An overview of hybrid fiber reinforced polymer (FRP) concrete steel double-skin tubular column (DSTC) members

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Abstract - *Hybrid fiber reinforced polymer (FRP) concrete steel double-skin tubular column (DSTC) members consist of an inner steel tube and an outer FRP tube. The space between the two materials is filled with concrete. The use of these hybrid columns is increased because it is functional as a confinement material, a reinforcement, and a structural column member.*
The inner steel tube acts as a reinforcement and formwork for the concrete, while the outer FRP tube acts as a confinement for the concrete. The concrete itself delays the local buckling of the inner steel tube. This hybrid FRP DSTC member shows tremendous advantages.
This paper reviews the knowledge of hybrid FRP DSTC in column or beam member applications in new or existing engineering structures.

Key Words: fiber reinforced polymer (FRP), double skin tubular column (DSTC), hybrid column members, tubular columns, circular tube, square tube

1. INTRODUCTION

In modern infrastructure, fiber reinforced polymer (FRP) composite materials in civil engineering structures have emerged rapidly popular, because of the better material properties they have over conventional concrete and steel materials. Some advantages of the FRP material are the corrosion resistance, the high durability, increased strength, damping ability, reduced construction time and lower maintenance costs [1].

A hybrid FRP double-skin tubular column (DSTC) member are composite members, which consists of an outer FRP tube, an inner steel tube and the space between the tubes filled with concrete (Fig. 1). The three materials (FRP, steel, and concrete) work cohesive with each other, which exploits their respective advantages.

The FRP DSTC members can take many forms like circular FRP DSTC, rectangle FRP DSTC, and square FRP DSTC. The placement of the inner steel tubes can also vary from being eccentric or concentric in the hybrid member (Fig. 2).

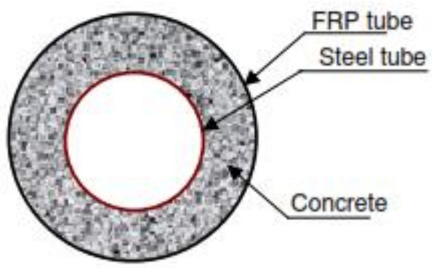

Fig -1: Cross section hybrid circular FRP DSTC

This paper reviews the research on the behavior of these structural hybrid FRP column members. The focus on these hybrid FRP members lies on the type of loading conditions varying from axial compressive to flexural or seismic loading.

1.1 Circular hybrid FRP column members

The very first type of FRP DSTC columns was examined by Teng et al. [2], [3] and his group. These type of columns were circular with a height of 305 mm and diameter of 152.5 mm. They consisted of an outer FRP tube, an inner steel tube and the annular section filled by concrete. The FRP tubes were fabricated by wrapping process with the fibres oriented mainly in the hoop direction of the tube. The study group reported that the test results confirmed the positive influence of confinement on the concrete by the FRP material and the concrete supporting the inner steel tube against buckling.

The effect of the inner steel tube diameter, the concrete infill and loading pattern on the axial behavior of FRP-concrete steel composite columns was investigated by Fanggi and Ozbakkaloglu [4]. They tested 32 specimens with concrete filled FRP tubes and two types of double skin tubular columns (DSTCs). The inner steel tube in the first type was filled with concrete while it was kept unfilled in the second one. The dimensions of FRP tubes had a height of 305 mm and diameter of 152.5 mm, and they were formed by layup process of S-glass fibre in the hoop direction. The unconfined concrete strength of the filler was ranging from 82.4 to 96.2 MPa. The results of filled specimens that were confined by both. FRP and steel tubes show a high level of improvement than others that were confined by FRP tube only due to the dual effects of FRP and steel confinements on the concrete. DSTCs specimens exhibit higher strength under cyclic loading as well. According to the study, the axial behavior was improved for filled compared to that of the hollow DSTCs especially when the diameter of the inner steel tube increases.

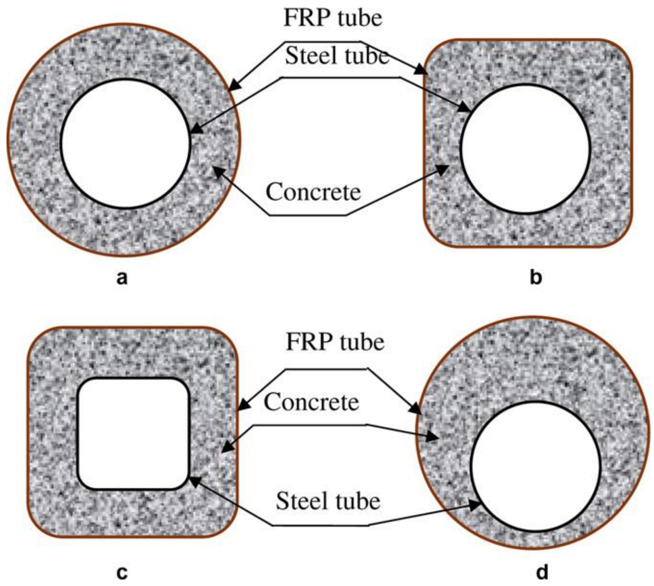

Fig -2: Typical sections of FRP DSTCs

Ozbakkaloglu [5] examined the effect of filling DSTCs with different concrete grades. Depending on the fill conditions of the inner steel tube, three series of specimens were set; hollow, filled with the same concrete that was used to fill the annular section between tubes and filled with concrete of higher strength than that used to fill the annular section. The research showed that specimens with dual grade concrete exhibit superior compressive behavior than those with single grade concrete.

1.2 Square hybrid FRP column members

The investigation of the effect of filling DSTCs with different concrete grades by Ozbakkaloglu [5] was also carried out with square FRP DSTCs. The research showed that the circular specimens exhibit superior compressive behavior than the square specimens with dual grade concrete.

Kaidi Peng et al. [6] examined the axial compressive behavior with the effect of the number, thickness, and width of rib stiffeners as well as the thickness of the FRP tube (Fig. 3). The researched showed that additional rib stiffeners are effective in delaying the local buckling of the steel tube in hybrid DSTCs and in enhancing the load capacity and ductility of the columns. The use of a more significant number of thin ribs is more effective in improving the structural performance of hybrid DSTCs than that of a smaller number of thick ribs with the same amount of additional steel material. The performance of hybrid DSTCs is generally improved with the increase of thickness or width of rib stiffeners when all the other parameters remain unchanged. When the amount of steel and the number of rib stiffeners are the same, the increase of thickness (and consequently the decrease in width) of rib stiffeners leads to the slightly improved performance of hybrid DSTCs. The increase of the thickness of the FRP tube leads to an increase in the load capacity of hybrid DSTCs and delays the buckling of the steel inner tube.

The effect of the behavior of fiber reinforced polymer (FRP) recycled concreted (RAC) under concentric compression was investigated by Junai Zheng, Togay Ozbakkaloglu [7]. The researchers were studying 24 hollow core circular and square DSTCs with parameters as the concrete strength, aggregate replacement ratio and the shape of the DSTC cross-section. Results indicate that the overall behavior and performance of RAC DSTCs closely resemble that of DSTCs manufactured with conventional concrete, which is highly promising for structural use. The replacement ratio has limited influence on the ultimate condition of DSTCs. On the other hand, the replacement ratio has some influence on the trend of the stress-strain curve of concrete in DSTCs, and this is more pronounced in square specimens than in circular specimens.

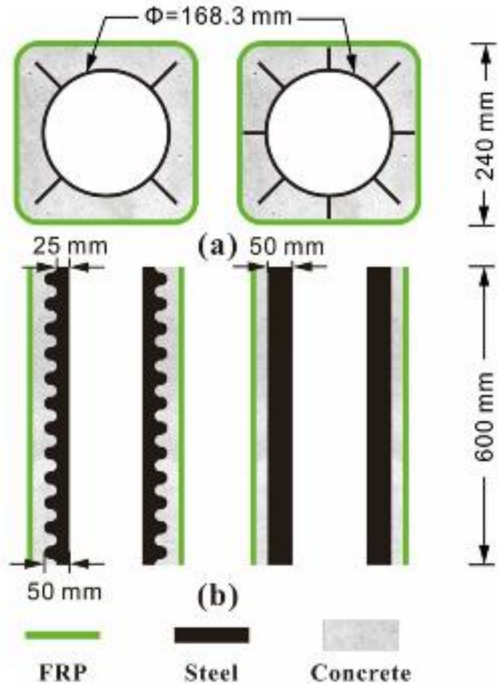

Fig -3: Details of hybrid R-DSTCs: (a) cross sections; (b) vertical sections

The research group of Jun-Jie Zeng et al. [8], investigated the axial compressive behavior of double-tube concrete columns (DTCCs). The DTCCS had an outer square FRP tube and an inner circular high-strength steel tube. The researchers tested eight square DTCC specimens with parameters that included the type of the FRP tube, the thickness and the width of the FRP tube. The results of the experiment show that, in square DTCCs, the concrete is well confined by both the HSS tube and the FRP tube. The buckling of the HSS tube is effectively restrained so that its high material strength can be effectively utilized, leading to an excellent column performance (Chart 1). The results also demonstrate that square DTCCs possess considerable post-peak strength. An indication of outstanding ductility and the potential to apply this new form of hybrid column members in [8] earthquake-prone zones.

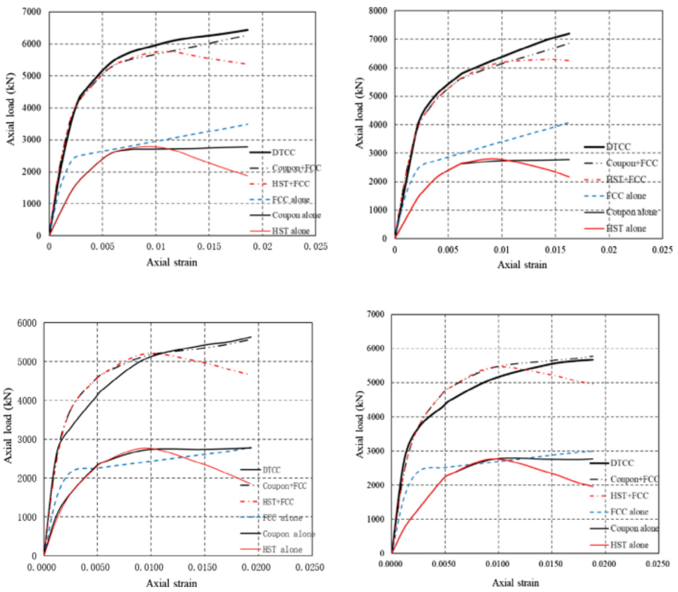

Chart -1: Components of axial load resistance in a square DTCC10

1.3 Other hybrid FRP column members

A new form of a hybrid column was proposed by Xue and Gong [9]. Their columns consist of GFRP tube filled with concrete and reinforced with steel I-section. They investigated effects of concrete strength by using two types of both concrete (39.5 MPa, 51.6 MPa), and reinforcement ratio and three values of FRP wall thickness. Three types of GFRP tubes with same inner diameter and different wall thickness (4,5, 6 mm) were fabricated using filament winding of fibres at an angle of 55° with the transverse direction and two different sizes of I-steel section. The reference specimen was a concrete filled GFRP tube. The research concluded that rupture of the GFRP tubes is the dominant failure mode, and the proposed hybrid column has higher strength and deformation (due to the steel I section reinforcement) than the concrete filled FRP tube.

2. SUMMARY FRP COLUMNS

The use of traditional construction material (steel and concrete) and the FRP tube to form hybrid FRP columns is similar to the first one because of the orientation of fibres sets towards the transverse direction of the column in order to create confining pressure. Furthermore, most studies were conducted on short column specimens. Although the main reason to innovate hybrid FRP columns is to provide the lightweight property, the hybrid FRP columns are ever evolving through the use of fillers, steel tubes or steel I sections. This process provides a hybrid FRP–steel concrete column which can be researched in two ways. The first one is the axial behavior of hybrid column and the second one is the improvement in the axial behavior of steel section due to strengthening with concrete filled FRP tube. Table 1 gives a summary of research on hybrid FRP DSTC members.

Factors that influence the degree of confinement are studied extensively in the past. Majority of the research used circular concrete specimens with a height-to-diameter ratio equal to 2. These short columns will not fail due to local or global buckling. The combined effect of the slenderness ratio and effects of other factors that influence the degree of confinement are not investigated for columns at a height-to-diameter ratio greater than 5 to specify how the axial strength and ductility of slender columns can be improved. Furthermore, it is essential to study FRP confined lightweight concrete intensively because most previous studies examined the axial behavior of FRP confined normal concrete or high strength concrete columns. The confinement of the lightweight concrete columns results in improvements in its ability to resist the axial load [10]. Consequently, the applicability to use FRP confined lightweight concrete columns instead of unconfined regular concrete columns in the construction industry will be increased [11]. Using this will be an economical application because the dead load of the structural column members will drop.

The application and potential opportunities of FRP closed sections in civil and structural engineering will be improved due to further investigations into overcoming the barriers that prevent them to be included in construction. Although extensive research has been done, significant and potential gaps in knowledge are still there. The combined effect of the slenderness ratio of the column and other factors such as the strength of infill concrete, thickness, and diameter of inner steel are not studied in depth. Particularly in the area of slenderness effects on the degree of confinement for concrete columns, the axial behavior of the hollow FRP tubes that is having fibre in multiple-directions and the different shapes of the hybrid FRP columns. Moreover, the use of lightweight concrete will provide an opportunity not to compromise much of the lightweight feature of the FRP profiles. These areas will contribute to fill the gaps in knowledge which will improve the use of FRP tube in the construction industry.

3. CONCLUSIONS

A concise review of different literature presented shows that there have been many published works on the study of hybrid fiber reinforced polymer (FRP) concrete steel double-skin tubular column (DSTC) members. This paper reviewed a broad area of hybrid FRP tubes in column application, in either new or existing engineering constructions. There are different variations in parameters such as length, diameter, thickness, the strength of inner steel tube and outer FRP tube, hollow section ratio, number of FRP layers.
The author identifies some critical findings as follows:

(1) The hybrid FRP DSTC members exhibit higher strength and bending stiffness, and excellent fire and seismic performance.

(2) Investigate the effect of the properties of filler material (lightweight, stiffness and creep) and properties of FRP (pre-stressed) on the behavior of FRP confined concrete columns under concentric and eccentric loads.

Table -1: Summary of hybrid FRP DSTC members

Reference	Cross section	FRP type	Dimensions(mm)		′fc(MPa)
			Steel section		
			d	t	
Teng et al. [2], [3]	Circular	Glass	76.1	3.2	39
Fanggi and Ozbakkaloglu [4]	Circular	S-Glass	60–114	3.2, 6	82–96
Ozbakkaloglu [5]	Circular, Square	Aramid	88.9, 114.3	3.2, 6	49–113
Peng et al. [6]	Circular, Square	Poly-ethylene naphtoate (PEN)	168.3	4.8	33
Zheng and Ozbakkaloglu [7]	Circular, Square	Carbon	88.9	3.2	39-67
Zheng et al. [8]	Circular, Square	Carbon	210	6	37
Xue and Gong [9]	Circular	Glass	I-section		39–51
Zhou et al. [10], [11]	Circular	Carbon	42-70	2	39.8

(3) Comprehensive research work on FRP confined concrete column with larger length/least dimension ratio to study the combined effect of slenderness ratio and other factors.

(4) Examine the improvement in the strength and strain capacities of the non-circular concrete columns. This improvement can be created through confining the core of the concrete column with circular FRP tube that has fibres only in the hoop direction. This improvement gives an opportunity to keep the original shape of the column and increase its capacity to resist loading.

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