# PERFORMANCE OF FRP STRENGTHENED SQUARE CFT COLUMNS CONFINED WITH GLASS FIBRE REINFORCED POLYMERS

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**Abstract**

In recent techniques of retrofitting, Fibre Reinforced Polymer (FRP) strengthening seems to be more effective as compared to the conventional strengthening methods. The strengthening property of FRP is because of its composite nature and easy application over damaged area. Hence external wrapping of FRP on steel as well as concrete structures has been rising now a day. In this experiment, the compressive behaviors of square Concrete Filled steel-Tubes (CFT) confined using Glass Fibre Reinforced Polymers (GFRP) were investigated. Square CFT columns of varying height (0.9m, 1.2m, 1.5m and 1.8m) and number of piles (single and double piles) are chosen as varying parameter to study the behaviour of GFRP confined square CFT columns. From the experimental investigation, it has been concluded that the square CFT columns of height 0.9m confined using GFRP shows greater strength in compression compared to other square CFT columns for both single as well as double piles.

**Keywords: GFRP; Column; Strengthening; Confinement; compressive strength.**

## 1. INTRODUCTION

In selecting the technique for strengthening, the current method of using steel and cementitious material is not proving to provide appropriate solution. The only alternative to such traditional techniques are strengthening using FRPs which is both cost effective and technically good. FRP composite materials provide excellent mechanical properties such as resistance to corrosion and impact, better durability, electromagnetic neutrality, ideal fatigue behavior, greater strength-to-weight ratio, weightless, versatility, easy to install, fire resistance, creep, stiffness and geometry. This in terms provide cost effective retrofitting work in terms of labour and equipment cost. **Teng**

**and Lam (2002)** carried out an investigation on FRP strengthened concrete in elliptical columns. They concluded that strengthening FRP turns into ineffectual when the specimen has high ellipticity, considerable gain of strength using FRP confinement may possible even for fully elliptical sections. **Arduini et al (2004)** investigated the one way RC slabs performance using externally bonded FRP strengthening. The load carrying capacity was increased by 122% with the benchmark slab. Analysis of the experimental results demonstrates that the effectiveness of strengthening technique using FRP laminates. **Lamanna et al. (2004)** conducted an investigation on split tensile confining of RC specimens by mechanically coupling FRP strips. It has been noticed that such strips exhibits substantial ductility compared to the specimen confined using bonded FRP strips. **Sen and Mullins (2007)** experimentally investigated utilization of FRP composites in underwater piles retrofitting. They recommended the bi-directional material can be preferable over uni-directional composites and also carbon fiber instead of glass fiber. **Ilki et al. (2008)** examined FRP strengthened concrete columns under axial compression. They found that the external incarceration of columns using CFRP sheets shows rise in strength as well as ductility. **Bousselham and Chaallal (2008)** investigated the resistance to shear of concrete specimens confined in shear using externally bonded FRP. Test results are indicates that concrete specimens strengthened in shear with externally bonded FRP shows greater shear resistance. **Eid et al. (2009)** experimentally investigated the normal as well as high strength circular concrete FRP wrapped specimens. These study concluded that the normal-strength concrete shows enhanced strength and strain. Furthermore it concludes that the rupture of FRP in specimens having greater volumetric transverse steel reinforcement ratios shows more axial strength in compression. **Hu et al. (2011)** investigated axial compression of circular concrete-filled thin steel tubes confined with FRP composites. These study includes tests in three series in that the varied parameters were steel tube thickness and stiffness of FRP wrap. They concluded that the FRP wrap can significantly retard as well as entirely suppress extension of local buckling deformation of steel tube. Therefore load-carrying capacity as well as ductility increased significantly with FRP strengthening. The performance of concrete is furthermore improved with FRP wrap. **Murugan et al. (2014)** have studied FRP confined concrete prisms under flexural behavior. From the investigation they concluded that in both the single and double plies the specimens wrapped with CFRP shows increases strength in compression compared to specimens wrapped with GFRP. Positioning of the fibres along length of the prisms shows greater flexural strength compared to positioning of the fibres along depth of the prisms in both CFRP as well as GFRP wrapping. **Mane and Pitale (2016)** reviewed the use of FRP composite system with RC beam and column. This survey briefly reviews the history of FRP composite system utilised in RC beams as well as columns. The different field of applications of FRP are also presented. **Eid and Paultre (2017)** reviewed the compressive behavior of FRP-confined RC columns. This study furnishes the development of a unified stress-strain model suitable to depicit the axial behavior of circular as well as square/rectangular reinforced-concrete columns confined internally with TSR, externally with FRP, or both internally and externally with TSR and FRP respectively. It was found that stress-strain curves estimated by the proposed model agree well with the already published test results.

## 2. MATERIALS AND METHODS

**Material properties:** Concrete of characteristic strength in compression 25 MPa was taken for the study. The mix ratio choosen was 1: 1.40: 2.75: 0.46 (cement: Fine aggregate: Coarse aggregate: Water). The strength in compression of concrete cubes after 28 days water curing was found to be 33.64 MPa.

**Properties of Square Steel tubes:** With the following properties structural steel tubes were used for this study. Properties of steel tube is presented in Table 1.

**Table 1.** Properties of square steel tube

| | |
|---|---|
| Grade | YSt 310 |
| Tensile strength | 450 N/mm$^2$ |
| Yield strength | 310 N/mm$^2$ |
| Size (Outer) | 100 x 100 mm |
| Thickness | 4 mm |
| Weight | 11.73 kg/m |
| Cross sectional area | 14.95 cm$^2$ |
| Sectional modulus | 45.27 cm$^3$ |
| Moment of Inertia | 226.35 cm$^4$ |

**Properties of Fibre Reinforced Polymers:** Glass fiber reinforced polymer was taken for the study. Properties of GFRP materials are presented in the Table 2.

**Table 2.** Properties of GFRP material

| **Properties** | **GFRP** |
|---|---|
| | **Unidirectional** |
| Weight of fibre (g/m$^2$) | 920 |
| Fibre thickness (mm) | 0.90 |
| Nominal thickness per layer (mm) | 1.5 |
| Fibre tensile strength (N/mm$^2$) | 3400 |
| Tensile modulus (N/mm$^2$) | 73000 |

## 3. FRP WRAPPING

The concrete mix which is designed was poured within the steel tube in layer with sufficient compaction by needle vibrator to prevent honey combing. After concreting, sufficient curing has done, FRP wrapping was carried out by several steps as follows.

**Rubbing:** The exterior of the square CFT columns were rubbed by silicon carbide water-proof paper sheet to remove loose and deleterious material.

**Primer Coating:** The material mixed of Nitowrap 30 primer was applied over the prepared cleaned surface and it was allowed to dry for 24 hours before the application of Nitowrap 410 saturant. Properties of Nitowrap 30 primer is given in Table 3.

**Table 3.** Properties of Nitowrap 30 primer

| | |
|---|---|
| Density | 1.14 g/cc |
| Pot life | 25 minutes @ $27^0$ C |
| Full cure | 7 days |

**Saturant Coating:** The Nitowrap 410 saturant system was made of two parts, resin and hardener. Before the application, the components were thoroughly mixed for 3 minutes manually. Properties of Nitowrap 410 saturant is given in Table 4.

**Table 4.** Properties of Nitowrap 410 saturant

| | |
|---|---|
| Colour | Pale yellow to amber |
| Application temperature | $15^0$C - $40^0$C |
| Viscosity | Thixotropic |
| Density | 1.25 – 1.28 g/cc |
| Pot life | 2 hours @ $30^0$ C |
| Full cure | 5 days @ $30^0$ C |

**FRP wrapping:** The early coat of saturant was applied over the primer coat and FRP sheet was confined directly on the surface FRP layer was confined around the square CFT columns having an overlap of $(¼)^{th}$ of the perimeter to evade sliding and debonding of fibres in course of testing and to make sure the attainment of full strength. FRPs confined and unconfined square CFT columns are shown in Fig.1.

|  |  |
|---|---|
| Unconfined square CFT columns | GFRP confined square CFT columns |

**Fig. 1.** GFRP confined and unconfined square CFT columns

## 3. EXPERIMENTAL INVESTIGATION

Square CFT columns were placed perpendicularly on the loading frame. The axial compression load was applied perpendicularly and consistently until the the square CFT columns fails. Experiment was conducted on 12 square CFT columns out of which 4 reference square CFT columns were tested without any confinement and the other 8 square CFT columns were confined using single and double plies of GFRP mats.

### Experimental Results and discussions

Table 5 shows the results of tested square CFT columns.

**Table 5.** Results of tested square CFT columns

| Sl.No. | Type of confinement | Height of the RC column | Number of plies | Strength in compression (kN) |
|---|---|---|---|---|
| 1 | Unconfined square CFT columns | 0.9 | - | 532 |
| | | 1.2 | - | 510 |
| | | 1.5 | - | 484 |
| | | 1.8 | - | 458 |
| 2 | Square CFT columns confined with unidirectional GFRP mat along the circumference | 0.9 | 1 | 661 |
| | | | 2 | 783 |
| | | 1.2 | 1 | 628 |
| | | | 2 | 740 |
| | | 1.5 | 1 | 591 |
| | | | 2 | 688 |
| | | 1.8 | 1 | 555 |
| | | | 2 | 638 |

**Effect of height of column on compressive load capacity**

The consequence of height of square CFT columns on compressive load capacity, 101.6 mm diameter square CFT columns of different heights such as 0.9m, 1.2m 1.5m and 1.8m were considered. The results are shown in Table 3 which indicated that the axial load carrying capacity of square CFT column decreases with increasing the height of square CFT column. This outcome is because of increase in slenderness ratio of square CFT columns. The compressive load carrying capacity of unconfined square CFT columns was significantly less when compared with GFRP confined square CFT columns of same height. Fig. 2 shows the variation of strength in compression for square CFT columns confined with glass fibre reinforced polymers.

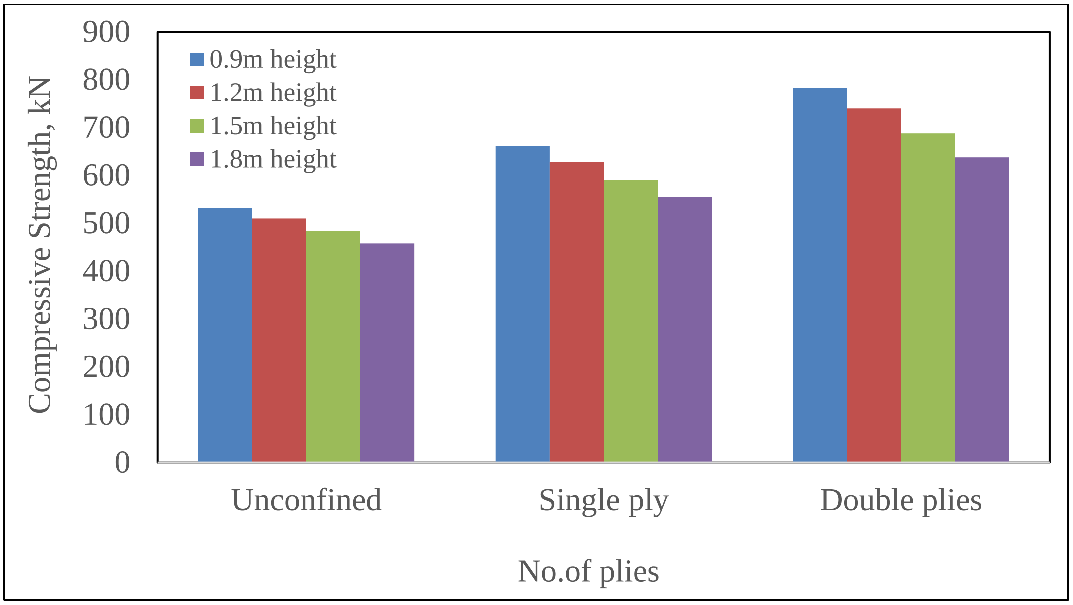


**Fig. 2.** Effect of height of square CFT column on compressive load capacity

- The percentage drop in strength in compression of 1.2m, 1.5m and 1.8m unconfined square CFT columns when compared with 0.9m unconfined square CFT column were 4.13 %, 9.02 % and 13.91 %.
- The percentage drop in strength in compression of 1.2m, 1.5m and 1.8m GFRP confined square CFT columns when compared with 0.9m GFRP confined square CFT column were 4.99 %, 10.59 % and 16.04 % for single ply and 5.49 %, 12.13 % and 18.52 % for double plies respectively.

**Effect of number of plies on compressive load capacity**

To determine the outcome of number of plies on strength in compression of square CFT columns, the square CFT columns were restrained with glass fibre reinforced polymers of single and double plies. The experimental result shows that the square CFT columns confined using double plies have higher strength in compression than the square CFT columns confined using single ply. This is because of rise in the thickness of confinement after wrapping with GFRP mat. Fig. 3 shows the variation of strength in compression of square CFT columns confined with single as well as double plies of GFRP.

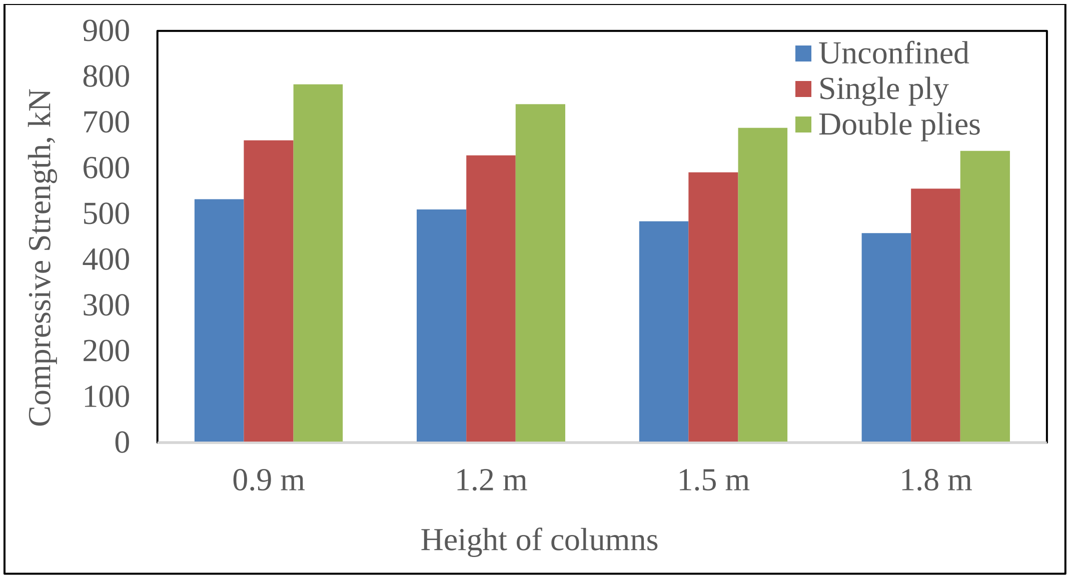


**Fig. 3.** Strength in compression of square CFT columns confined with single as well as double plies of GFRP

- The percentage rise in strength in compression of 0.9m square CFT columns confined using single as well as double plies-unidirectional GFRP mat has been 24.25 % as well as 47.18 % with the unconfined square CFT columns.
- The percentage rise in strength in compression of 1.2m square CFT columns confined using single as well as double plies-unidirectional GFRP mat has been 23.14 % as well as 45.10 % with the unconfined square CFT columns.
- The percentage rise in strength in compression of 1.5m square CFT columns confined using single as well as double plies-unidirectional GFRP mat has been 22.11 % as well as 42.15 % with the unconfined square CFT columns.
- The percentage rise in strength in compression of 1.8m square CFT columns confined using single as well as double plies-unidirectional GFRP mat has been 21.18 % as well as 39.30 % with the unconfined square CFT columns.

## 5. CONCLUSIONS

The present study used 12 square CFT columns, confined with unidirectional GFRP. On the basis of test results, the subsequent conclusions are stated.

- Axial load carrying capacity drops with rising the height of square CFT column. This is because of the hike in slenderness ratio of square CFT columns. The compressive load carrying capacity of unconfined square CFT columns was significantly low when compared with GFRP confined square CFT columns of same height.
- The experimental result shows that the square CFT columns confined with double plies have higher strength in compression than the square CFT columns confined with single ply. This is because of raise in the thickness of confinement after wrapping with GFRP mat.

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