

Behavior of Concrete Columns Confined with Circular Imbedded Glass Fiber-Reinforced Polymer Tubes

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Abstract:

This research work describes the behavior of axially loaded concrete-filled circular imbedded glass fiber-reinforced polymer tubes (GFRP). Ten specimens were tested. Five of them had the dimensions of 200*200 mm, and five had the dimensions of 200*250mm. Two samples had tubes of 1300 mm length, two had rings of 250 mm length, two had rings of 20 mm length at every 200 mm, and two had rings of 20 mm length at every 100 mm. Also, two control specimens of no GFRP were tested. For all the specimens, the GFRP tubes or rings were imbedded inside the columns. For the case of columns with GFRP tubes, only the concrete core was axially loaded, as the tubes were shorter than the columns. The study revealed that the strength and ductility of concrete columns were improved due to confinement using GFRP tubes or rings. The columns with 1300 mm tubes recorded the highest confinement level. Analytical model to predict the entire stress-strain curve of concrete-filled FRP tubes was verified using the experimental results and the model showed close correlation to the experimental results in the ascending part of the curve. The comparison between the experimental results and those of the analytical models indicated that the model of Fardis and Khalili [1] yields the best prediction of the ultimate compressive confined strength while the model of Karbhari et al. [1] yields the best prediction of the strain at peak confined strength.

Experimental program:

Ten reinforced concrete columns were casted. The length of each column is 1500 mm. Each column was reinforced with four deformed bars of 10 mm diameter and of grade 360/520. Plain mild steel stirrups of 8 mm diameter, 240/350, were used with average spacing of 210 mm. GFRP tubes or rings were placed inside the stirrups for protection of possible fire. Columns C0-20 and C0-25 were control columns without any GFRP. Columns C130-20 and C130-25 had 1300 mm GFRP pipe inside the stirrups, see the following figure. Four GFRP rings of length 250 mm each were installed in columns C25-20 and C25-25. The rest four columns had GFRP rings of 20 mm length located inside the stirrups.



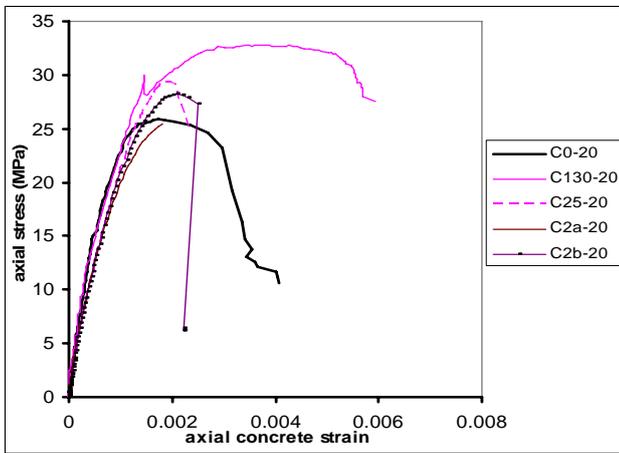
Discussion of test results:

Glass fiber-confined concrete columns exhibited superior ultimate strength and strain to that of unconfined. The maximum increase in the ultimate compressive strength was attained by column C130-20 which had a continuous FRP pipe of length 1300 mm. The increase in strength was 26.66%. The column C2a-20, which had GFRP rings of length 20 mm on 200 mm intervals, recorded no increase in the strength. The percentage of the increase in the strength with confinement for the 200*250 mm columns was generally small compared to that of the 200*200 mm columns. This is because the dimensions of the confined core for both the 200*200 mm columns and the 200*250 mm columns was the same, as similar dimensions for the GFRP tubes and rings were used for both types of columns. With regard to the strain at the ultimate compressive strength, the maximum percentage for the strain increase was obtained by column C130-20 and is equal to 106.32%. The corresponding percentage for the increase in the strain for column C130-25 was 25.38%. As explained above, this is due to the fact that the dimensions of the confined core is the same for both the 200*200 mm and the 200*250 mm columns. Generally, the rest of the columns recorded small change in the strain.

The peak confined strength (f'_{cc}) and the corresponding strain (ϵ'_{cc}) were calculated for specimen C130-20 using the equations of the different confinement models. The f'_{cc} and ϵ'_{cc} predictions for specimen C130-25 are identical to those of specimen C130-20 because similar GFRP

tube-diameter was used for the confinement of both specimens. The model of Fardis and Khalili [1] gave the best prediction for the peak confined strength. However, for the corresponding strain, the model of Karbhari et al. [1] yielded the best estimate of the strain at peak confined strength.

Axial stress-strain behavior:

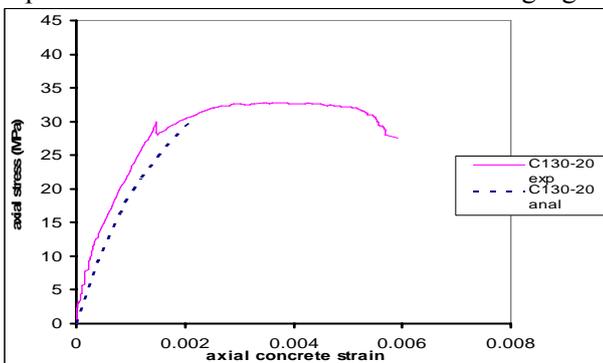


Axial stress-strain curves for the columns of 200*250 mm cross section

The above figure shows the axial stress-axial strain curves for some of the tested columns. All the curves start with linear part where the slope of the confined concrete is close to that of the unconfined concrete. At stress levels near the ultimate stress of unconfined concrete, the curves start to bend indicating that concrete had cracked and consequently the GFRP started its confining effect because the lateral expansion of the concrete core became greater than that of the GFRP tube or rings

Modeling of axial stress-strain curve:

The equations of Fam and Rizkalla [2] were used after some modifications to predict the axial stress-strain curve of specimen C130-20. The ascending part of the predicted curve is close to the experimental result as shown in the following figure.



Analytical modeling for the axial stress-strain of column C130-20

Strength measures:

The column strength is evaluated using two measures. The first measure is the effective

confinement (K_s) which is defined as the ratio between the confined core, inside the GFRP tube or rings, strength (f_{cc}) to the unconfined concrete compressive strength (f_{co}). The unconfined concrete compressive strength (f_{co}) is taken equal to 0.70 times the standard cube compressive strength (f_{cu}). The confined core strength (f_{cc}) is equal to the load carried by the concrete core only ($P_{c\ max}$) divided by the area of the confined core (A_{co}). $P_{c\ max}$ equals to the total attained experimental load (P_{max}) minus the load which can be resisted by the vertical reinforcement (P_{st}) and minus the load resisted by the concrete cover, which is f_{co} times the area of the cover. The second measure for the column strength is the gain of the confined core strength (Δf_c) which is the difference between the confined core strength (f_{cc}) and the unconfined core strength (f_{co}).

Both the strength measures are increased when confining using GFRP tubes or rings, with the exception of specimens C2a-20 and C2a-25 which had rings of 200 mm spacing. The maximum increase is recorded for specimens C130-20 and C130-25. The percentage of increase for column C130-20 in K_s and Δf_c was 53.5 and 233.5, respectively. Similarly, the percentage of increase for column C130-25 was 17.2 and 82.8, respectively.

Conclusions:

1. Confinement of rectangular columns with circular GFRP tubes or rings imbedded inside the column generally leads to improvement in the ductility of the columns as well as the axial load carrying capacity. The highest improvement level is achieved for the case of specimens with continuous tubes.
2. The slightly modified model of Fam and Rizkalla was capable to accurately predict the axial stress-strain curve.
3. The model of Fardis and Khalili gives the best prediction for the ultimate confined strength while the model of Karbhari et al. gives the best prediction for the strain at peak confined strength.
4. The strength measures, as defined above, are generally both increased due to confining with the maximum increase attained by the specimens with 1300 mm GFRP tubes.

References:

1. Saafi, M.; Toutanji, H. A.; and Li, Z., "Behavior of Concrete Columns Confined with Fiber Reinforced Polymer Tubes," ACI Materials Journal, V. 96, No. 4, July- August 1999, pp. 500-510.
2. Fam, A. Z.; and Rizkalla, S. H., "Confinement Model for Axially Loaded Concrete Confined by Circular Fiber-Reinforced Polymer Tubes," ACI Structural Journal, V. 98, No. 4, July- August 2001, pp. 451-461.