 & 2 layers of CFRP increased by 2.63 and 4.12 times respectively that of unwrapped specimen, showing that CFRP confinement contributes to both increase in the load carrying capacity & additional deformation capacity.

- **Stress Strain Behaviour:**

Fig 5.8 compares stress strain behaviour of Square micro concreted to circular (SMC) specimen wrapped with 1 & 2 layers of CFRP with unwrapped SMC column specimen. Stress strain behaviour is exactly similar to load deformation behaviour, basically because of the equal area of cross section of all specimens. Ultimate compressive stress of SMC2 specimen is 81.2 MPa and the ultimate compressive stain of SMC2 specimen is found to be .002.

Fig 5.6 Stress-strain behaviour of SMC0 , SMC1 & SMC2 specimens

- **Failure Patterns**

The behaviour of all column specimens were monitored visually during loading & the application of load was stopped just after the peak load (indicated by the pointer moving in the reverse direction) & failure of the specimen, the corresponding ultimate load & ultimate deformation were noted. The failure pattern was recorded after failure of the specimens

- **Unwrapped Specimens**

The failure of the R.C square , Integral circular & SMC column specimens (SR0) under concentric compression loading is shown in fig 5.17 (a),(b) & (c) respectively. The SR0 column specimen failed by crushing of concrete due to development of vertical cracks on the surface of the specimen. In case of Integral circular (CR0) column specimen, as the load progressed, vertical surface cracking developed leading to crushing of concrete at ends. The failure of the square micro-concreted to circular (SMC0) column specimen leads to development of vertical cracks in the central zone of the specimen (SMC0), failed due to de-bonding of micro concrete at the interface with old concrete.

- *Column Specimen Confined With 1 Layer of CFRP Sheets.*

Failure of R. C square column specimen (SR1) with corners rounded off & wrapped with 1 layer of CFRP is due to crushing of concrete & rupture of CFRP when load approached the ultimate load. Failure occurred near the top portion of specimen as shown in fig.5.18 (a). The final failure occurred suddenly with

an explosive sound. No de-bonding of CFRP overlap was observed. Failure of integral circular specimen wrapped with 1 layer of CFRP (CR1) was similar to SR1 specimen; however, failure was spread to bottom half portion of the specimen as shown in fig. 5.18(b). The failure pattern of SMC1 specimen was similar to CR1specimen but extent of rupture was less than CR1 column specimen as shown in fig.5.18 (c).

- *Column Specimen Confined With 2 Layers of CFRP (SR2, SMC2 & CR2)*

The failure patterns of all specimens confined with 2 layers of CFRP (SR2,CR2 & SMC2) were similar to that of specimens confined with one layer of CFRP, but here, the rupture of CFRP generally occurred in the central portion of the specimen associated with slight crushing of concrete as shown in fig 5.19(a,b & c). Failure was characterized by explosive sound in all cases





VII. CONCLUSIONS

- The axial compressive load- axial deformation and longitudinal stress-longitudinal strain responses of SMC specimens are found to be superior to square specimens and comparable with integral circular specimens.
- Retrofitting of square column specimen (SR0) by modified micro-concreting method (SMC0 specimen) is found to enhance the ultimate load carrying capacity by 1.9 times, which is also found to be equal to equivalent integral circular column specimens(CR0).
Retrofitting by modified micro-concreting method was not found to increase the ultimate deformation but, the equivalent circular specimen showed ultimate deformation of 2.4 times that of SR0 specimen.
- Retrofitting R.C square column specimens with CFRP confinement (after rounding off the corners) results in considerable enhancement of the ultimate load carrying capacity & substantial increase in ultimate deformation.
The ultimate load & ultimate deformation of SR0 specimen increases by 1.35 times & 2.38 times for single layer CFRP confinement & 1.75 times & 3.91 times respectively for confinement of 2 layer of CFRP.

- The ultimate stress & ultimate strain of SR0 specimen are found to be 35.83 N/mm^2 & 0.0073 mm/mm . These respectively increase by 1.26 times & 2.38 times for single layer confinement & 1.78 times & 3.91 times respectively for confinement of 2 layer of CFRP.
- The increase in ultimate load of CFRP confined SMC specimens are very high compared to square (SR) specimens with CFRP confinement. Whereas, these are comparable to that of CFRP wrapped integral circular specimens, which shows the effectiveness of SMC specimens.
In comparison to ultimate load of SR specimen confined with 1 layer of CFRP, the ultimate load of SMC specimen increased by 1.84 times that of square & in comparison to corresponding integral circular specimen enhanced by 1.15 times.
- Ultimate deformation of CFRP confined square, SMC & circular specimens are comparable to each other.
- The ultimate strain of confined specimens SR1, SMC1 & CR1 are 2.38 times, 2.63 times & 2.13 times higher than their respective unconfined specimens (SR0,SMC0,CR0) for single layer confinement, whereas for 2 layer of CFRP confinement, ultimate strains increased by 3.91 times , 3.60 times & 3.34 times with respect to their unconfined specimens.

- The extent of enhancement of ultimate loads & ultimate strains due to CFRP confinement is almost same for different specimens considered.
- As the compressive load progressed, all unconfined specimens developed vertical cracks leading to crushing of concrete at ends of specimens in Integral circular specimens and square specimens, but debonding at the concrete- micro concrete interface followed by some concrete crushing occurred in SMC specimens.
- The failure in CFRP confined specimens was characterised by bulging of concrete prior to snapping and rupture of CFRP sheets, the rupture covering over 60% of height of columns. Crushing of concrete in case of square & Integral specimens and crushing of micro-concrete in SMC specimens also took place.
- The failure of specimens confined with 1 layer of CFRP occurred at top or bottom portions of specimen, but in case of specimens confined with 2 layers of CFRP, failure generally occurred in the middle portion of column specimens.

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