Effect of void Ratio of Inner Steel Tube on Compression Behavior of Double Skin Tubular Column

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Abstract. Hybrid double skin tubular columns (DSTCs) are a composite members that consist of outer FRP tube and inner steel tube and concrete filled in between. These three materials combination in one element have several advantages do not found in common columns. The total 12 circular DSTCs were poured and tested under axial load. Every specimen is average of a pair of samples of the variables, diameter and thickness of steel tube, to investigate effect of inner steel tube void ratio on compression behavior of hybrid DSTC. The void ratio was defined as a ratio between the two inner steel and outer FRP tube diameter. The test results show that the stress-strain behavior of concrete material in the hybrid DSTCs has a better confined by two tubes. While the DSTC with small diameter has similar behavior to concrete filled FRP tube (CFFT). Thickness of inner steel tube is slightly effect on concrete stress inside DSTC.

Keywords: Double skin tubular columns, FRP tube, Steel tube and void ratio.

1. Introduction

Over the past two decades, the fiber reinforced polymer (FRP) composites confining concrete. At recent years excessive research on the hybrid composites fiber-reinforced polymer (FRP) confined concrete because of unique property of excellent corrosion resistance, hybrid FRP concrete tubular columns have great potential for using to be exposed to a harsh environment in outward. Concrete filled FRP tube (CFFT) by Yu et. al. 2014[1], Xie et. al. 2015[2]. Concrete filled steel tube (CFST), Shi et. al. 2015[3]. Hybrid double skin tubular column (DSTC) composite section was proposed by Teng et. al. 2004[4] consists of outer FRP tube, inner steel tube and concrete filled in between. This composite section is perfectly used for compression members when steel tube centricity. Also it is used for tension members when steel tube is eccentricity (but in this case shear connectors is needed). Yu et. al. 2007 studied concept and behavior of DSTC [4], Yu et. al. 2012 studied compressive behavior of circular and square DSTC [5]. Ozbakkaloglu et. al. 2013 investigated the effect of high and normal strength concrete on compressive behavior of DSTC [6]. Fanggi et. al. 2014 studied effect of inner steel tube cross section on DSTC [7]. Ozbakkaloglu el. at. 2014 investigated seismic behavior of DSTC [8]. These studies were illustrate a better ductile behavior of the DSTCs under axial load, combined axial and flexure load and seismic load. FRP tube thickness was significant effect on stress and strain curve and inner steel tube prevent concrete spalling from inward. Concrete material inside the hybrid DSTCs restrained by two tubes leads to increasing its compressive strength. The experimental procedure of this paper includes investigation of the effect of inner steel tube void ratio on compressive behavior of carbon FRP –concrete –steel double skin tubular columns. The study was aimed to investigating the circular DSTCs with cross section of dimension (100 mm*310 mm) to provide properties of column according to ACI CODE [9].
2. Experimental Testing Description

All 12 DSTCs have 100 mm in diameter (D) and 310 mm in height, the outer FRP tubes were made by embedded carbon fiber sheet on polymer resin Table 1 illustrates details of specimens. The first letter of specimens name refers to double skin tubular column (D) and the letter (C) refer to concrete compressive strength of cubic fcu (70mm* 70mm) C60. The letters (ds) refer to diameter of inner steel tube diameter 48mm ds48, diameter 38mm ds38, diameter 32mm ds32 and diameter 25mm ds25. The letters (ts) refer to thickness of inner steel tube thickness 1.5mm ts1.5, thickness 2mm ts2 and thickness 3mm ts3. The roman numeral (I) refer to number of carbon fiber reinforced polymer layers I: one layers.

| Specimens Designation | Cubic Compressive Strength of Concrete fcu (MPa) | Cylinder Compressive Strength of Concrete fć (MPa) | Diameter of Inner Steel Tube (mm) | Thickness of Inner Steel Tube (mm) | Number of layers of FRP Tube |
|-----------------------|-----------------------------------------------|-----------------------------------------------|---------------------------------|---------------------------------|----------------------------|
| DC60ds48ts1.5I        | 60                                            | 50                                            | 48                              | 1.5                             | 1                          |
| DC60ds48ts2I          | 60                                            | 50                                            | 48                              | 2                               | 1                          |
| DC60ds48ts3I          | 60                                            | 50                                            | 48                              | 3                               | 1                          |
| DC60ds38ts2I          | 60                                            | 50                                            | 38                              | 1.5                             | 1                          |
| DC60ds32ts2I          | 60                                            | 50                                            | 32                              | 1.5                             | 1                          |
| DC60ds25ts2I          | 60                                            | 50                                            | 25                              | 1.5                             | 1                          |

3. Column Materials

3.1. Concrete material

The specimens were poured with high strength self-compact concrete (mortar) with cement: sand 1:1.5, water/cementitious ratio 0.35. The silica fume was added by 15% to increase concrete compressive strength and to attain workable of mix super plasticizer with 2.17% was added.

3.2. Fiber Reinforced Polymer (FRP)

Fiber reinforced polymer (FRP) includes the imbedded fibers in polymeric resin and has several advantages compared with steel. These advantages are good corrosion resistance and high strength to its weight ratio. Carbon fiber reinforced polymer tube (CFRP) was used in this work consists of two components, unidirectional carbon fiber sheet and epoxy resin. Table 2 illustrate the properties of carbon fiber sheet from data sheet. The carbon sheet was cut into three pieces, two small with 50 mm width and third pieces with 310mm width, with overlapping zone 100mm, that pieces embedded with epoxy and rounded on PVC tube with diameter 100 mm after 48 hours carbon fiber reinforced polymer (CFRP) tube was removed from PVC tube and ready to use.
Table 2. Properties of Carbon Fiber

| Nominal thickness t_f (mm-ply) | Tensile strength f_f (MPa)(nominal) | Ultimate tensile strain ε_f (%) | Elastic modulus Ef (GPa)(nominal) |
|-------------------------------|-------------------------------------|-------------------------------|---------------------------------|
| 0.12                          | 4100                                 | 1.7                           | 231000                          |

3.3 Steel Tubes

Six types of circular hollow steel tubes (HST) was set up inside of DSTCs specimens in center, three specimens for each type of steel tubes were prepared to compression test, test result include average of these three specimens, ds refer to diameter and ts refer to thickness of steel tube. Specimens prepared to compression test by sit up, four leaner variable displacement transducer (LVDT) were placed on two opposite sides between loading steel plate and support to measure axial displacement, axial shortening was gain of average of four reading, four strain gauges with 5mm was installed in mid height of steel tube two vertically to measured axial strain and two horizontal to measured lateral strain, capacity of testing machine 2000 kN, with load control rate 1kN/sec. testing was occur in civil engineering lap at university of diyala. Data obtained from test include that was axial load-strain curve, axial stress–strain curve, peak load, yield load, yield stress and max strain were shown in Table 3.

Table 3. Properties of Steel Tube

| Specimens Designation | Peak load (kN) | Yield load (kN) | Yielding stress (MPa) | Axial strain (mm/mm) | Lateral strain (mm/mm) | Modes Failure |
|-----------------------|----------------|----------------|-----------------------|----------------------|------------------------|---------------|
| HSTds25ts2            | 55             | 40             | 315                   | -1.500               | 2.380                  | G.B.¹ and E.F.² |
| HSTds32ts2            | 67             | 55             | 324                   | -1.548               | 1.823                  | G.B.¹ and E.F.² |
| HSTds38ts2            | 70             | 65             | 325                   | -1.624               | 2.224                  | G.B.¹ and E.F.² |
| HSTds48ts2            | 97             | 80             | 327                   | -1.557               | 2.308                  | G.B.¹ and E.F.² |
| HSTds48ts1.5          | 75             | 60             | 327                   | -1.550               | 2.034                  | G.B.¹, E.F.² and R.³ |
| HSTds48ts3            | 175            | 130            | 350                   | -1.666               | 1.167                  | G.B.¹ & E.F.² |

¹ G.B. global buckling, ² E.F. elephant footing, ³ R. rippling

4. Test of Specimens

Concrete was poured between two tubes with no compaction in order to not made any movement of tubes. Every specimen was poured in a pair of columns, after 48 hours columns was remove from mold, double skin tubular columns were covered them with nylon, at day of 30 columns were subjected to axial compressive load until failure. The specimens were prepared for testing by setting specimen at the positions between loading and supporting in the beginning of test loading plate touch steel plate (steel disc with diameter 95 mm willed on rectangular steel plate with dimension 140*200 mm and thickness 3mm), Figure 1 illustrate test machine, data logger read axial compression load number (1), and four L.V.D.T. were fixed
on two opposite sides of column its end touch the steel plate and its wired to the logger number 2 to read axial shortening, strain gauges were reach to the data logger number 3 to read strains of two tubes.

![Figure 1. Testing machine.](image)

4.1 Axial Load Capacity of Specimens

Table 4 shown the axial load capacity of double skin tubular columns (DSTC), the values of $\frac{P_u}{P_{c+P_s}}$ ratio define as percentage between ultimate load of specimens ($P_u$) to ultimate load capacity of concrete ($P_c$) and ultimate load of steel test ($P_s$), $P_c$ was get from multiplying strength of unconfined concrete ($f_{\text{c}}$ of cylinder) by cross section of concrete in side DSTC. $P_s$ was ultimate load of steel get from compression test of steel tubes. The $\frac{P_u}{P_{c+P_s}}$ ratio shown the axial load was decrease by (4% and 8%) in DSTCs with $t_s$ (2 and 3) mm respectively, compared with DSTC of $t_s$ (1.5) mm, that’s refer to inner steel tube thickness was not clear effect on axial load because small cross section of DSTC. While the axial load was increase by (5%, 7% and 16%) in DSTCs with $d_s$ (38, 32 and 25) mm respectively, compared with DSTC of $d_s$ (48) mm, because of better restrained of concrete by two tubes, steel tube inside and FRP outside.

4.2 Load- Shortening Behavior of Specimens

The load-shortening of DSTCs with $t_s$ (1.5, 2 and 3) mm was shown in Figure 2, the behavior of curve at first part was bilinear and in DSTCs, while drop in load was occur after transition point in specimens with $t_s$ (2 and 3) mm, that’s happen because redistribution stress of concrete after yielding of inner steel tube had been happen. Table 4 shown the test results, it can be seen that the service shortening at (0.7$P_u$) [10,11,12,13] decreased by (27% and 55%), and ultimate shortening slightly increase by (1.4% and 5.3%), in DSCTs with $t_s$ (2 and 3) mm, respectively, compared with those of $t_s$ (1.5) mm. Figure 3 illustrate load -shortening relationship of DSTCs with $d_s$ (48, 38, 32 and 25) mm, when decrease inner steel tube diameter ultimate load was increase, behavior of the DSTC approximately became similar to behavior of concrete filled fiber tube column, the service shortening decreasing by (12%, 31% and 46%) and the ultimate shortening was increase by (1.6%, 2.5% and 17%) in DSTC with $d_s$ (38, 32 and 25) mm, respectively compared with reference DSTCs of $d_s$ (48) mm.

4.3 Axial Stress-Axial Strain Behavior

Axial stress of unconfined concrete ($f_{\text{c}}$) was obtained from cylinder of dimension of 100 mm × 200 mm, strain was measured by strain gauges were installed axially on mid height of cylinder, the axial stress of concrete inside DSTC ($f_c$) evaluated by ultimate load of DSTC subtraction from ultimate load of steel tube test to same strain, axial strain of columns was get from average of two strain gauges at mid of
height of specimen, enhancement ratio (ER), \((f_c/\bar{f}_c)\) was percentage between ultimate stress of concrete confined by FRP tube to ultimate stress of unconfined concrete.

**Table 4. Summary of Test Result**

| Specimens Designation | Pu (kN) | As (mm) | Au (mm) | Pc (kN) | Ps (kN) | Pu/(Pc + Ps) (MPa) | fc (MPa) | CR | ER (mm/mm) | εa (mm/mm) | K1 | εh (mm/mm) |
|-----------------------|--------|--------|--------|--------|--------|-------------------|---------|----|-------------|------------|----|------------|
| DC60ds48ts1.5I        | 518    | 2.8    | 5.90   | 303    | 75     | 1.37              | 74.0    | 0.188 | 1.48        | -3.5       | 2.14 | 3.20       |
| DC60ds48ts2I          | 527    | 2.2    | 6.20   | 303    | 97     | 1.32              | 69.0    | 0.188 | 1.38        | -3.70      | 2.26 | 3.35       |
| DC60ds48ts3I          | 603    | 1.8    | 6.77   | 303    | 175    | 1.26              | 70.5    | 0.188 | 1.41        | -3.82      | 2.34 | 3.50       |
| DC60ds38ts2I          | 561    | 2.3    | 6.30   | 335    | 70.0   | 1.39              | 75.05   | 0.188 | 1.50        | -3.75      | 2.30 | 2.65       |
| DC60ds32ts2I          | 590    | 1.8    | 6.36   | 352    | 67.0   | 1.41              | 76.50   | 0.188 | 1.53        | -4.35      | 2.67 | 3.30       |
| DC60ds25ts2I          | 646    | 1.4    | 6.70   | 368    | 55.6   | 1.53              | 80.50   | 0.188 | 1.61        | -4.75      | 2.91 | 2.80       |

The nominal confinement ratio (CR) of designing outer FRP tube was percentage between confining pressure to concrete compressive strength, calculated from Eq. (1) with different compressive strengths of concrete assemblage as uniform distribution of confinement DSTCs. (T. Ozbakkaloglu 2013)

\[
\frac{f_L}{f_c} = \frac{2\varepsilon_f E_f}{D_f} \quad (1)
\]

Where: \(f_L\): confining pressure, \(f_c\): concrete compressive strength, \(E_f\): modulus of elasticity of FRP, \(\varepsilon_f\): ultimate tensile strain of the fibers, \(D_f\): internal diameter of the FRP tube.

**4.4 Effect of Inner Steel Tube Thickness**

Figure 4 to 6 illustrate the stress–strain relationship of DSTCs with ts (1.5, 2 and 3) mm, from Table 4, it can be seen that the stress of concrete inside DSTC was decrease and enhancement strength ratio, while axial strain increased with increase thickness of inner steel tube, with ts (1.5, 2 and 3) mm respectively, that’s because small cross section of specimens and effect of inner steel tube thickness did not appear clearly.

**4.5 Effect of Inner Steel Tube Diameter**

Ultimate stress of concrete in DSTC effected by change diameter of inner steel tube, void area ratio was increase by increase diameter of inner steel tube, stress-strain curve of DSTC with ds (38, 32, 25) mm as illustrated in Figure 7 to 9, ultimate stress of concrete were increase because of core of concrete, by confined concrete by two tubes of DSTC the ER was increase in DSTCs with ds (48, 38, 32 and 25) mm, axial strain was increase in DSTCs with decreased inner steel tube diameter, because reduce inner void and increase amount of concrete.
Figure 2. Load - Shortening relationship of DSTCs with ts (2 and 3) mm.

Figure 3. Load –shortening relationship of DSTCs with ds (48, 38, 32 and 25) mm.

Figure 4. Stress-strain relationship of specimen DC60ds48ts1.5I.

Figure 5. Stress-strain relationship of specimens DC60ds48ts2I.

Figure 6. Stress-strain relationship of specimens DC60ds48ts3I.

Figure 7. Stress-strain relationship of specimens DC60ds38ts2I.
4.6 Hoop Strain

Hoop strain of FRP tube of DSTCs (εh) was get from average of three strain gauges distribution along overlap region. The hoop strain of specimens was illustrated in Table 4, it can be seen that the εh slightly increased by (5% and 9%) in DSTCs with ts (2 and 3) mm, respectively compared with DSTCs of ts (1.5) mm and the εh was decreased by (20%, 1.4% and 16%) in DSTCs with ds (38, 32 and 25) mm compared with DSTC of ds (48) mm.

4.7 Modes of Failure

Figure 10 shown modes failure of DSTCs, all specimen in this study were failed by hoop rupture at top height of outer FRP tube because under high ultimate load movement of concrete was occur, while specimens DC60ds48ts1.5I and DC60ds48ts3I failed by hoop rupture at the mid height of specimens, the position of failure of FRP was corresponded to the location of steel tube deformation.
5. Conclusion

This paper has presented the results of an experimental study on the behavior of FRP-concrete-steel double-skin tubular columns under axial load. The experimental producer involved 12 high strength concrete specimens with DSTCs designed and manufactured. Those experimental testing are implemented in this paper to investigate the influence of the void ratio on the concrete stress-strain relationship.

The following conclusions can be drawn:

1- High strength self-compact concrete was effective confined by two tubes, steel tube inward and FRP outward lead to high ductile behavior and strength of concrete inside DSTCs.

2- When increased thickness of inner steel tube from (1.5 to 2 and 3) mm, the nominal confinement ratio didn’t effected by properties of inner steel tube, the ultimate load increased by (2% and 16%), the service shortening decreased by (27% and 55%), the ultimate shortening slightly increase by (1.4% and 5.3%), the stress of concrete inside DSTCs and strength enhancement ratio decreases by (7% and 5%), the enhancement axial strain increased by (6% and 9%) and hoop strain slightly increased by (5% and 9%) in DSTCs.

3- When increase diameter of inner steel tube from (25 to 32, 38 and 48) mm, the ultimate load decreased by (9% to 18%), the service shortening increasing by (39% to 88%) and the ultimate shortening was decrease by (5% to 7%), the stress of concrete inside DSTCs decreased by (5% to 14%), the strength enhancement ratio decreased by (2% to 14%), enhancement of axial strain decreased by (8% to 22%) and hoop strain decreased by (5% to 20%).

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