International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 03 Issue: 08 | Aug-2016 www.irjet.net p-ISSN: 2395-0072

Study on the Behaviour of Concrete Hollow Cylinder with External Confinement by CFRP, Subjected to Internal Radial Pressure

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Abstract - *In the recent years, FRP technology has been one of the promising technology in the field of retrofitting of deteriorated structural members. Providing FRP confinement around the structural members such as beam, column and slab has shown substantial increment in the strength of existing member. FRP technology around the hollow members such as water supply pipes, water tanks and special structures used in hydro-electric power generation is not yet studied. In this study, hollow concrete cylinders with confinement using CFRP composites are taken for study and their structural behaviour is compared with that of unconfined hollow concrete cylinders. The results obtained show a higher radial pressure sustaining capacity, increased ductility & stiffness properties for CFRP confined hollow specimens as compared to the unconfined specimens. Also, optimum number of CFRP layers has shown highest strength.*

Key Words: CFRP, Radial pressure, Hollow concrete cylinder, Lateral deformation, UTM, Thick cylinder.

1.INTRODUCTION

In recent construction activities with the use of concrete as a major requirement of construction industry, many technics have been used to increase the strength of concrete as well as that of structural members built with concrete. There are several technics, which can be used during the mixing process to enhance the properties of concrete such as using fly ash, steel fibers etc. Structural members, which are already cast in concrete can also be strengthened even after construction to provide additional strength and stiffness using FRP technology. FRP technology is mainly used in retrofitting the deteriorated structures to increase their serviceability.

In this study, it is proposed to subject hollow concrete cylinders to increasing radial pressure and observe the structural action of cylinders. Cylinders with & without CFRP wrapping are tested to focus on the improvements in radial pressure resistance and ductility of cylinders. Two grades of concrete M20 and M25 were considered for casting hollow cylinders and CFRP wrapping was given in 1/2/3 layers on these cylinders. For both grades of concrete, 2-layer wrapping was found to be optimum, which showed maximum strength as compared to 1/3/0 layer confinements.

2. BACKGROUND

Moderalli R et al. (2005) [1] conducted experiment to evaluate the influence of various parameters on the effectiveness of FRP jackets applied to hollow concrete columns, cylinders, prisms under uniaxial compressive load. A total of 124 specimens were tested including 85 specimens wrapped with FRP and 39 plain concrete specimens.

FRP confinement revealed to be effective for hollow core concrete sections. And it was observed that strength and ductility reduced from circular to square and rectangular cross sections. For higher concrete strength, the effect of FRP confinement decreased. Dimensions of corner radius for square and rectangular had significant influence in terms of ultimate strength and ductility, since the stress concentration was more on the corners of the rectangular and square specimens.

Rahai A R *et al.* (2008) [4] studied the experimental behaviour of concrete cylinders confined with CFRP composites. Their study included 40 small scale specimens (150×300 mm) subjected to uniaxial compression up to failure; the stress-strain behaviours were also recorded. The various parameters such as wrap thickness and fiber orientation were considered. Different wrap thicknesses (1, 2, 3 and 4 layers), fibre orientation of 0^o, 90^o, $\pm 45^o$ and combinations of the patterns were investigated. The size of their specimen was 150mmX300mm and M20 Grade of concrete was used. Based on the experimental work it was concluded that confined concrete strength was increased from 39MPa to 79MPa and ultimate strain from 0.22 to 0.62% for one layer of transverse orientation of CFRP. The 2, 3 & 4 layers confined concrete strengths were 96.4Mpa, 125.7Mpa 143.3Mpa and corresponding ultimate strains were 0.96%, 1.61% and 1.76%, respectively.

Yu-Fei Wu and Yang Wei (2015) [3] developed a new and general stress strain model for concrete confined by steel or FRP composites. This provided unified platform for modelling stress strain of concrete confined by different materials such as steel or FRP.

To Calculate ultimate stress (f_{cu}) and ultimate strain (ε_{cu}) for CFRP wrapped specimen the following mathematical expressions were proposed in this model [3]

- Ultimate stress(f_{cu})

$$\frac{f_{cu}}{f_{co}} = 0.75 + 2.7 * \left(\frac{f_l}{f_{co}}\right)^{0.9}$$

Where

f_{co} = unconfined compressive strength of concrete

f_l = confinement Strength

$$f_l = 2 * f_t * \frac{t}{D}$$

Where f_t = tensile strength of FRP material

t = thickness of FRP material

D = diameter of Specimen

- Ultimate strain(ε_{cu})

$$\frac{\varepsilon_{cu}}{\varepsilon_{co}} = 1.75 + 140 * \left(\frac{f_l}{f_{co}}\right) * \varepsilon_{fu}{}^{0.6}$$

Where, ε_{co} = unconfined compressive strain of concrete

ε_{fu}= rupture strain of FRP

3. EXPERIMENTAL PROGRAM

3.1 Specimen Layout

In this study ,24 hollow concrete cylindrical specimens with internal diameter 100mm, external diameter 150mm & height 300mm were cast. For each grade, 3specimens were prepared with each of 1/2/3-layer confinements, and 3 specimens were kept as control specimens. Line diagram for both unconfined and CFRP confined hollow cylinders are shown in Fig.1 and Fig.2

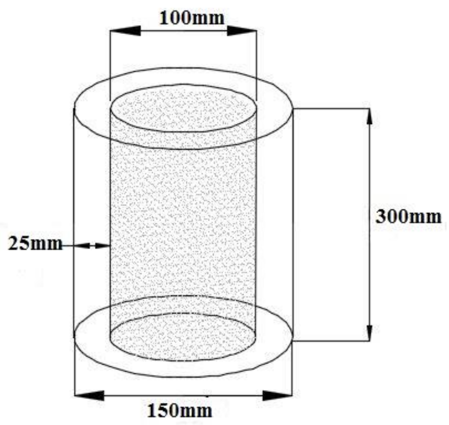

Fig -1: Line diagram of unconfined hollow cylinder

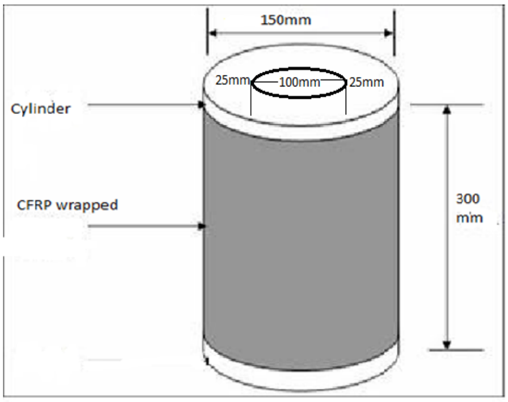

Fig -2: Line diagram of CFRP confined hollow cylinder

3.2 Material Properties

Concrete

Mix Design for the targeted strength of M25 and M20 was carried out using coarse aggregate of size 10mm and river sand of size passing through 4.75mm sieve. IS 10262-2009[10] code procedure was adopted to prepare the concrete of above targeted strength. Standard cubes of size 150mmX150mmX150mm were used to determine the compressive strength of concrete cube. The mix proportions were taken at 1:2.37:2 & 1:2.0:1.8 as given in table 1.

Table -1: Mix design proportions

Sl.No.	Mix Designation	Binder (Kg/m³) cement	Proportion B: FA:CA	W/C Ratio	Compressive strength at 28 Days (N/mm²)	Slump (mm)
1.	M20	400	1:2.37:2.0	0.55	21.32	65
2.	M25	420	1:2.0:1.80	0.50	26.52	50

CFRP sheets

Carbon fiber reinforced polymer composite (Nitowrap CF) sheets were used in present study. CFEP sheets used were of unidirectional, two types of epoxy resins i.e. primer and saturant were used to provide CFRP confinement around the hollow concrete cylinders. Properties of CFRP are given in table 2.

Table -2: Properties of CFRP

Properties	Nitowrap EP(CF)
Weight of fiber	200 g/m^2
Density of fiber	1.8 g/cc
Fiber thickness	0.111 mm
Fiber orientation	Unidirectional
Tensile strength	3500 N/mm^2
Tensile modulus	280x10^3 N/mm^2

Preparation of hollow cylinder moulds

Hollow concrete cylinders of grade M20 and M25 were prepared using the hollow moulds of internal diameter 100mm and external diameter of 150mm.Hollow cylinder moulds were fabricated using mild steel of which exterior jacket of diameter 150mm was removable and was supported with nuts & bolts system in order to demould the specimen easily. On the inner side, another cylinder of 100mm diameter was provided to maintain the uniform thickness of 25 mm in cylinders. The inner & outer steel cylinders were attached in base plate using nuts &bolts as shown in Fig. 3.

Fig -3: MS moulds for casting hollow cylinder

Test specimens

Three specimens of each of M20 and M25 grade hollow concrete cylinders were kept as control specimens, as shown in Fig.4. Similarly, three specimens of M20 and M25 grade hollow concrete cylinders were wrapped with 1/2/3 layer of carbon fiber confinement as shown in Fig. 5.

Fig -4: Unconfined hollow cylinder

Fig -5: Confined hollow cylinder

Experimental setup

Hollow concrete cylinders were kept for drying after the wrapping the carbon fibers and were brought to the testing platform after 7 days. In order to generate the radial pressure on the inner wall of hollow cylinder, uniformly graded sand was used as the medium to convert plunger load applied through the UTM machine into radial pressure on the inner wall of the hollow concrete cylinder. Hollow concrete cylinders were subjected to Plunger load with UTM machine of capacity 1000kN and least count of the load on the digital display of UTM was 0.1 kN. A magnetic supported analogue dial gauge was attached at the mid portion of the hollow concrete cylinders to measure the lateral deformation, the least count of the analogue dial gauge was 0.01mm. The arrangement of specimen in UTM is shown in Fig. 6.

Fig -6: CFRP confined hollow concrete testing in UTM

Assumptions made in analysis

The plunger load develops a vertical compressive pressure in sand given by $P_V = \frac{P}{A}$, where P is plunger load, A is area of plunger face. The sand particles, in turn, will develop a horizontal pressure P_1 on the internal face of the wall of the concrete cylinder. This internal pressure P_1 could be determined as $k_a * P_V$ if the sand body were free to deform/displace. But the cylindrical wall offers restrictions, hence $P_1 = k_a * P_V$ is not suitable. On the other hand, the cylindrical wall also bulges with increase in P and therefore it does not offer 100% restrictions either. Hence we cannot use $P_1 = k_a * P_V$. Therefore, it is assumed that with increment in P, the sand body compresses and behaves like a liquid, in which case $P_1 = P_V$ itself. Also, the wall by itself does not push the sand inwards in radial direction, hence we cannot use $P_1 = k_p * P_V$ .Line diagram for application of plunger load on sand filled hallow portion of cylinder is shown in Fig.7.

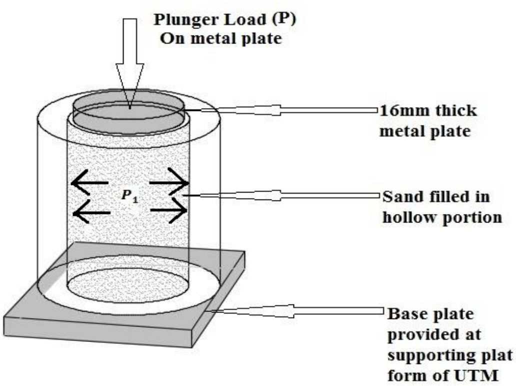

Fig -7: Line diagram showing the application of load on hollow cylinder

4. TEST RESULTS AND DISCUSSION

To understand the behaviour of hollow concrete cylinders, structural parameters like radial pressure and lateral deformation were estimated theoretically.

Comparison of theoretical and experimental values

Maximum radial pressure values obtained were compared with theoretical radial pressure values calculated using model proposed by Yu-Fei Wu and Yang Wei[3] with the help of thick cylinder theory. Following equations derived using thick cylinder theory were used in radial pressure calculations.

$$\sigma_r = \left(\frac{P_1 * R_1^2}{R_2^2 - R_1^2}\right) * \left(1 - \left(\frac{R_2^2}{R^2}\right)\right)$$

$$\sigma_\theta = \left(\frac{P_1 * R_1^2}{R_2^2 - R_1^2}\right) * \left(1 + \left(\frac{R_2^2}{R^2}\right)\right)$$

Where, R_1=Internal Radius

R_2=External Radius

R=Radial Distance

P_1=Internal Radial Pressure

Table -3: Comparison of theoretical and experimental results

Sl.No	Test Specimen	Theoretical Radial pressure(P_1) N/mm²	Experimental Radial pressure(P_1) N/mm²	% Variation=((Theoretical-Experimental) *100)/Experimental
1	M20 CFRP1L	19.375	17.145	13.01
2	M20 CFRP2L	28.04	28.01	0.11
3	M20 CFRP3L	36.26	22.28	62.75
4	M25 CFRP1L	21.95	21.01	4.47
5	M25 CFRP2L	30.8	38.19	19.35
6	M25 CFRP3L	39.21	29.28	33.91

The theoretical and experimental values are nearly matching. For concrete hollow cylinders of both M20 & M25 grades wrapped with one layer CFRP and two layer CFRP, % variation in radial pressure values are 13.01 %,4.47%,0.11% and 19.35%. This shows that the values are in par with theoretical values, but for the CFRP three layered specimens, the result shows slightly lesser pressure and load carrying capacities when compared to theoretical estimations. The slight deviation in the case of CFRP three layered specimens may be due to the practical difficulty occurred while providing third layer of CFRP, improper bonding between second & third layer of CFRP composites and ineffective bonding with concrete surface.

Radial pressure bearing capacity of hollow concrete cylinder

Compared to unconfined specimen CFRP, two layered specimen carries 84% more radial pressure in case of M20 grade concrete for lateral deformation of 1.48mm and 85% in M25 grade of Concrete for 2.15mm lateral deformation. M20 CFRP1L carries 72.41% for lateral deformation of 1.01mm and M25 CFRP1L carries 72.63% more pressure than the unconfined hollow concrete with lateral deformation of 1.25mm. The M20 CFRP three layered specimen carries 79.98% for lateral deformation of 1.80mm and M25 CFRP 3L carries 80.36% for lateral deformation of 2.35 mm. Theoretical contribution of 3L confinement is slightly lesser than the CFRP two layered specimen. In the outset, CFRP composites are effective in enhancing radial pressure compared to unconfined hollow concrete cylinder. Chart 1 shows the variation of load with concrete grade M20 and M25.

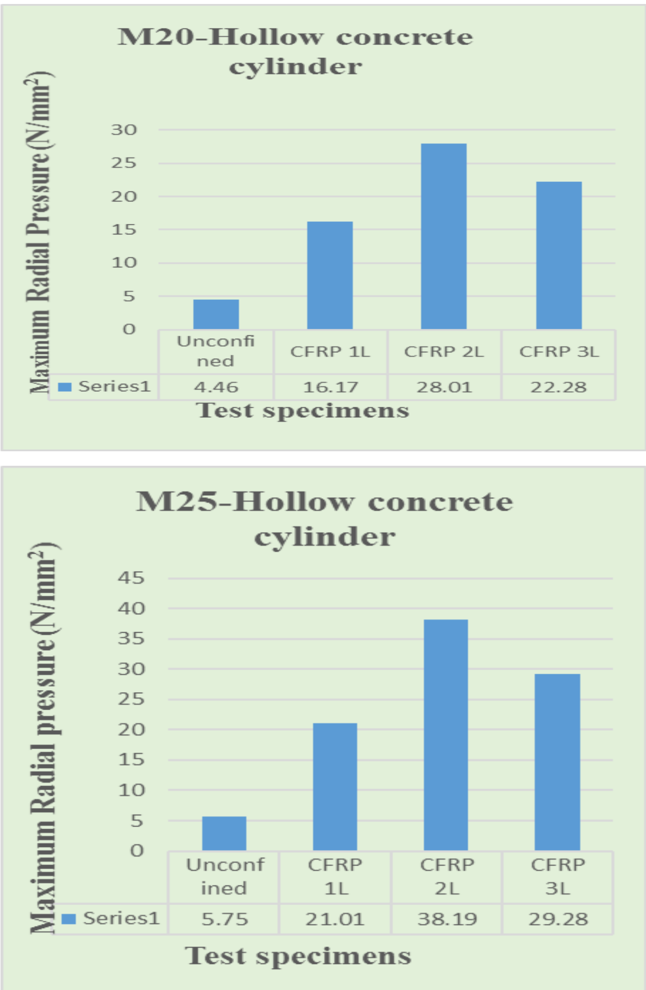

Chart -1: Variation of radial Pressure

Radial pressure v/s lateral deformation

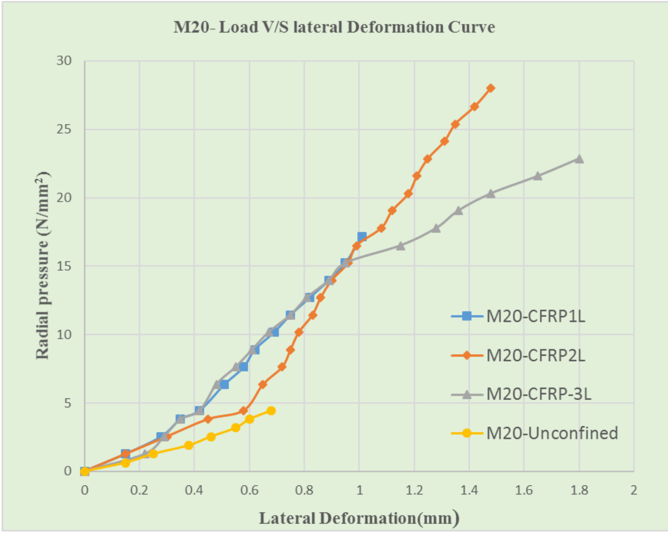

Chart -2: Radial Pressure v/s Lateral Deformation curve for M20 grade of hollow concrete cylinder

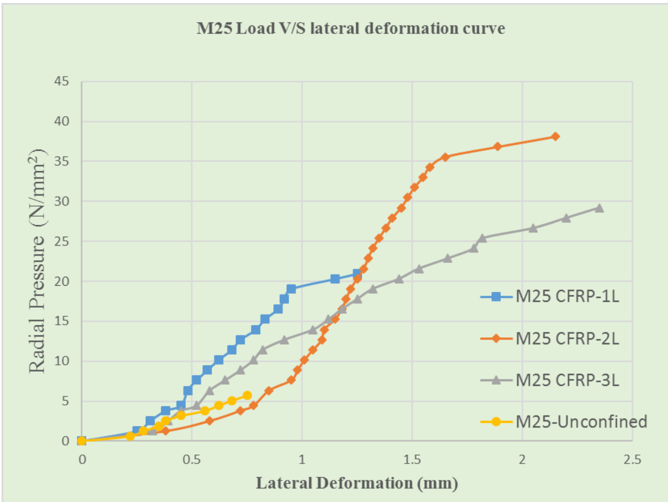

Chart -3: Radial Pressure v/s Lateral deformation curve for M25 grade of hollow concrete cylinder

Radial Pressure v/s Lateral deformation curve for M20 grade of hollow concrete cylinder is as shown in chart 2. The specimen with two layer of CFRP composite showed maximum strength and was able to sustain maximum radial pressure of 28.04 N/mm² with lateral deformation of 1.48mm, which is 54.05% more than the lateral deformation of unconfined hollow concrete cylinder. The specimen with three layers of CFRP composite was able to sustain radial pressure of 22.86 N/mm² for lateral deformation of 1.80 mm, which is 62.22% excess than unconfined specimen. Specimen with one layer CFRP confinement shows considerable increment in radial pressure for lateral deformation of 1.01mm, which is 32.67% more than unconfined specimen. In case of M25 grade specimens with two layered CFRP confinement can sustain more radial pressure as compared to unconfined specimen with increase lateral deformation of

65.11%. Similarly, specimens with one layer CFRP is able to sustain radial pressure of 21.59 N/mm^2 for lateral deformation of 1.25mm, which is 40% more than unconfined specimen. Specimen with three layer CFRP confinement can take up radial pressure of 29.21N/mm^2 for lateral deformation of 2.35mm, 68% more than unconfined specimen.

Failure mode and crack patterns

When the gradual increasing plunger load is applied on the sand filled hollow portion, the load applied is converted into radial pressure on the inner wall of hollow cylinder. When the concrete reaches its ultimate stress point, longitudinal cracks developed in wall of the hollow cylinder. Fig.8 shows the failure of unconfined hollow concrete cylinder. In case of CFRP confined hollow cylinder, it was observed that cracks developed in concrete walls prior to the straining of wrapping layers. In the ultimate stage of loading CFRP failed by producing crackling sound in an explosive way. Failure pattern of the CFRP wrapped 1/2/3 layer hollow cylinders are shown in Fig. 8.

Fig -8: Failure pattern of unconfined and 1/2/3 layer CFRP confined hollow concrete cylinders

5. CONCLUSIONS

1.Hollow concrete cylinders provided with external carbon fiber polymer composite confinement were effective in enhancing the radial pressure resisting capacity.

2.Specimens with two layer CFRP confinement were more effective when compared to one layer and three layered CFRP confinement, the ultimate radial pressure sustained were 85% larger as compared to unconfined hollow cylinder.

3.Ductility property of the material increases with increasing number CFRP layer. % increments were 62.22% for CFRP three-layer specimen with M20 grade of concrete cylinder and 68% for CFRP three-layer specimen with M25 grade of concrete.

4.Lateral deformation increases with increase in number of CFRP layers. Increase in the lateral deformation of specimens with M20 grade of concrete are 32.67%,54.05% and 62.22%. For Specimens with M25 grade of concrete lateral deformation varies as 40%,65.11% and 68.00% for one, two and three layered specimens when compared to unconfined specimens.

5.Increase in the radial pressure for specimens of hollow concrete cylinder of grade M20 was 72.41%,84.00%, and 79.98% for CFRP one layer, two layer, and three layered specimens when compared to unconfined specimens. And in case of M25 concrete cylinders 72.63%,85.00%, and 80.36% for CFRP one layer, two layer, and three layered specimens when compared to unconfined specimens.

6.Providing three layer of CFRP confinement is found to be ineffective in sustaining the radial pressure. Hence it is clear that increase in number of CFRP confinement more than two layers may not enhance the performance of the member.

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