Experimental and Analytical Analysis of Concrete Filled Square and Circular Tubes

Prathamesh S. Padwal[1], Dr. S. R. Parekar[2]

[1]*M.E. Structures, AISSMSCOE, Savitribai Pune University, Maharashtra, India*

[2] *H.O.D., Associate Professor, Dept. of Civil Engineering, AISSMSCOE, Savitribai Phule Pune University, Maharashtra, India*

Abstract - *This paper presents the experimental and theoretical results for the concrete filled FRP tubes (CFFT) columns. A total of 8 specimens were tested for the axial compressive load. Three different thick fabricated FRP tubes were used for the experimental analysis. Many researchers carried out tests for compression member and compare their test results with the available codal formulae. One of them also proposed mathematical model on the basis of their test results. This paper presents the formulae provided in 'ACI 440_2r.08' and Chinese code, and also equation proposed by 'Hamdy M. Mohamed and Radhouane Masmoudi' for the analysis of the FRP confined or FRP wrapped cylinders. The experimental results then compared with the presented methods of analysis. Also, the steps included in the fabrication of FRP tubes also been included in this paper.*

Key Words: FRP, CFFT, compressive load.

1.INTRODUCTION

From many years, Fiber Reinforced Polymer is used in various industries due to their advantages over traditional material. Their properties such as thermo-mechanical properties such as high strength and stiffness, light weight, excellent corrosion resistance, magnetic transparency, design flexibility, and long-term durability under harsh service environments makes them preferable material than any of the composite material available in the market. Also, Composites can be much stronger, several times stiffer, and lighter than metals such as steel and aluminium. That attracted many of the researcher's attention. In last decade, many of the researchers have done significant researcher regarding the various uses of the FRP in several different industries. Many design standards, guidelines, construction and maintenance standards including standardized test method were developed. Various researchers and organizations have been contributing to cover a wide variety of applications. Large volume usage of FRPs in civil infrastructure is increasing the interest of field evaluation and development of design and construction specifications. FRP is now frequently used for increasing strength of concrete members. It has been used as an internal reinforcement for beams, slabs and pavement (Masmoudi et al. 1998; Benmokrane et al. 2006) and also as an external reinforcement for rehabilitation and strengthening different structures (Demeres and Neale 1999).

Concrete filled Fiber reinforced polymer tubes (CFFTs) (Mirmiran and shahawy 1997; Fam and Rizkalla 2001a, b) are combination of the concrete and the FRP sheets along with the epoxy in which concrete is filled in the pre-fabricated FRP tube. Those tubes can be made with varying thickness depending on the requirement of the strength of the column. Several methods can be adopted for the fabrication of the FRP tube. But the most feasible and simple way of the fabrication is Hand Layup process for the in-situ fabrication and filament winding process for the machine fabrication. FRP Tube provides lateral confinement to the concrete under compression. This lateral confinement from the FRP Tube can significantly increase both the strength and the ductility of the concrete (B. Zhang, T. Yu and J. G. Teng 2014), because of this advantages, FRP tubes are good for use where the structure is supposed to face harsh environments such as freezing or thawing or the corrosive environment like near see shore.

FRP Tubes are being used more and more for the construction having advantages like sacrificial formwork. It can also reduce clear cover which introduced into IS 456 revision for the durability consent; and, reduce the amount of confinement reinforcement and the longitudinal reinforcement. For the application of CFFTs in construction, there are several methods available which can be used for analysis of FRP Tubes filled with plane concrete or reinforced concrete. But very few can be used for both circular and square or rectangular columns. So, in this study, the axial compression tests were conducted on both circular and square column. Experimental results were compared to the Analytical models available for the analysis of the FRP confined concrete. Where the thickness of the FRP tube is taken as the key factor in the study.

2. EXPERIMENTAL STUDY

2.1 Test Specimens

In total of 6 Concrete Filled FRP Tube Column (Short Circular Columns) were prepared and tested. In that 3 were square CFFTs and 3 were circular CFFTs. All circular specimens had external diameter of 200mm and height of 600mm. And square having dimension of 200mmx200mmx600mm. Also, 2 control specimens were casted in which circular had diameter of 200mm and square having cross-section of 200mmx200mm both having 600mm height. Tubes were made with one layer, two layers and three layers of FRP sheets. Overlapping of 100mm was given over the joint of the FRP sheets. Concrete filled in the FRP tube was taken of M30 grade concrete for all the specimens. Concrete mix were calculated as per the IS 10262: 2009 and IS 456:2000.

2.2 Fabrication of Test Specimens

2.2.1 Mould

FRP tubes ware made in the steel square and circular mould. Square moulds had internal dimension of 200x200x600mm and circular had diameter of 200mm with 600mm height. Mould was prepared for the application of the FRP with the epoxy for easy removal of the tube after epoxy sets. For that the epoxy releasing was applied on the surface of the mould. The coating was done enough so that the epoxy will not reach to the mandrel surface.

2.2.2 Glass FRP

Glass FRP was used for the fabrication of the FRP Tube. The glass fiber sheet is made up of the glass roving manufactured by Owens Corning LTD. The glass fiber has the description like B-E-586g/m^2-1210mm. in which around 520g/m2 roving is used in 0^o direction and around 54g/m2 roving is used in the 90^o direction for weaving. The roving used is SE 1200 type 30 single end roving. The glass fiber used is E-glass type 1200 TEX glass. The main advantage of the SE 1200 roving is, one can use any type of epoxy for the adhesive purpose. The epoxy resin specially manufactured for application of E-glass fiber on concrete were used for the fabrication of the Tubes.

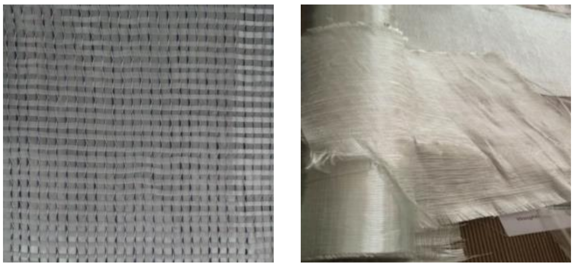

Fig-1: Photograph of Glass FRP Sheet

2.2.3. Steps Followed for the Fabrication of FRP Tubes

The wet layup process had used for making of FRP Tube. Wet layup FRP systems ware typically installed by hand using dry fiber sheets and a saturating resin, typically asper the manufacturer's recommendations. The detailed process followed is as follows,

Glass Fiber sheet cut into required shape and size as per perimeter and height of the square and the rectangular steel mould. The cut sheets then laid on the clean surface. As per the supplier's recommendations the mix is prepared in 1:1 proportion of resin and hardener. Mix proportion then carefully applied with the brush to the cut FRP sheets in direction perpendicular to the direction of the fibers. The saturating resin applied uniformly to all prepared surfaces of the FRP. Sufficient saturating resin applied to achieve full saturation of the fibers. The epoxy saturated FRP sheets then carefully pasted on the inner sides of the moulds. Successive layers of saturating resin and fiber materials placed before the complete cure of the previous layer of resin. If previous layers are cured, interlayer surface preparation, such as light sanding or solvent application may be required. The fibers of the sheet had orientation along the perimeter (in hoop stress direction). Entrapped air between layers and between the mould surface and the FRP sheet released or rolled out before the resin sets. Total of 100mm overlap is given on the joint for proper and strong bond at the joint so that the failure not in the joint section. Also, the epoxy Saturant layer also increased on the joint for proper bonding of FRP sheet with each other. After required layer FRP, the mould kept for at least for 24 hours for setting. After 24 hours, the set FRP tube removed from the steel mould.

2.2.4 Axial Load Test Setup

Each Concrete filled FRP Tubes and Control specimens were tested for their ultimate load carrying capacity. For that the specimens were axially loaded up-to the failure of each specimen. Load testing machine was used for applying the load on the specimens. Machine have the vertical load capacity up-to 15000kN. For measuring the vertical deflection two dial gauges were used as shown in the Fig-3.

Fig-2: Photograph of FRP Tubes

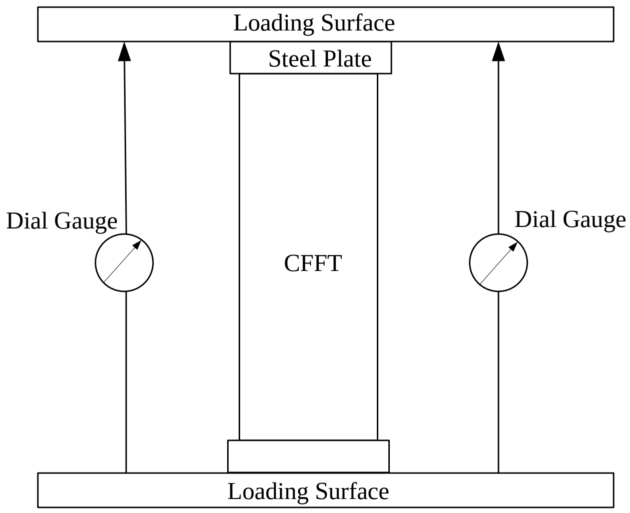

Fig-3: Line diagram for Test setup

3. ANALYTICAL STUDY

1. American Code Institute, ACI 440.2R-08 [1] is the "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures". This code has provided the empirical equation for the analysis of the FRP wrapped square, rectangular and circular columns. Maximum confining pressure due to the FRP jackets, can be obtained by the following equation,

$$f_1 = \frac{f'_{cc} - f'_c}{3.3k_a} \quad (1)$$

Where,

$$k_a = \frac{A_e}{A_C}\left(\frac{b}{h}\right)^2 \quad (2)$$

$$\frac{A_e}{A_C} = \frac{1 - \dfrac{\left[\left(\frac{b}{h}\right)(h-2r_c)^2 + \left(\frac{h}{b}\right)(b-2r_c)^2\right]}{3A_g}\rho_g}{1-\rho_g} \quad (3)$$

The value of k_a is 1 for circular columns and calculate according to "Eq. (1)" for other shapes. f'_{cc} is confined concrete strength. f'_c is non-confined concrete strength. f_l is maximum confining pressure due to the FRP jacket can be obtained by formula

$$f_1 = \frac{2E_f nt_f \varepsilon_{fe}}{D} \quad (4)$$

where, n is number of FRP layers and t_f is thickness of FRP layer

2. Y. M. Hu [10] conducted tests on seven specimens under axial compression and studied its behaviour. Out of seven specimens, three were plane concrete, one was concrete filled steel tube and remaining were CFFTs with the varying thickness of the FRP layer. The analysis was made as per the ACI 440.2R-08 provisions for concrete filled FRP tubes. The confining stress is calculated by the following equations,

$$\sigma_{r,frp} = \frac{E_{frp} t_{frp} \varepsilon_{frp}}{(R + t_s)} \quad (5)$$

$$\sigma_{r,steel} = \frac{\sigma_{\theta,steel} t_s}{R} \quad (6)$$

Where, $\sigma_{r,frp}$ is confining pressure , E_{frp} is elastic modulus in the hoop direction and t_{frp} is thickness of the FRP wrapping, ε_{frp} is hoop strain of the FRP wrap, R is radius of the concrete core, $\sigma_{r,steel}$ is confining pressure provided by the steel tube; and $\sigma_{\theta,steel}$ and t_s is hoop stress and thickness of the steel tube, respectively.

3. The Chinese technical code has given the recommendation for circular CFFTs under axial compression, bending and combined bending and axial compression [8]. Variable confinement model is specified in the Code for the stress-strain behaviour of the confined concrete, taking into consideration the effect of the strain on confinement ratio. This Code provides the method of analysis for evaluating the mechanical properties and the ultimate strength of the FRP tube and testing approach for the design of CFFTs in the paper as per the code provisions. The empirical equation for stress calculation under concentric axial compression is given below.

$$\sigma_{cc} = E_1\varepsilon_{cc} - \frac{(E_1-E_2)^2}{4f_c}\varepsilon_{cc}^2 \quad (7)$$

$$\sigma_{cc} = f_c + E_2\varepsilon_{cc} \quad (8)$$

$$\varepsilon_t = \frac{2f_c}{(E_1-E_2)} \quad (9)$$

$$E_2 = \frac{f_{cc}-f_c}{\varepsilon_{cc,u}} \quad (10)$$

where, σ_{cc} is axial stress and ε_{cc} is axial strain; E1 is elastic modulus of unconfined concrete; E2 is slope of the linear second portion; ε_t is strain at which the parabolic first portion meets the linear second portion; f_{cc} is design compressive strength of confined concrete; $\varepsilon_{cc,u}$ is design ultimate axial strain of confined concrete and should not exceed the design ultimate axial strain (i.e., compressive coupon tests of FRP). f_{cc} and $\varepsilon_{cc,u}$ are by the equation,

$$f_{cc} = f_c + 3.5\frac{E_{\theta t,eff}t_{frp}}{r}\left(1 - \frac{6.5}{\beta_j}\right)\varepsilon_{ru} \quad (11)$$

Where, β_j is confinement stiffness parameter and is given by,

$$\beta_j = \frac{E_{\theta t,eff}t_{frp}}{f_{c,k}r} > 6.5 \quad (12)$$

Also $\varepsilon_{cc,u}$ is given by the formula,

$$\varepsilon_{cc,u} = 0.003 + 0.6\beta_j^{\;0.8}\varepsilon_{ru}^{1.45} \quad (13)$$

Where ε_{ru} equivalent design ultimate hoop strain of the FRP Tube and is given by the formula

$$\varepsilon_{ru} = \frac{\sigma_{frp}\theta_u}{E_{\theta t,eff}} \quad (14)$$

4. Hamdy M. Mohamed [5] conducted tests on CFFTs filled with plane concrete and reinforced concrete the under axial compression and compared their results with the codes ACI 440.2R-08, CSA-S6-06, and CSA-S806-02. From their test results, they concluded that the codes of FRP wrapped columns can be used for the FRP tubes with modification suggested by them. The modified model is as given below.

$$f'_{cc} = f'_c\left[0.7 + 2.7\left(\frac{f_{lfrp}}{f'_c}\right)^{0.7}\right] \quad (15)$$

Where, f'_{cc} is the confined compressive strength of the concrete column, f'_c is the unconfined compressive strength of the concrete. And f_{lfrp} is the lateral pressure and is given
by the following equation,

$$f_{lfrp} = \frac{2E_{frp}nt_{frp}\varepsilon_{fe}}{D} \quad (16)$$

$$\varepsilon_{fe} = k_\varepsilon \varepsilon_{fu} \text{ and } k_\varepsilon = 0.55 \quad (17)$$

Where, ε_{fe} is effective strain level in the FRP at failure. The minimum lateral pressure is limited to be not less than 0.08 times f'_c

4. RESULTS:

Table-1 shows the experimental results and the results Obtained from Analytical Methods.

Sr. No.	Specimen Designation	Experimental Results	Analytical Results		
			ACI 440-2r.08	Mohamed	Chinese code
1	CCC	0801.88	556.0	556.00	630.0
2	CC1F	1190.85	739.0	1050.00	935.3
3	CC2F	1297.15	960.0	1148.14	1005.6
4	CC3F	1395.50	1192.0	1203.33	1168.44
5	SCC	0780.45	600.0	600.00	675.00
6	SC1F	1130.92	762.0	1260.21	1330.57
7	SC2F	1254.34	900.0	1473.14	1530.34
8	SC3F	1437.48	1040.0	1677.57	1760.1

5. CONCLUSION:

The behavior of short CFFT columns subjected to concentric axial compression loading conditions was investigated in this study. The test results of this study combined with other reported data in the literature were evaluated. The analyses used to evaluate the ultimate strength of the CFFTs are the North American code and design guideline ACI 440.2R-08 and Chinese code for design of CFFT. Also, the nonlinear empirical model for ultimate strength of CFFT by Hamdy M. Mohamed et al is used for the analysis.

1. Considering the environmental factor by ACI 440.2r_08 leads to conservative predictions of the confined concrete compressive strength.
2. The Chinese code and the mathematical model proposed by the Mohamed predicts less conservative results for the circular shape CFFTs than that of ACI code. But the bot code and mathematical model overestimates the factored axial load capacities of the CFFTs as compared with the yield and cracks load levels of experimental results.

REFERENCES

[1] American Concrete Institute (ACI), "Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures." *ACI 440.2R-08*, Farmington Hills, Mich, 2008.

[2] B. Zhang; T. Yu; and J. G. Teng, "Behaviour of Concrete-Filled FRP Tubes under Cyclic Axial Compression", 10.1061/(ASCE)CC.1943-5614 .0000523, 2014.

[3] Fam, A. Z., and Rizkalla, S. H. "Confinement model for axially loaded concrete confined by circular fiber-reinforced polymer tubes." ACI Struct. J., 98(4), 451–461, 2001.

[4] Fam, A. Z., and Rizkalla, S. H, "Behaviour of axially loaded concrete-filled circular fiber-reinforced polymer tubes." ACI Struct. J., 98(3), 280–289. 2001.

[5] Hamdy M. Mohamed and Radhouane Masmoudi, "Axial Load Capacity of Concrete-Filled FRP Tube Columns: Experimental versus Theoretical Predictions", 10.1061/_ASCE_CC.1943-5614.0000066.

[6] Mirmiran, A., and Shahawy, M, "Behaviour of concrete columns confined by fiber composites." J. Struct. Eng., 10.1061/(ASCE) 0733-9445(1997)123:5(583), 583–590, 1997.

[7] T. Yu; X. L. Fang; and J. G. Teng, "FRP-Confined Self-Compacting Concrete under Axial Compression", DOI: 10.1061/ (ASCE) MT.1943-5533.0000993. 2014.

[8] T. Yu and J. G. Teng, "Design of Concrete-Filled FRP Tubular Columns: Provisions in the Chinese Technical Code for Infrastructure Application of FRP Composite", 10.1061/ (ASCE) CC.1943-5614.0000159, 2011.

[9] Togay Ozbakkaloglu and Deric J. Oehlers, "Concrete-Filled Square and Rectangular FRP Tubes under Axial Compression", 10.1061/(ASCE)1090-0268(2008)2:4(469), 2008.

[10] Y. M. Hu; T. Yu; and J. G. Teng, "FRP Confined Concrete filled thin steel tubes under axial compression", 10.1061/(ASCE)CC.1943-5614.0000217, 2011.