

Cyclic Response Study on Strength Behaviour of Circular Hybrid FRP Concrete Steel Double Skin Tubular Columns

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Abstract - Composite columns have been widely used in the construction industry mainly due to its high strength, durability, ease of construction and cost saving. Hybrid FRP Concrete Steel Double Skin Columns (Hybrid DSTC's) are newly developed composite column which combines the structural properties and advantages of FRP, steel and concrete. Hybrid DSTC's composed of inner steel tube, outer FRP tube and concrete is filled between the tubes. Two tubes in hybrid DSTC's are concentrically placed to produce a section form more suitable for columns. The Hybrid DSTC's possess excellent ductility hence they are well suited for seismic regions. Thus behaviour of Hybrid DSTC's under axial cyclic loading is of great importance. This paper investigates the strength behaviour of circular Hybrid DSTC's under axial cyclic loading using ANSYS 16.2 WORKBENCH software. The effect of parameters such as void ratio, steel tube thickness, different FRP's and H/t_c ratio on circular Hybrid DSTC's were also investigated.

Key Words: ANSYS 16.2 WORKBENCH, Hybrid DSTC's, FRP, Ductility, Void ratio, H/t_c ratio.

1. INTRODUCTION

In construction industry now a days various technologies are used for construction methods, materials etc. In case of column construction, reinforced concrete (RC) columns are commonly used for any building due to its easily availability of materials, initial cost of construction etc. These RC columns can only withstand load up to certain extent hence they are not suited for all building constructions. And also reinforced concrete is not suited for every column construction.

In case of construction in coastal areas, bridge piers etc., the concrete gets abraded due to continuous contact of sea water and also lead to corrosion in reinforcement. In such cases, new types of columns such as Concrete Filled Steel Tubular Columns (CFST), Concrete Filled FRP Tubular Columns (CFFT), Concrete Filled Double Skin Tubular Columns (CFDST), Hybrid FRP Concrete Steel Double Skin Tubular Columns (Hybrid DSTC's) etc. are serve as a solution.

It is well recognized that FRP confined concrete can highly improve the strength and deformation of concrete and also it is self-evident that to reduce the self-weight of concrete is the most effective way to reduce the dead load on buildings and thus save construction cost and therefore

lightweight and high performance structures have attracted extensive attentions nowadays [13]. Hence developed a new form of hybrid columns known as Hybrid FRP Concrete Steel Double Skin Tubular Columns (Hybrid DSTC's). Among the various new types of columns, Hybrid FRP Concrete Steel Double Skin Tubular Columns (Hybrid DSTC's) are effective because it possess various advantages over others types of columns. The new Hybrid column is an attempt to combine the advantages of all three constituent materials such as FRP, concrete and steel, so as to achieve a high performance structural member [1].

1.1 Hybrid FRP Concrete Steel Double Skin Tubular Columns (HYBRID DSTC's)

Hybrid FRP Concrete Steel Double Skin Tubular Columns (Hybrid DSTC's) is the new form of Hybrid columns. It consists of outer tube made of FRP and inner tube made of steel, with the space between the filled with concrete. The Figure 1 shows the cross section of Hybrid DSTC's. The inner void may be filled with concrete if desired. The FRP tube is provided with fibers which are predominately oriented in the circumferential direction to provide confinement to concrete and additional shear resistance to columns. The steel tube acts as the main reinforcement and prevents the concrete from inward spalling. The two tubes (FRP tube and steel tube) may be concentrically placed to produce a section more suitable for columns. Hybrid DSTC's may be constructed in situ or precast, with the two tubes acting as the stay-in-place form. It is lightweight due to hollow cross-section. Hybrid DSTC's possess significant advantages which includes lightweight, high strength, high ductility, excellent corrosion resistance and seismic resistance [1]. Shear connectors are provided between the steel tube and concrete, particularly in situations where bending dominates and such shear connectors are generally not needed between concrete and FRP tube if FRP tube has only a small longitudinal stiffness [2].

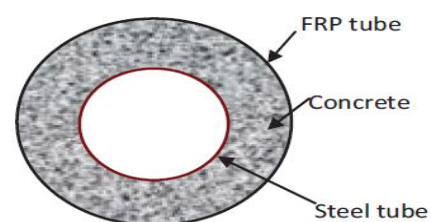
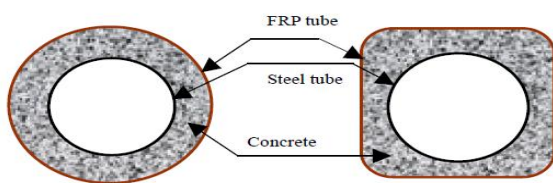


Fig -1: Cross section of Hybrid FRP Concrete Steel Double Skin Tubular Columns (Hybrid DSTC's) [1]

Hybrid DSTC's also uses FRP tube confinement mechanism as that of concrete filled FRP tubular columns (CFFT's) and they offer several advantages, including improved structural performance, improved durability that prolongs the design life, thereby reducing the cost of structural maintenance and urban renewal, significant improvements to the ease of construction that results in reduced construction costs, significant reduction to carbon footprint through more efficient use of materials that reduces required amount of raw materials. And also the inner void in the Hybrid DSTC's reduces the column weight without significantly affecting the flexural rigidity of the section and allows the easy passage of service ducts. The Hybrid columns are lighter due to elimination of redundant concrete. This new form of hybrid columns represents an innovation which combines the advantages of all three constituent materials such as FRP, concrete and steel and those of the structural form of DSTC's to deliver excellent structural and durability performance [6].

1.2 Cross Section of Hybrid DSTC's

The Hybrid DSTC's has several cross sections. And the most common sectional form of Hybrid DSTC's is both tubes are circular, referred as circular Hybrid DSTC's. These circular hybrid DSTC's are attractive for use as bridge piers. And another form of Hybrid DSTC's is square Hybrid DSTC's in which there is square FRP tube and circular steel tube. A circular inner tube is preferred over a square inner tube is that because circular inner tube provides better confinement to the concrete and less prone to local buckling. These square Hybrid DSTC's are used as columns of buildings because of aesthetic and other reasons. The confinement effect applied to concrete is best when hybrid columns are circular [3, 5]. Fig -2 shows common cross sections of Hybrid DSTC's.



Circular Hybrid DSTC's Square Hybrid DSTC

Fig -2: Common cross sections of Hybrid DSTC's [5]

The present study explores numerically the strength behaviour of circular Hybrid DSTC's under axial cyclic loading. The effect of parameters such as void ratio, steel tube thickness, different FRP's and H/t_c ratio on circular Hybrid DSTC's is also investigated.

2. NUMERICAL MODELLING AND ANALYSIS OF CIRCULAR HYBRID DSTC BASE MODEL

Numerical modelling of circular Hybrid DSTC base model was done using ANSYS 16.2 WORKBENCH, a finite element software for mathematical modelling and analysis. A

circular Hybrid DSTC consists of an inner steel tube and outer GFRP tube with space between the tubes filled with concrete. The steel tube and GFRP tube is of circular cross section.

2.1 Specifications of Circular Hybrid DSTC Base Model

The circular Hybrid DSTC base model was modelled in ANSYS 16.2 WORKBENCH with outer diameter of GFRP tube of 156.8 mm, inner diameter of steel tube of 88.9 mm, thickness of GFRP tube of 0.17 mm, thickness of steel tube of 5 mm and height of 400 mm. The space between the two tubes is filled with concrete and the circular Hybrid DSTC base model was modelled with loading plates at top and bottom of size 250 x 250 mm and 20 mm thick. Fig -3 shows modelled view of circular Hybrid DSTC base model.

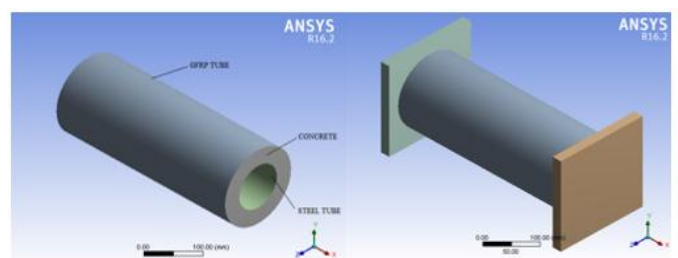


Fig -3: Modelled view of circular Hybrid DSTC base model

2.2 Cyclic Loading Program for Circular Hybrid DSTC Base Model

The cyclic loading program for circular hybrid DSTC's was adopted as per the specifications of ATC 24. The cyclic loading program adopted has 27 cycles. With the help of Ansys software, the cyclic loading was given to analyze the behaviour of circular Hybrid DSTC base model. Fig 4 shows the cyclic loading program adopted for circular Hybrid DSTC base model.

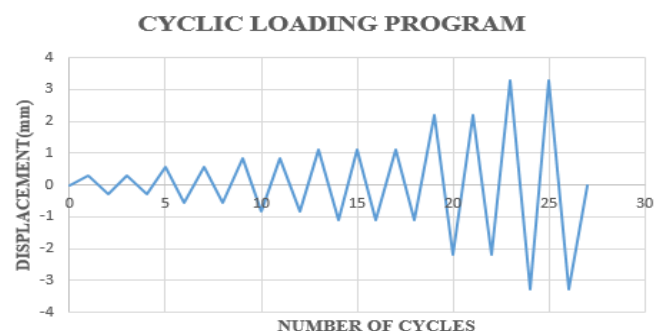


Fig -4: Cyclic loading program for circular Hybrid DSTC base model [16]

3. PARAMETER STUDIES ON CIRCULAR HYBRID DSTC's

The parameter studies were conducted on circular Hybrid DSTC's. The key parameters studied, include void ratio, steel tube thickness, different FRP's, and H/t_c ratio. The

influence of each parameter on the behaviour of circular Hybrid DSTC's were studied. For every parameter investigation the circular Hybrid DSTC base model was kept as a reference model for comparison.

3.1 Void Ratio (VR)

The void ratio is defined as the ratio between the inner diameter and outer diameter of the annular concrete section of Hybrid DSTC. Void ratio is said to be an important parameter that affects the performance of Hybrid DSTC's. The void ratio of circular Hybrid DSTC base model was 0.57. The void ratios studied were 0.53, 0.51, 0.48, 0.46, and 0.43. Table 1 shows the specifications of the void ratio models of circular Hybrid DSTC's used for the study. The height of the circular VR models is kept as 400 mm. The thicknesses of GFRP tube and steel tube is taken as 0.17 mm and 5 mm respectively.

Table -1: Specifications of different VR models of circular Hybrid DSTC's

Model name	Void ratio	Outer diameter of GFRP tube (mm)	Inner diameter of steel tube (mm)
C-VR 0.57	0.57	156.8	88.9
C-VR 0.53	0.53	166.7	88.9
C-VR 0.51	0.51	173.9	88.9
C-VR 0.48	0.48	186	88.9
C-VR 0.46	0.46	190.5	88.9
C-VR 0.43	0.43	205.3	88.9

The cyclic loading program for VR models were adopted as per the specifications of ATC 24. The cyclic loading program adopted has 27 cycles. Fig 5 shows the cyclic loading program adopted for void ratio models of circular Hybrid DSTC's.

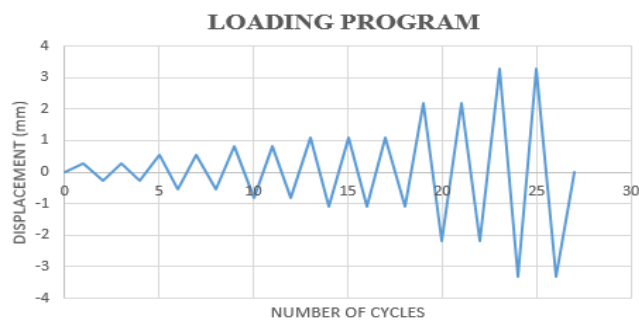


Fig -5: Cyclic loading program for void ratio models of circular Hybrid DSTC's [16]

3.2 Steel Tube Thickness (ST)

The steel tube thickness is the thickness of the steel tube which acts as main reinforcement in Hybrid DSTC's. Steel tube also prevents the concrete from inward spalling thus the thickness of steel tube plays an effective role in the

performance of Hybrid DSTC's. The steel tube is of circular cross section. The thicknesses of steel tube used for the study are 1.6 mm, 2.3 mm, 3.2 mm, 3.6 mm, 4 mm, 5 mm and 6 mm. A circular model was also modelled with no steel tube denoted as C-WST. All other circular steel tube thickness models were compared with C-WST model. Table 2 shows the specifications of steel tube thickness models of circular Hybrid DSTC's used for the study.

Table -2: Specifications of different ST models of circular Hybrid DSTC's

Model name	Steel tube thickness (mm)	Outer diameter of GFRP tube (mm)	Inner diameter of steel tube (mm)
C-ST 1.6	1.6	156.8	88.9
C-ST 2.3	2.3	156.8	88.9
C-ST 3.2	3.2	156.8	88.9
C-ST 3.6	3.6	156.8	88.9
C-ST 4	4	156.8	88.9
C-ST 5	5	156.8	88.9
C-ST 6	6	156.8	88.9
C-WST	-	156.8	-

The cyclic loading program for Steel tube thickness (ST) models were adopted as per specifications of ATC 24. The cyclic loading program adopted has 27 cycles. Fig 6 shows the cyclic loading program adopted for steel tube thickness models of circular Hybrid DSTC's. The cyclic loading program adopted for C-WST is different from those of steel tube thickness models. Fig 7 shows the cyclic program adopted for C-WST model.

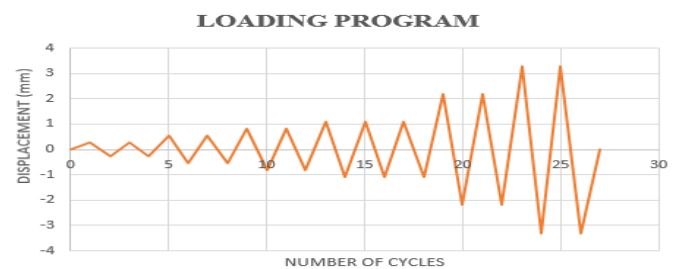


Fig -6: Cyclic loading program for ST models of circular Hybrid DSTC's [16]

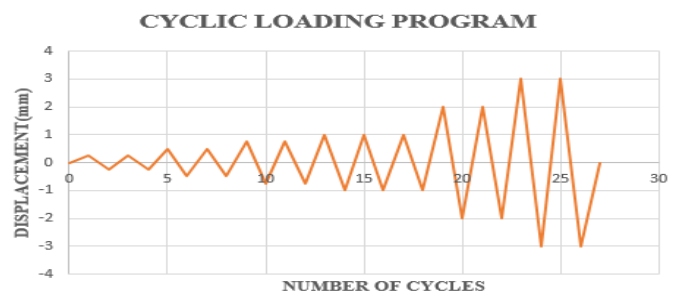


Fig -7: Cyclic loading program for C-WST model [16]

3.3 Different FRP's

The FRP used for circular Hybrid DSTC base model was glass fiber reinforced polymer (GFRP). The other FRPs used for the study were carbon fiber reinforced polymer (CFRP), aramid fiber reinforced polymer (AFRP) and basalt fiber reinforced polymer (BFRP). Table 3 shows the material properties of each FRP's used for the study.

Table -3: Material properties of different FRP's used

FRP used	Density (kg/m ³)	Modulus of elasticity (GPa)	Poissons ratio	Tensile strength (MPa)
GFRP	2550	80.1	0.3	1825.5
CFRP	1600	251	0.3	3626
AFRP	1450	128.7	0.3	2390
BFRP	2650	87	0.3	2900

Table 4 shows the specifications of different FRP models of circular Hybrid DSTC's. After modelling different FRP models, each FRP's material properties were assigned to the models using Ansys software.

Table -4: Specifications of different FRP models of circular Hybrid DSTC's

Model name	FRP used	Outer diameter of GFRP tube (mm)	Inner diameter of steel tube (mm)
C-GFRP	GFRP	156.8	88.9
C-CFRP	CFRP	156.8	88.9
C-AFRP	AFRP	156.8	88.9
C-BFRP	BFRP	156.8	88.9

The cyclic loading program for different FRP models were adopted as per the specifications of ATC 24. The cyclic loading program adopted has 27 cycles. Fig 8 shows the cyclic loading program adopted for different FRP models of circular Hybrid DSTC's.

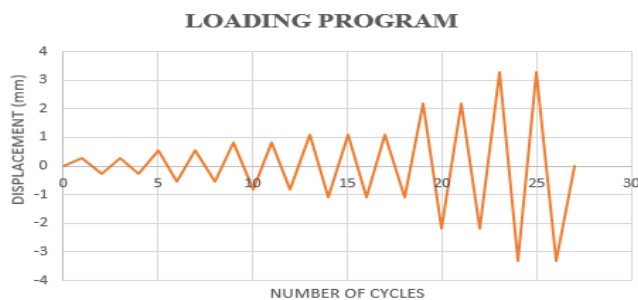


Fig -8: Cyclic loading program for different FRP models of circular Hybrid DSTC's [16]

3.4 H/t_c Ratio

The H/t_c ratio is defined as ratio of height of Hybrid DSTC's to the thickness of annular concrete section of Hybrid DSTC's. The thickness of annular concrete section is constant whereas changing parameter is the height of Hybrid DSTC's. The H/t_c ratio of circular Hybrid DSTC base model is 5.9. The other H/t_c ratios used for the study were 4.6, 5.3, 5.9, 6.6, 7.2 and 7.9. The height of circular Hybrid DSTC's used for the study were 310 mm, 360 mm, 400 mm, 450 mm, 490 mm and 540 mm respectively. Table 5 shows the specifications of different H/t_c ratio models of circular Hybrid DSTC's used for the study.

Table -5: Specifications of different H/t_c ratio models of circular Hybrid DSTC's

Model name	H/t _c ratio	Height, H (mm)	Thickness of annular concrete section, t _c (mm)
C- H/t _c 4.6	4.6	310	67.9
C- H/t _c 5.3	5.3	360	67.9
C- H/t _c 5.9	5.9	400	67.9
C- H/t _c 6.6	6.6	450	67.9
C- H/t _c 7.2	7.2	490	67.9
C- H/t _c 7.9	7.9	540	67.9

The cyclic loading program for different H/t_c ratio models were adopted per the specifications of ATC 24. The cyclic loading program adopted has 27 cycles. Fig 9 shows the cyclic loading program adopted for different H/t_c ratio models of circular Hybrid DSTC's.

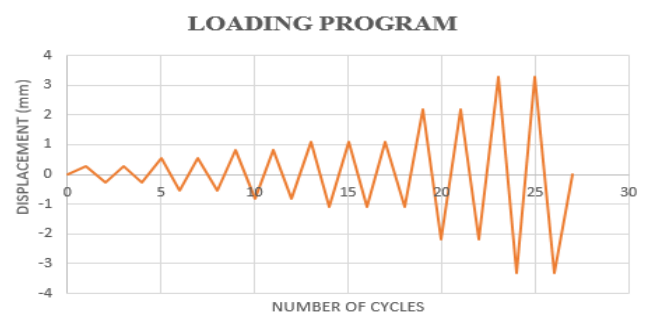


Fig -9: Cyclic loading program for different H/t_c ratio models of circular Hybrid DSTC's [16]

4. RESULTS AND DISCUSSIONS

Static analysis of circular Hybrid DSTC's with axial cyclic loading was done using ANSYS 16.2 WORKBENCH. After the axial cyclic loading, the total deformation and hysteresis curves of circular Hybrid DSTC's were obtained from the ANSYS 16.2 WORKBENCH. From the hysteresis curves the energy absorption was calculated by calculating the area under the hysteresis curves. The effect of void ratio, steel tube thickness, different FRP's, H/t_c ratio on circular Hybrid DSTC's were also examined.

4.1 Total Deformation of circular Hybrid DSTC base model

Total deformation of circular Hybrid DSTC base model was determined. Fig 10 shows the total deformation of circular Hybrid DSTC base model obtained from ANSYS 16.2 WORKBENCH. The total deformation obtained for circular Hybrid DSTC base model was 0.15276 mm.

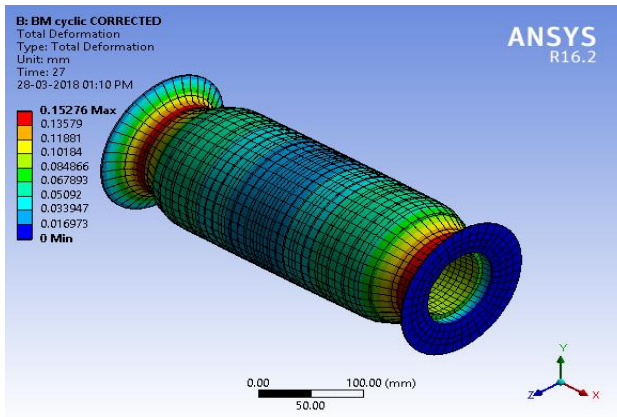


Fig -10: Total deformation of circular Hybrid DSTC base model

4.2 Energy Absorption of Circular Hybrid DSTC Base Model

From the ANSYS 16.2 WORKBENCH, the hysteresis curve for circular Hybrid DSTC base model was obtained. The Fig 11 shows the hysteresis curve of circular Hybrid DSTC base model obtained from Ansys software.

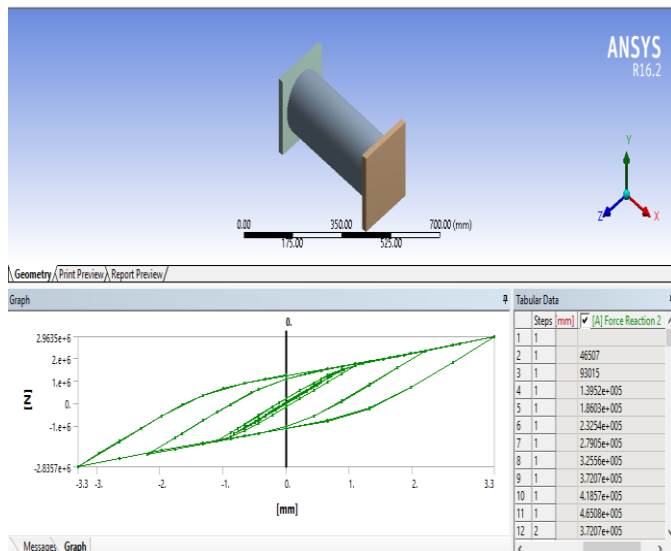


Fig -11: Hysteresis curve of circular Hybrid DSTC base model

The area under the hysteresis curve gives the energy absorption. The energy absorption of circular Hybrid DSTC base model calculated from hysteresis curve was 33.026 kJ.

4.3 Effect of Void Ratio (VR) Total deformation

Total deformation

The Total deformation for different void ratios such as 0.57, 0.53, 0.51, 0.48, 0.46, 0.43 of circular Hybrid DSTC's were obtained. Fig 12 shows the total deformation obtained from Ansys software for different void ratio of circular Hybrid DSTC's.

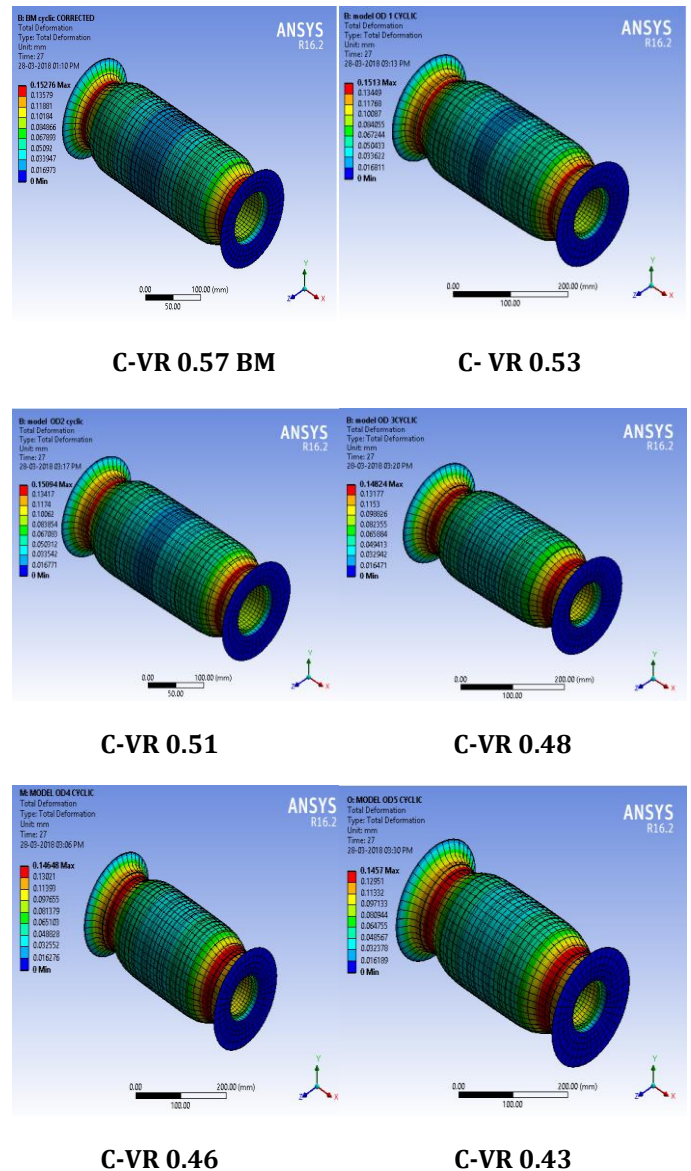


Fig -12: Total deformation for different void ratios of circular Hybrid DSTC's

From the results it was inferred that the total deformation is decreasing with decrease in void ratios. And it was found that for the void ratio of 0.43 is having the least total deformation of 0.1457 mm.

Energy Absorption

From the ansys, the hysteresis curves for different void ratios of circular Hybrid DSTC's were obtained. The area under the hysteresis curve gives the energy absorption. Energy absorption of circular Hybrid DSTC's with different void ratios were calculated from hysteresis curves. Table 6 shows the results of energy absorption of circular Hybrid DSTC's with different void ratios. Chart 1 shows the comparison of hysteresis curves of different void ratios of circular Hybrid DSTC's.

Table -6: Energy absorption of circular Hybrid DSTC's with different void ratios

Model name	Void ratio	Energy absorption (kJ)
C-VR 0.57	0.57	33.026
C-VR 0.53	0.53	38.827
C-VR 0.51	0.51	43.207
C-VR 0.48	0.48	51.198
C-VR 0.46	0.46	55.742
C-VR 0.43	0.43	65.311

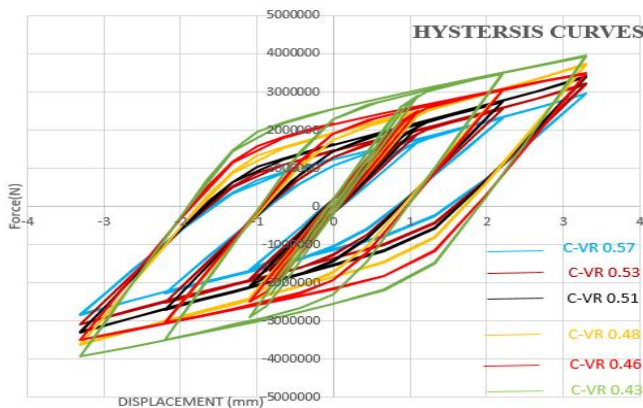


Chart -1: Comparison of hysteresis curves of different void ratios of circular Hybrid DSTC's

From the results we can infer that, the energy absorption capacities of circular Hybrid DSTC's were increasing with decrease in void ratios. And also found that the circular Hybrid DSTC of void ratio 0.43 has the highest energy absorption capacity. This increase in energy absorption capacity might be due to increase in annular concrete section.

4.4 Effect of Steel Tube Thickness (ST)

Total deformation

The Total deformation for different Steel tube thicknesses 0 mm, 1.6 mm, 2.3 mm, 3.2 mm, 3.6 mm, 4 mm, 5 mm and 6 mm of circular Hybrid DSTC's were obtained. Fig 13 shows the total deformation obtained from Ansys software for different steel tube thicknesses of circular Hybrid DSTC's

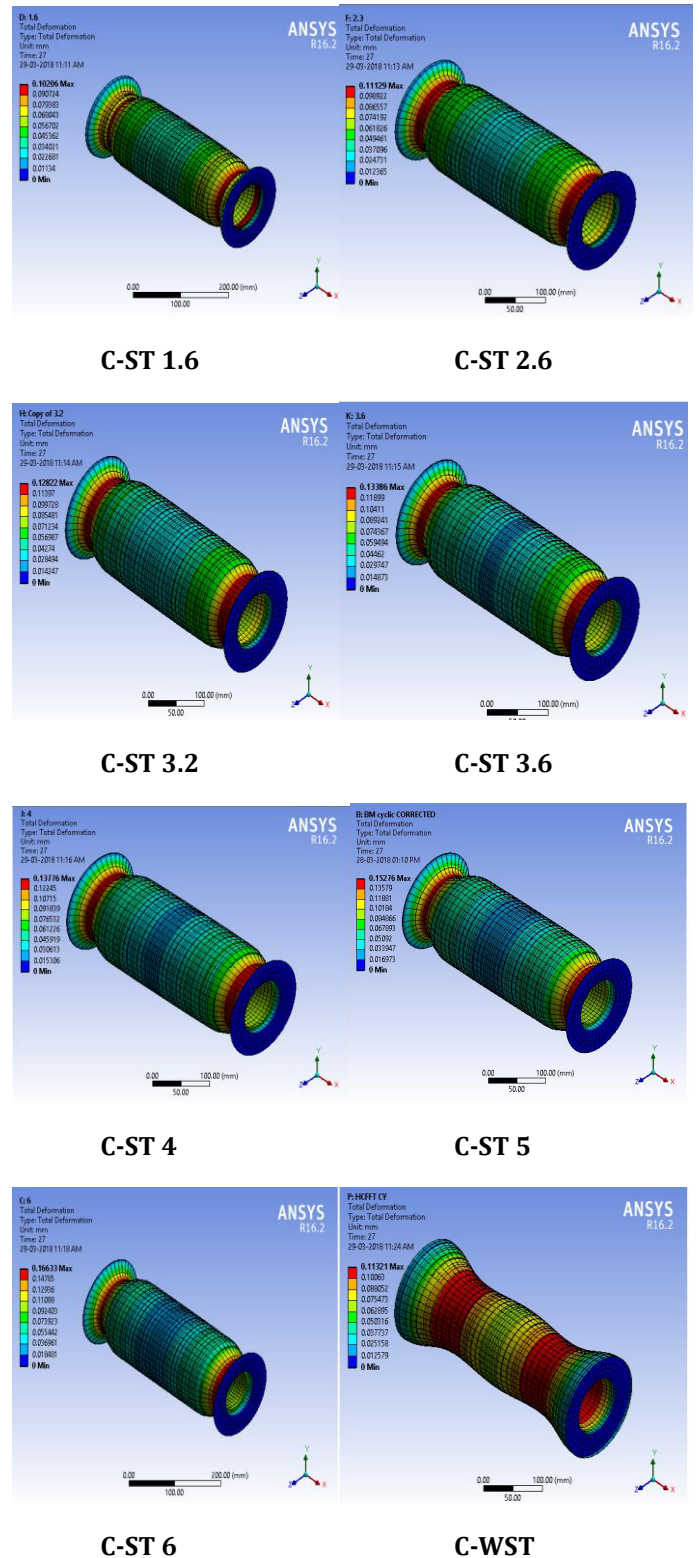


Fig -13: Total deformation for different steel tube thickness of circular Hybrid DSTC's

From the results it was inferred that, the total deformation of circular Hybrid DSTC's with different steel tube thicknesses were increasing with increase in steel tube thickness. And it was found that, the circular Hybrid DSTC with the steel tube thickness of 1.6 mm is having the least

total deformation of 0.10206 mm. The total deformation of 0 mm steel tube thickness circular DSTC denoted as C-WST is 0.11321 mm.

Energy Absorption

From the ansys, the hysteresis curves for different steel tube thicknesses of circular Hybrid DSTC's were obtained. The area under the hysteresis curve gives the energy absorption. Energy absorption of circular Hybrid DSTC's with different steel tube thicknesses were calculated from hysteresis curves. Table 7 shows results of energy absorption of circular Hybrid DSTC's with different steel tube thicknesses. Chart 2 shows the comparison of hysteresis curves of circular Hybrid DSTC's with different steel tube thicknesses.

Table -7: Energy absorption of circular Hybrid DSTC's with different steel tube thicknesses

Model name	Steel tube thickness (mm)	Energy absorption (kJ)
C-ST 1.6	1.6	25.37
C-ST 2.3	2.3	30.88
C-ST 3.2	3.2	31.182
C-ST 3.6	3.6	31.795
C-ST 4	4	32.086
C-ST 5	5	32.36
C-ST 6	6	33.026
C-WST	-	33.677

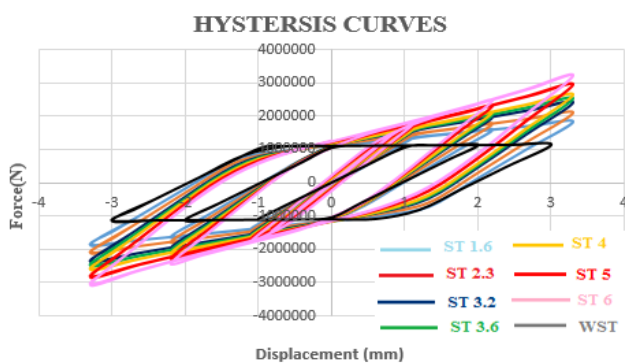


Chart -2: Comparison of hysteresis curves of circular Hybrid DSTC's with different steel tube thicknesses

From the results we can infer that, the introduction of steel tube increases the energy absorption capacities of circular Hybrid DSTC's. The energy absorption capacities of circular Hybrid DSTC's were increasing with increase in steel tube thicknesses. This increase might be due to the additional stiffness contributed by steel tube. And also found that the circular Hybrid DSTC of steel tube thickness of 6 mm has the highest energy absorption capacity of 33.677 kJ. And the energy absorption capacity of C-WST is very lower when compared circular Hybrid DSTC's with different steel tube thicknesses.

4.5 Effect of Different FRP's

Total deformation

The Total deformation for different FRP's such as GFRP, CFRP, AFRP and BFRP of circular Hybrid DSTC's were obtained from ansys. Fig 14 shows the total deformation obtained from Ansys software for circular Hybrid DSTC's with different FRP's.

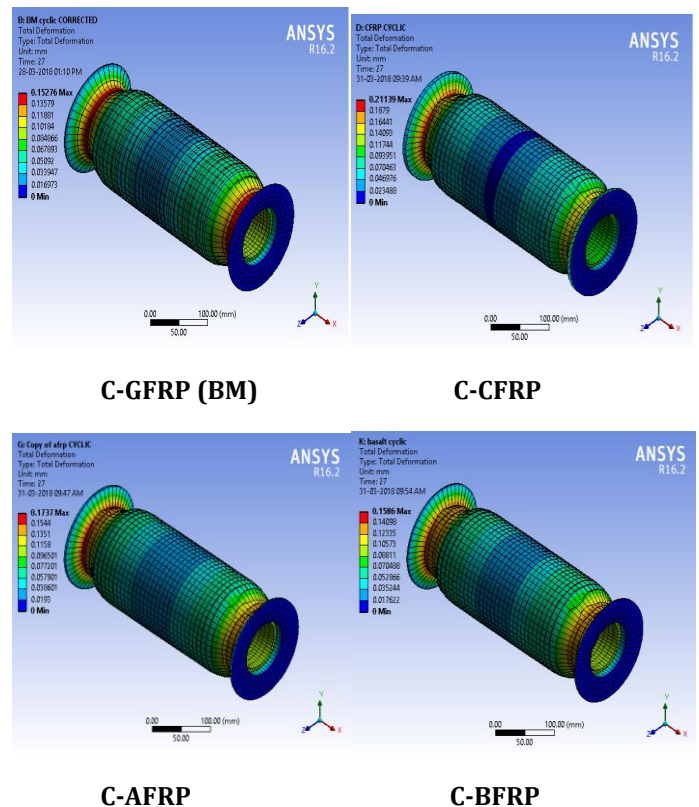


Fig -14: Total deformation for circular Hybrid DSTC's with different FRP's

Energy Absorption

From the ansys, the hysteresis curves for different FRP's of circular Hybrid DSTC's were obtained. The area under the hysteresis curve gives the energy absorption. Energy absorption of circular Hybrid DSTC's with different FRP's were calculated from hysteresis curves. Table 8 shows the results of energy absorption of circular Hybrid DSTC's with different FRP's. Chart 3 shows the comparison of hysteresis curves of circular Hybrid DSTC's with different FRP's.

Table -7: Energy absorption of circular Hybrid DSTC's with different FRP's

Model name	FRP used	Energy absorption (kJ)
C-GFRP	GFRP	33.026
C-CFRP	CFRP	45.613
C-AFRP	AFRP	39.641
C-BFRP	BFRP	33.885

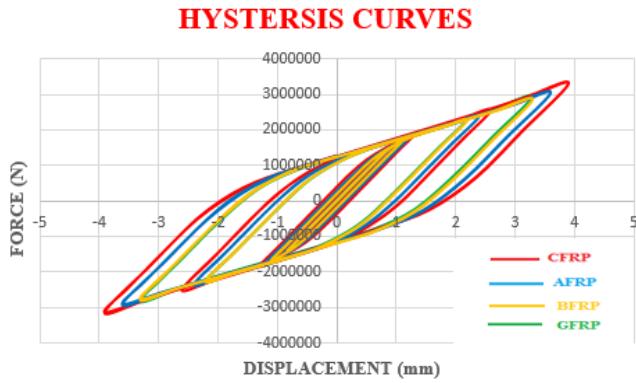


Chart -3: Comparison of hysteresis curves of circular Hybrid DSTC's with different FRP's

From the results we can infer that, the circular Hybrid DSTC's with CFRP tube has the highest energy absorption capacity of 45.613 kJ than other FRP tubes. And also found that the circular Hybrid DSTC with GFRP tube has the least energy absorption capacity of 33.026 kJ.

4.5 Effect of H/t_c Ratio

Total Deformation

The Total deformation for different H/t_c ratios 4.6, 5.3, 5.9, 6.6, 7.2 and 7.9 of circular Hybrid DSTC's were obtained. Fig 15 shows the total deformation obtained from Ansys software for different H/t_c ratios of circular Hybrid DSTC's.

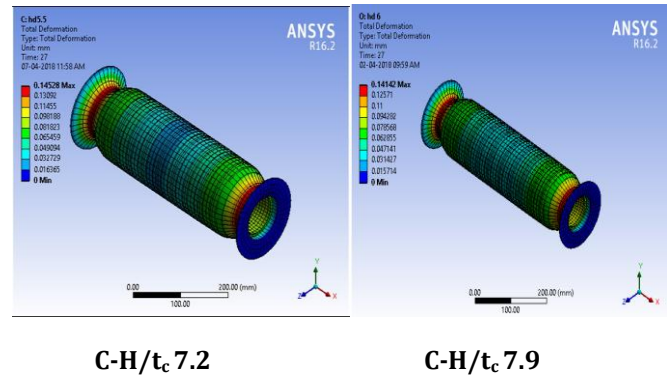
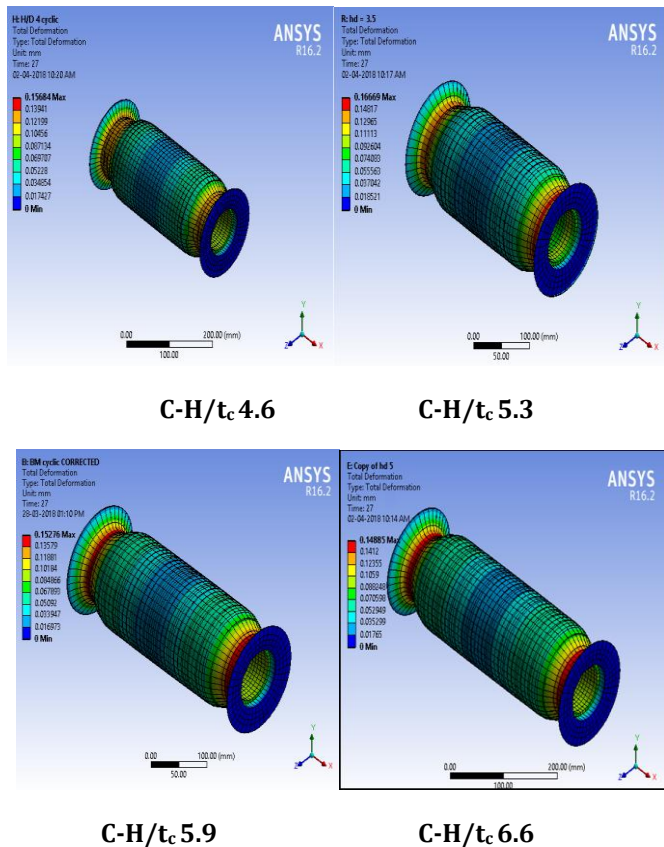


Fig -15: Total deformation for circular Hybrid DSTC's with different H/t_c ratios

From the results it was inferred that, the total deformation of circular Hybrid DSTC's with different H/t_c ratios were decreasing with increase in H/t_c ratios. And it was found that, the circular Hybrid DSTC with H/t_c ratio of 7.9 is having the least total deformation of 0.14142 mm.

Energy Absorption

From the ansys, the hysteresis curves for different H/t_c ratios of circular Hybrid DSTC's were obtained. The area under the hysteresis curve gives the energy absorption. Energy absorption of circular Hybrid DSTC's with different H/t_c ratios were calculated from hysteresis curves. Table 8 shows the results of energy absorption of circular Hybrid DSTC's with different H/t_c ratios. Chart 4 shows the comparison of hysteresis curves of circular Hybrid DSTC's with different H/t_c ratios.

Table -7: Energy absorption of circular Hybrid DSTC's with different H/t_c ratios

Model name	H/t _c ratio	Energy absorption (kJ)
C- H/t _c	4.6	29.251
C- H/t _c	5.3	30.373
C- H/t _c	5.9	33.026
C- H/t _c	6.6	34.996
C- H/t _c	7.2	32.351
C- H/t _c	7.9	29.239

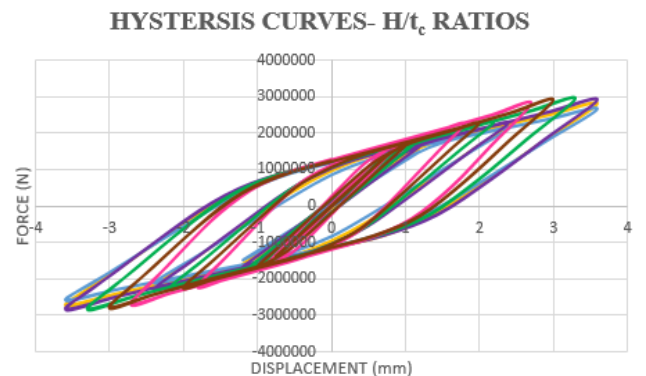


Chart -4: Hysteresis curves for circular Hybrid DSTC with different H/t_c ratios

From the results we can infer that, the energy absorption capacities of circular Hybrid DSTC's were increasing with increase in H/t_c ratio up to 6.6, beyond H/t_c ratio 6.6 the energy absorption capacities were decreasing. And also found that the circular Hybrid DSTC's of H/t_c ratio 6.6 has the highest energy absorption capacity of 34.996 kJ. For H/t_c ratios 7.2 and 7.9 the energy absorption capacities of circular Hybrid DSTC's were found to be decreasing. This decrease in energy absorption capacities may be due to the change in the performance of short column to intermediate column and also the change in failure mode from crushing to bending. As the height of column increases, the energy absorption capacity also increases but up to a limit, beyond the limit the energy absorption capacity decreases due to the change in column type from short column to intermediate column.

5. CONCLUSIONS

The strength behaviour of circular Hybrid DSTC's under axial cyclic loading were studied using numerical analysis. The influence of parameters such as void ratios, steel tube thickness, different FRP's and H/t_c ratios on circular Hybrid DSTC's were also investigated.

The following are the conclusions derived from the studies conducted as part of this study:

- Circular Hybrid DSTC's showed improved performance under axial cyclic loading in terms of energy absorption capacity.
- Energy absorption capacity of circular Hybrid DSTC's increases with decrease in void ratios. This increase might be due to increase in annular concrete section.
- Energy absorption capacity of circular Hybrid DSTC's increases with increase in steel tube thicknesses. This increase may be due to the additional stiffness provided by the steel tube.
- Energy absorption capacity of circular Hybrid DSTC's Increases when CFRP tubes are used in Hybrid DSTC's. This increase may be due to high value of modulus of elasticity of CFRP.
- Circular Hybrid DSTC's with CFRP tubes showed superior performance than Hybrid DSTC's with GFRP tubes.
- H/t_c ratios is an influencing parameter that affects circular Hybrid DSTC's.
- Energy absorption capacity of circular Hybrid DSTC's Increases up to H/t_c ratio of 6.6.
- Energy absorption capacity of circular Hybrid DSTC's Decreases beyond H/t_c ratio of 6.6. This decrease may be due to change in the performance

of short column to intermediate column, thereby changes the failure mode from crushing to bending.

- From the study it was found that Performance of tube sections can be enhanced by providing inner stiffening steel tubes.

Finally it can be concluded that, Performance of circular Hybrid DSTC's are very effective under axial cyclic loading. Thus the circular Hybrid DSTC's are well suited for seismic regions than other column types.

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