Ultimate Bearing Capacities of Concrete Filled Hybrid Composite Tubular Short Columns

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Abstract. The new reinforcement material, Hybrid Composite (HC), is new innovative material and made of carbon fiber or other fibers in the form of tubular weave or braid. HC tubes has been used in column and pier to restrict the lateral expansion of concrete to improve the compression performance, while protecting the column as well. In this paper, the mechanical behavior of HC reinforced concrete short columns under axial and eccentric compression loading is analyzed. By testing the model and analysis the result using finite element software ABAQUS, the displacement, and load capacity of all specimens are collected and analyzed in terms of the number of HC layers and eccentricity ratios. The results show that the ultimate load capacity of columns increases with the number of HC layers under axial compression, and the ductility of the reinforced columns was significantly improved by HC reinforcement, compared with plain concrete columns.

1. Introduction
The Hybrid Composite (HC) is made of carbon fiber or other fibers in the form of tubular weave or braid (Figure 1), which can replace the steel reinforcement to reinforce the concrete. Most of the infrastructures were built by steel reinforced concrete structure. However, the steel is easily affected by surrounding environment to be corrosion, which will change the steel material properties to decrease the load capacity [1]. This effect will cause the damage to the structure. Lightweight fiber reinforced polymer (FRP) has been developed and show great potential but major technical challenges remain, including a lack of reinforcement ductility and installation difficulties [2-5]. HC material compare to traditional reinforcement material have many advantages [6,7]. However, there is limited research related to concrete filled HC tubular material. This paper will conduct experiment and finite element analysis on concrete filled HC tubular short columns using different number of HC layer under different eccentricity loading, and compare their performance characteristics with the FRP reinforced concrete short columns and normal concrete short columns.

2. Experiment design
2.1. Specimen design
All specimens have same diameter 305mm, high 915mm circular shape. The eccentricity has 0, 0.1, 0.2, 0.3. Furthermore, for the concrete filled HC tubular short column will have three different set of specimens under four different assigned eccentricity loading such as one layer of concrete filled HC
tubular short column will under four different assigned eccentricity loading. The detail of specimens as shown in Table 1.

Table 1. List of specimen

| No.  | Number of HC layer | Number of FRP layer | Eccentricity |
|------|--------------------|---------------------|--------------|
| HC-1-0 | 1                  | -                   | 0            |
| HC-2-0 |                    | 0                   |              |
| HC-2-0.1 | 2                  | -                   | 0.1          |
| HC-2-0.2 |                    | -                   | 0.2          |
| HC-2-0.3 |                    | -                   | 0.3          |
| HC-3-0 |                    | 0                   |              |
| HC-3-0.1 | 3                  | -                   | 0.1          |
| HC-3-0.2 |                    | -                   | 0.2          |
| HC-3-0.3 |                    | -                   | 0.3          |
| FRP-2-0 | -                  | 2                   | 0            |
| NC-0-0 | -                  | -                   | 0            |

2.2. Material properties
Normal concrete material ingredient is listed in Table 2. HC Tube properties provided by Wayne State University listed in Table 3.

Table 2. Ingredient of normal concrete (C30)

| Type   | Cement (kg/m³) | Sand (kg/m³) | Aggregate (kg/m³) | Water (kg/m³) |
|--------|----------------|--------------|-------------------|---------------|
| C30    | 461            | 512          | 1252              | 175           |

Table 3. HC material properties

| Diameter (mm) | Thickness (mm) | Density (kg/m³) | Braid angle | Axial modulus (GPa) | Transverse modulus (GPa) | Axial strength (MPa) | Transverse Strength (MPa) |
|---------------|----------------|-----------------|-------------|---------------------|--------------------------|----------------------|--------------------------|
| 300           | 0.79           | 0.675           | 45°         | 24.1                | 24.1                     | 241                  | 241                      |

2.3. Specimen setup
HC has very flexible property and will cost additional set up work during the experiment which is different from other reinforced concrete procedure. Applying the steel spiral tie as HC framework will be necessary to hold the HC reinforcement as expected position for reinforcement before pouring concrete. Meanwhile, the premade plastic tube will hold HC tube through the concrete curing time, as shown in Figure 2. After pouring the concrete, the steel spiral tie will be removed for concrete curing process. For different layer of concrete filled HC tubular short column will follow the same procedure, as shown in Figure 2. Normal concrete column, concrete filled HC tubular column, FRP reinforced concrete short column, and their testing device are shown in Figure 3. All the specimens are under compression testing used to test the ultimate capacity. The experiment is performed in general accordace with ASTM C39 “Standard test method for compressive strength of cylindrical concrete specimen” [8]. The failure mode is an important factor to understand the internal and the external
behaviors of the concrete filled HC tubular short column. Meanwhile, by comparing with the other specimen, the HC reinforcement behavior can be presented and discussed.

2.4. Experimental Result
For one-layer concrete filled HC tubular short column (HC-1-0), there is no significant outcome at the beginning of the compression due to the small loading. With the increasing loading, the local buckling, as lateral displacement, becomes larger. Once the concrete filled HC tubular short column reaches the ultimate capacity, at the top of the HC specimen generated the local HC material breaking (Figure 4).

For two-layers HC reinforced concrete shirt column (HC-2-0), when the ultimate capacity reached, the large area of the buckling becomes more obvious. Then the capacity starts to decrease, there are more buckling generated at the same time (see Figure 5). For three-layers HC reinforced concrete shirt column (HC-3-0), it has similar process with two-layers specimen.

By setting the loading type as constant, the ultimate capacity is increasing while the number of HC layer is increasing. Meanwhile, the normal concrete (NC-0-0) reached the ultimate capacity, the capacity decreased sharply as same as FRP reinforced concrete (FRP-2-0). However, the HC specimen has slowly decreasing capacity which is similar as steel yielding process. Therefore, under the same loading type, the HC can provide the increased ultimate capacity the higher number of HC layer, the higher ultimate capacity as well as avoiding sudden failure due to the HC confinement. (see Fig. 6)
For eccentricity loading as 0.1, 0.2 and 0.3, using two-layer and three-layer HC reinforced concrete short column are to find the relationship between the ultimate capacity and number of HC reinforcement layer. While the eccentricity is increasing, the HC failure section becomes more obviously which the top section of specimen starts bending and the HC material rapture (Figure 7). All different eccentricity loading set as one discussion group. By comparing all the two layers specimen or three layers specimen, the ultimate capacity is decreasing with the increasing eccentricity. After reaching the ultimate capacity, the capacity decreasing slowly as the vertical displacement increasing due to the compression loading. (Figure 8).

3. Finite element analysis
For further studying of the compression behaviour of concrete filled HC composite tubular columns, the finite element program, ABAQUS, was used for 3-D analyses of specimen. Using simple cylindrical shell (element M3D4R) to replace the woven shape, because the complexity about woven composite
material in finite element analysis, as shown in Figure 9. The core concrete was used by element C3D8R. The result shows that the FE data match the experimental data before 70% of the ultimate capacity for all the HC reinforced concrete short column. Between 70% of the ultimate capacity and ultimate capacity, the FE results are slightly larger than experimental result. The finite element analysis is focus on the data before the failure occur due to the simplified model cannot best represent the woven material property (Figure 10).

Figure 9. FE model

![FE Model](image)

![FE Model](image)

Figure 10. Experimental and FE displacement V.S Load Capacity

It has been shown that the FE can be used to model the concrete filled HC composite tubular short columns with excellent accuracy. In order to compare the influencing parameter, i.e. eccentricity (0.1~0.6) and number of layer (1~6), respectively, were studied numerically. Other geometric factors were kept the same as those in the test specimens. Figure 11 shows the ultimate bearing capacity of specimens decreases linearly with the eccentricity increase and increases linearly with the added of number of layer. Eccentricity and HC layers are two most important influencing parameter on the failure form and bearing capacity of HC tube-concrete column.

Figure 11. Numerical result of ultimate bearing capacity

(a) eccentricity

(b) number of layer
4. Conclusion
After all the experiment data analysis, the HC reinforcement has shown many beneficial for concrete reinforcement comparing with existing FRP material. All HC specimen show the gradually decreasing capacity when the ultimate capacity reached. It shows the ability to avoid sudden failure other than FRP brittleness property. Under the same loading condition, the increasing number of HC layer will provide increasing ultimate capacity. Under the different eccentricity loading condition, the increasing eccentricity will provide decreasing ultimate capacity while the number of HC layer set as constant. The calculated results are in good agreement with the experimental results. Eccentricity and HC layers have more influence on the failure form and bearing capacity of HC tube-concrete column.

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References
[1] Xiao, X., Wu, H. (2000) Compressive behavior of concrete confined by carbon fiber composite jackets. Journal of Materials in Civil Engineering, 12(2): 139-146.
[2] Lu, X.Z., Teng, J.G., Ye, L.P. (2005) Bond-slip models for FRP sheets/plates bonded to concrete. Engineering Structures, 27(6): 920-937.
[3] Teng, J.G., Jiang, T., Lam, L., Luo, Y.Z. (2009) Refinement of a Design-Oriented Stress-Strain Model for FRP-Confined Concrete. Journal of Composites for Construction, 13(4): 269-278.
[4] Tobbi, H., Bennokrane, B., Farghaly, A.S. (2012) Concrete columns reinforced longitudinally and transversally with glass fiber-reinforced polymer bars. ACI Structural Journal, 551-558.
[5] Wang, X.X., Qi, Y.J., Sun, Y.L., Xie, Z.J. Liu, W.Q. (2019) Compressive behavior of composite concrete columns with encased FRP confined concrete cores. Sensor, 19(8): 1792.
[6] Diallo, B.S. (2014) Innovative approach to column reinforcement using hybrid composite reinforcement, Wayne State University, Detroit, Michigan, Master thesis.
[7] Wu, H.C. (2000) Mechanical Interaction between Concrete and FRP. Journal of Composites for Construction, 4(2): 96-98.
[8] ASTM C39/C39M – 09a. (2009) Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.