Strengthening of concrete square column using FRP composites

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Abstract. Strength and energy absorption capacity are the important parameter for axially loaded column. This paper investigates the strength of unconfined square concrete column and externally confined square column with fiber-reinforced (FRP) composites with synthetic carbon fiber and natural banana fiber. This type of strengthening of column is widely accepted in practice. Axial strength test is performed on confined square column with different parameters such as number of layers of FRP materials, wrapping patterns like full wrapping, center wrapping and hybrid pattern. Both natural and synthetic fibers are used for FRP-confined square concrete column. It was found that external confinement using FRP material improved the axial-load carrying capacity, load-deformation and ductility of the square column compared to the unconfined square column.

1. Introduction
Extensive study has been carried on the behaviour of Fiber reinforced polymer (FRP) confined concrete. Over past years many investigations are carried out in confined circular column rather than the rectangular and square columns. The existing studies also reveals that the confinement efficiency and axial strength is better for circular sections than rectangular sections. The main reason is that for square column only a part is effectively confined [1]. But as in terms of construction, square columns are preferred because it is more convenient to construct than circular column. Taking the effect of confinement, the square column is less confinement than circular column. RC structures are less corrosion resistant because of the damage that happen in steel. Strengthening of reinforced concrete columns are widely accepted in practice. During last decades researches are carried out on synthetic fiber for strengthening of existing concrete structure and retrofitting works. FRP materials has remarkable properties such as corrosion resistance, high strength-to-weight ratio and the externally wrapped FRP materials has notable change in the construction field [2,3]. The various types of FRP products are synthetic (carbon, glass, aramid, and basalt) and for synthetic fibers (sisal, bamboo, hemp, polypropylene, and banana). Conversely, the production of synthetic fibers is not eco-friendly, non-biodegradable and high cost [4,5]. Though natural fibers are wrested from renewable materials it is easily degradable in nature, eco-friendly and very economically sustainable. Similar properties of natural and synthetic fiber composites were reported in earlier study [6-8]. In recent, researches are carried out using natural fibers for external confinement mechanism. Nevertheless, the strength and durability of natural fibers is less compared to synthetic fibers [9]. Compared to the individual natural fiber, hybrid composites like natural synthetic enhances the strength and ductility. The work oriented...
towards to determine the performance of the square column confined in hoop direction with FRP materials. Uniaxial compression test is carried out on confined square column to determine the effect of confinement, ductility, axial load carrying capacity and failure mode. The performance of the hybrid confined column is evaluated with individual FRP materials such as synthetic fiber as CFRP and natural fiber as Banana. The different parameters are used for wrapping such as full wrapping, hybrid wrapping and strip wrapping. Similar wrapping method was reported in earlier study [10].

2. Methodology

2.1. Materials

2.1.1. Concrete. Ordinary Portland Cement of grade 53 is used for concrete preparation. The specific gravity of cement is 2.84. The size of coarse aggregate is 12.5mm, specific gravity is 2.7, water absorption is 0.79% and bulk density of 1.75kg/l. The fine aggregates used was river sand with a specific gravity of 2.5, water absorption is 1.42% and bulk density of 1.67kg/l. The mix proportioning of concrete was carried out according to codal provisions of IS 10262-2009 [18] for a characteristic compressive strength of 15 MPa. The mix proportion by weight of cement: sand: coarse aggregate was maintained as 1:1.5:2. Water cement ratio of 0.5 was used. Twenty-six square columns with 100 mm thickness and 600 mm height were cast and cured for 28 days.

2.1.2. Fiber reinforced polymer (FRP). Banana fibers are extracted from the stem of banana plant (Musa plant) and fibers are woven to make a sheet like material for wrapping. 100 gsm of Carbon fabric was used in this work. For the preparation of epoxy resin araldite LY 556 and hardener HY 991 was used with a ratio of 100:75 by weight.

2.2. Wrapping of column with FRP

After curing, kept the specimens for drying and specimens are cleaned thoroughly. Cut the FRP sheets corresponding to the dimensions of the column. Epoxy and hardener were mixed in the ratio of 100:75 by weight. First spread the epoxy resin hardener mix on the surface of column for filling up the pores on the surface and allowed to dry for five hours. After primer coating, hand layup method is proposed for wrapping (i.e., manually laying a coat of resin-hardener mix on top of FRP material using roller/brush). Mix was applied using gloved hand and smoothen out. Similar wrapping method was reported in earlier study [11]. While FRP material was wrapped on the hoop direction, a constant pull has been maintained to avoid air gaps between the surface of column and the FRP material. After that 3days curing was provided for the specimens. All specimens are kept in room temperature. For two-layer of FRP, on top of first layer a spread a coat of epoxy-hardener mix , and repeat the procedure until the required layers were attained. The steps involved in the wrapping of column is illustrates in Figure 1-3. Different pattern of wrapping adopted in this study are shown in Figure 4-6.

Figure 1. (a) CFRP; (b) Banana fiber
Figure 2. Coating of epoxy hardener on FRP material

Figure 3. Wrapping of column with FRP material

Figure 4. Full layer pattern of wrapping
2.3. Testing

After 3 days of curing, axial compression test was executed on both confined and unconfined square column specimen using a compression testing machine of 2000 kN capacity. Load was applied on column with a constant rate of 1.0mm/min. Two LVDTs are mounted on mid height of specimen for measuring the deformations in column [12]. The test setup is presented in Figure 7.
3. Results and discussion

3.1. General

Axial Compression behaviour of confined FRP square column and unconfined square column were evaluated in this study. The columns are subjected to axial compressive loading with a testing machine of 2000 kN capacity. The parameters like load, lateral deformations and axial deformations are measured and compared. Details of the specimens are provided in Table 1.

| Nomenclature | Mix description                        |
|--------------|----------------------------------------|
| C1           | Conventional                           |
| C2           | Full length of CFRP                    |
| C3           | Center layer of CFRP                   |
| C4           | Two-layer center of CFRP               |
| C5           | Full length of banana fiber            |
| C6           | Two-layer center wrap of banana fiber  |
| C7           | Hybrid (CFRP and banana fiber)         |

3.2. Axial Load comparison

FRP confined square column shown enhancing in load carrying capacity compared to unconfined column (Table 2). Comparing all specimens, enhancement in load carrying capacity is shown by two-layer of CFRP. Two-layer CFRP confined square column exhibited a maximum increase in axial load carrying capacity by 33.5%, followed by center one-layer CFRP confined column increased by 23.2%, then followed by hybrid banana-CFRP increased by 22.6% and then full wrap CFRP increased by 16.1%. In banana fiber confined columns, the maximum increase in load carrying capacity is visible for hybrid natural-synthetic (banana-CFRP) combination (22.6%), followed by two-layer center wrap of banana (14.0%) and followed by full length of banana (0.2%). Due to the confining action of FRP on hoop direction of column is the reason for enhancement in load carrying capacity [13]. Both natural fiber (Banana) and synthetic fiber (CFRP) shown a remarkable increase in the load carrying capacity compared with unconfined square column. The full-length wrapping of hybrid banana-CFRP
composite was shown a better load carrying capacity than individual full length CFRP and banana fiber confinement.

| Specimen | Maximum load (kN) | Name | Maximum load (kN) | % Increase in load |
|----------|-------------------|------|-------------------|--------------------|
| C1       | 179.82            | C1   | 179.82            | -                  |
| C2       | 208.82            | C5   | 180.2             | 16.1               |
| C3       | 221.46            | C6   | 204.92            | 23.2               |
| C4       | 239.98            | C7   | 220.38            | 33.5               |
| C7       | 220.38            |      |                   | 22.6               |

3.3. Load-deformation response

The axial load deformation details of unconfined and confined specimens are shown in Table 3 and Table 4. The load-deformations curves of unconfined and confined specimens are shown in Figure 8 and Figure 9. Basically, curves of confined specimen showing three stages. The first stage exhibits a linear straight line (it is like the control unconfined specimen of brittle behaviour). Increase in strength was occurred in second stage (where it increased the strength than unconfined specimen). Confining action initiates when CFRP expands laterally. Third stage shows a reduced slope line. The confinement is mainly exhibited in second and third stages, that is after first stage of the curve. The unconfined column showing a failure at first stage itself, because unconfined specimen exhibited a brittle failure whereas the FRP wrapped specimen exhibiting a ductile mode (that is failure after yielding). In CFRP wrapped specimen, the maximum strength is observed for two-layer of CFRP followed by hybrid and one-layer of CFRP composites. For column confined with one and two-layer of banana fibers also showed same pattern of load deformation curve. In banana fiber confined column, maximum load is observed for hybrid confined FRP column, followed by two-layer and one-layer wrapped column. Similar findings are observed in previous researches [14,15]. This shows that combination of natural and synthetic is better choice than individual banana fiber.

| Specimen | Maximum Load (kN) | Lateral Deformation (mm) | Axial Deformation (mm) | Compressive Strength (f'co) (MPa) |
|----------|-------------------|--------------------------|------------------------|-----------------------------------|
| C1       | 179.82            | 0.0075                   | 2                      | 18                                |
| C2       | 208.82            | 0.0217                   | 3                      | 20.9                              |
| C3       | 221.46            | 0.035                    | 3.7                    | 22.1                              |
| C4       | 239.98            | 0.039                    | 5.1                    | 24                                |
| C7       | 220.38            | 0.042                    | 4.5                    | 22                                |
Table 4. Axial compression performance of banana fiber wrapped concrete column

| Specimen | Maximum load (kN) | Lateral Deformation (mm) | Axial Deformation (mm) | Compressive Strength (f'co) (MPa) |
|----------|-------------------|--------------------------|------------------------|----------------------------------|
| C1       | 179.82            | 0.0075                   | 2                      | 18                               |
| C5       | 180.2             | 0.017                    | 3.6                    | 18.02                            |
| C6       | 204.94            | 0.018                    | 3.9                    | 20.5                             |
| C7       | 220.38            | 0.042                    | 4.5                    | 22                               |

3.4. Ductility behaviour

All column specimens confined with FRP showed a highly ductile behaviour. Ductility behaviour is shown in Table 5. Ductility is the deformation capacity of the specimen. Ductility is the deformation capacity of the specimen. Ductility increases when confinement increases. The specimen showing maximum ductility is will show a warning before failure also it will have a higher energy absorption rate. Here ductility index is the ratio of energy absorbed rate of the confined specimen to unconfined specimen. Comparing with the ductility behaviour of CFRP, the hybrid specimen exhibits the maximum value of ductility, followed by two-layer CFRP wrapped specimen. Comparing with single layer Banana fiber, the hybrid specimen showing highly ductile nature followed by two-layer banana
Comparing to the synthetic carbon fiber and natural banana fiber both showing a reasonable increase in ductility. For more economical one and it can be suitable for earthquake prone areas [16].

| Specimen | Energy absorbed (Nm) | Ductility index |
|----------|----------------------|-----------------|
| C1       | 548.93               | 1.0             |
| C2       | 754.89               | 1.4             |
| C3       | 2244.81              | 4.1             |
| C4       | 3033.41              | 5.5             |
| C5       | 1538.33              | 2.8             |
| C6       | 1659.16              | 3.0             |
| C7       | 3726.27              | 6.8             |

3.5. Confined effectiveness

Confinement effectiveness of CFRP and banana FRP of confined concrete are presented in Table 6 and Table 7. The f'cc and εcc represents the compressive strength and axial strain of confined square column and f'co and εco represents the compressive strength and axial strain of unconfined square column. f'cc/f'co and εcc/εco represents the confinement effectiveness and confinement ratio of confined square column. Similar findings are observed in previous researches [17].

From the results it is clear that, comparing with unconfined column, all wrapped specimens exhibited increased confinement. The confinement action increases by enhancement in load carrying capacity of specimen, Maximum axial load carrying capacity is for two-layer CFRP and it is because of increase in confinement. There is also a interlink between the ductility and confinement property. Enhancement in confinement increases the ductility of the structure. For CFRP and banana wrapped column, confinement effectiveness and ratio increase with increases with increase in number of wrapping layers.

| Specimen | Compressive Strength (f'co or f'cc) | Axial Strain (εcc or εco) | Confinement Effectiveness(f'cc/f'co) | Confinement Ratio (εcc/εco) |
|----------|------------------------------------|--------------------------|-------------------------------------|-----------------------------|
| C1       | 18                                 | 0.003                    | 1                                   | 1                           |
| C2       | 20.9                               | 0.005                    | 1.16                                | 1.6                         |
| C3       | 22.1                               | 0.006                    | 1.2                                 | 2                           |
| C4       | 24                                 | 0.009                    | 1.3                                 | 3                           |
| C7       | 22                                 | 0.008                    | 1.2                                 | 2.6                         |

| Specimen | Compressive Strength (f'co or f'cc) | Axial Strain (εcc or εco) | Confinement Effectiveness(f'cc/f'co) | Confinement Ratio (εcc/εco) |
|----------|------------------------------------|--------------------------|-------------------------------------|-----------------------------|
| C1       | 18                                 | 0.003                    | 1                                   | 1                           |
| C5       | 18.02                              | 0.006                    | 1                                   | 2                           |
| C6       | 20.5                               | 0.007                    | 1.1                                 | 2.3                         |
| C7       | 22                                 | 0.008                    | 1.2                                 | 2.6                         |
4. Conclusion
Confinement effectiveness of CFRP and Banana fiber is analysed in this work and following conclusions are drawn out of it.
• For confined column a remarkable increase in load carrying capacity is observed compared to unconfined column. The increase in load carrying capacity comparing to unconfined column is 33.5% for two-layer CFRP.
• Ductility is improved for wrapped specimen with hybrid fiber pattern (both natural and synthetic fibers) compared to that with individual natural fiber. So, for earthquake prone areas, the hybrid fiber wrapping is the better choice. Also, the hybrid structures are viable choice to replace the costly synthetic fibers.
• Axial load carrying capacity, Confinement effectiveness and confinement ratio of the square column increases with increase in number of wrapping layers. Both double layer CFRP and Banana fiber wrapped specimen showed improvement in performance compared to its corresponding single layer specimen.

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