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Investigate the Behavior of the Composite Short Columns with Variable Sections under Torsional Load

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***Abstract* – Composite columns consist of an internal carbon steel tube and an external stainless steel wall that the between the walls are filled with concrete. In the present paper, ABAQUS software is used for finite element analysis and the behavior of different types of DST columns has been studied under Torsional load, finally, the results of ultimate strength of the composite sections are illustrated.**

***Keywords* – ABAQUS, Straigh Columns, Tapered Columns, DST.**

I. Introduction

In recent decades, several tests were conducted on composite columns; Han has done a research on the behavior of composite CFT columns under pure torsion. Han in this research examined the performance and square steel tubular columns filled with concrete under pure torsion using the ABAQUS software. The finite element method (FEA) was used to assess the impact of important parameters that determine the ultimate tensional strength of composite sections. Han found that steel pipe plays an important role in the tensional resistance of composite columns which are square or circular, and the composite columns show a good Stability and plastic behavior under torsion. [1-6]

Elremaily performed a Research on composite columns under earthquake loads [7]. He found that CFT columns under seismic loads, show very high levels of ductility and energy dissipation. It was also observed that the test samples maintained the torsional capacity until the test to be concluded.

Oyawa has done tests on composite steel columns filled with polymer concrete under axial load [8]. He found that polymer concrete has high tensile adhesion capacity, less weight, less shrinkage, reversible and ductility than conventional concrete. The polymer concrete has a high resistance against chemical and physical blows.

Recent laboratory researches in Japan affirmed the growing demand and strong potential use in Japan (CFDT) in the construction of highways and airways free, especially as a middle ground lift bridges (with a height of more than m 100) in remote areas of steep mountains. The good damping characteristics and relatively light weight are the main reasons to use (CFDT) for dynamically sensitive structures.

Yagishita and colleagues [9] have done six tests on tubular steel columns CFDT soft thin circular diameter thickness ratio D/t = 130-250 and filled with normal concrete collar. They concluded that the multilayer columns had a better performance than CFT members in terms of the characteristics of strength, ductility and energy absorption under lateral cyclic loading and constant axial force, respectively.

Nakanashi and colleagues [10] conducted ten tests of periodic launches on pillars of CFDT and CFT, Their goal was to propose a new design for the central base of bridge to not be damaged after strong earthquakes (so g 8/0) , but a little forces were transmitted to the foundations. The outer casing was made from Composite cans (MPa 315 = fy) with a width-to-thickness ratio B / t = 14 ~ 66. Circular tube is made of plastic or metal lining. Light concrete with compressive strength MPa 13 = fc was used to fill the cylinder to reduce loads. They s compared the periodic remnants for CFDT with rigid and prefabricated containers and CFT. Their conclusions are similar to the conclusions of Yagishita and colleagues. Where CFDT improved the behavior of remnants and the most ductile member was found compared to most other types.

Some studies have been done on elliptical hollow steel sections filled with concrete. A series of short columns of steel - concrete - FRPDST have been done by Tang [11-13].

Results of tests of short CFT columns showed that filling Steel pipe with concrete increases the strength, ductility and energy absorption higher than the diameter of the hollow tube thickness (D / t). This is due to the confining the concrete core and steel tube wall to restrain local buckling. If the module level increases using multi-layer technique tubular steel columns and circle centre filled with towering concrete materials (CFDT), In this case, the overall Sustainability of the members is greater when compared with CFT.

The advantages of making multilayer CFDT when compared with CFT columns are as following:

High torsional stiffness, avoiding instability under external pressure, interactions of three components of (outer steel pipe, concrete, inner steel pipe) results in a good position stability, increased Section modulus, improved overall stability, better seismic strengthening, better coupled with a circular steel columns, lighter weight, and performance characteristics of a good attenuation. Multi-layer construction technique uses a variety of filler materials. For example it is used as epoxy filler for pressure tanks, concrete water tanks, deep, tunnel construction, manufacturing base in the middle of the bridge in Japan, seismic strengthening and foundation piles.

It is believed that the excellent performance of a composite member will be shown than a simple set of concrete and normal pipes. Due to the high cost, stainless was not commonly used as a material of construction in the past. However, after the developments over the past decade, both in terms of material availability and terms of durability, sometimes it is suggested that the main structural material of stainless steel, can be used. The studied parameters for composite column samples are considered as follows:

Type of column: Straight and muscular. The tapered angle for DST columns is designed as 1 degree to refer to the Structural muscular columns.

Type of cross-section: Circular, square, rectangular, round or elliptical corners.

In this study, firstly the anchor of DST composite short column for the rotation applied to the free end of the column was calculated by the software and the ultimate torsional capacity is determined. Rotation applied to the free end of the column is 0.30 Radian as shown in Fig.1.

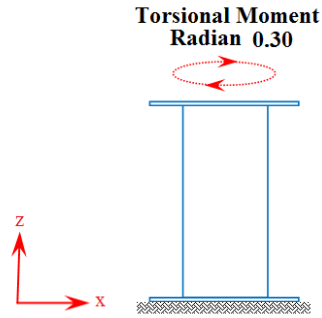


Fig.1. applying torsion to the free end of the column and determining the bending moment at the foot of the column

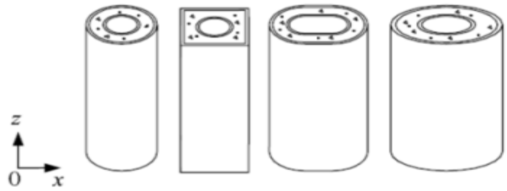
II. The Examples Presented in the Analysis in ABAQUS Software

A collection contains 24 specimens were tested in this program, which includes 16 DST Stainless Steel - Concrete - carbon steel columns and 8 samples with empty sections. Figure (2) offers a schematic view of the test samples.

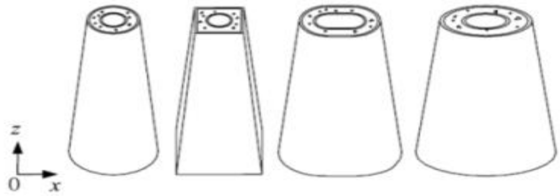
Test parameters for composite column samples include:

Type of column: Straight and tapered. The tapered angle for DST columns is designed as 1 degree to refer to the Structural muscular columns.

Type of cross-section: Circular, square, rectangular, round or elliptical corners, as is shown in Figure (3).



(a) Straight Column



(b) Tapered Column

Fig.2. DST column types used in the bending capacity test

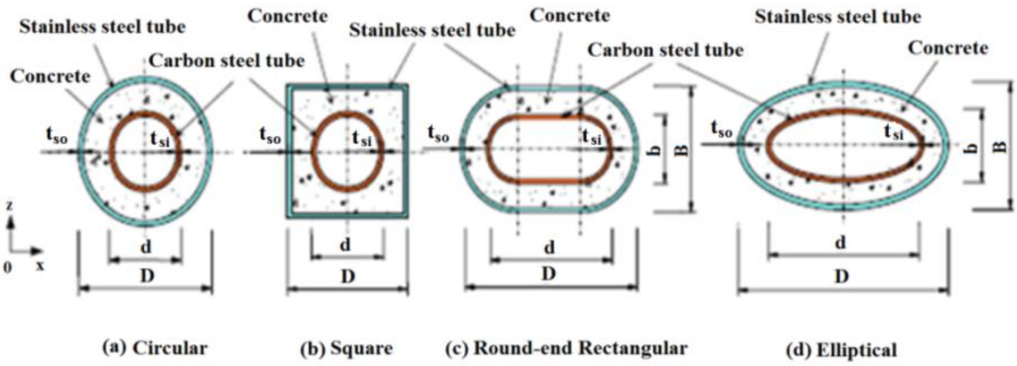


Fig.3. Types of cross section for DST columns used in the bending test

The ratio of DST composite cross-section hole and x can be presented as follows:

$$x = \frac{d}{D - 2t_{so}} \quad (1)$$

For circular and square sections

$$x = \sqrt{\frac{bd}{(B - 2t_{so})(D - 2t_{so})}} \quad (2)$$

For rectangular sections

A summary of the sample data are provided in Table (2). The following procedure is used for naming samples (Table 1).

The main character of "T" represents the muscular columns. The directions of x, y, z are shown in Figure 2, If (not written) remain white, they represent straight columns.

Characters of C, S, R, E represent the circular cross section, square, rectangular, round or elliptical corners, respectively.

The last character of H (if any) indicates the empty column without filling concrete.

The first figures represent the different groups of the same

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type of column.

The second figures represent a different sample of the same groups.

Both stainless and carbon steel pipes have been provided by steel plates. Steel plates are bent into two sections or half-oval for circular and elliptical cross sections and are butt-welded together in order to achieve a circular or elliptical section.

For a square cross section, 4 parts of steel plate are butt-welded together to form a square cross section and for rounded corners of the rectangular cross section, 2 sections of steel plates are bent into circular sections and are butt-welded together in order to obtain the desired level.

Self-compacted concrete (scc) is designed to place the distance between the outer stainless steel pipe and carbon steel inner tube and then the DST samples are placed vertically to test. During the curing of the concrete, a very small amount of longitudinal shrinkage of the sample occurs. Then a high-strength concrete is used to fill the gap length in order to align the concrete surface with a steel pipe. To ensure the complete transfer of vertical load on the composite section, two carbon-based steel plates with a thickness of 20cm are butt-welded to the inner and outer tubes at the ends of each DST sample and one plate is welded before pouring concrete and the other one is welded before the test.

III. Materials Properties

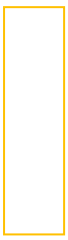
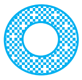
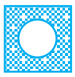
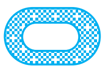
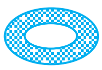
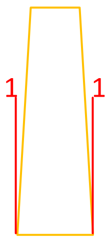
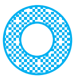
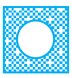
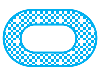
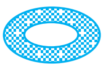
Steel:

A stainless steel and carbon steel are used in order to make the inner and outer tubes. Standard tensile tests are done to measure material properties of stainless steel and carbon. The average measured yield strength (fy), ultimate strength (fu), modulus of elasticity (Es) and Poisson's ratio are listed in Table (1).

Table 1: Properties of materials used in the steel

Type	Thickness (mm)	f_y (MPa)	f_u (MPa)	E_s (N/mm^2)	y_s
Carbon steel	3.72	380.6	519.1	1.92x105	0.282
Stainless Steel	3.62	319.6	626.5	2.01x105	0.286

Table 2: Summary of data samples

Series	section	No	Specimen label	Outer tube D × B × tso		Inner tube d × b × tsi		x
				Section A-A	Section B-B	Section A-A	Section B-B	
		1	C1-1	220×220×3.62	220×220×3.62	159×159×3.72	159×159×3.72	0.75
		2	C2-2	220×220×3.62	220×220×3.62	106×106×3.72	106×106×3.72	0.5
		3	CH1-1	220×220×3.62	220×220×3.62	159×159×3.72	159×159×3.72	0.75
		4	S1-1	220×220×3.62	220×220×3.62	159×159×3.72	159×159×3.72	0.75
		5	S2-2	220×220×3.62	220×220×3.62	106×106×3.72	106×106×3.72	0.5
		6	SH1-1	220×220×3.62	220×220×3.62	159×159×3.72	159×159×3.72	0.75
		7	R1-1	240×160×3.62	240×160×3.62	186×106×3.72	186×106×3.72	0.75
		8	R2-2	240×160×3.62	240×160×3.62	142×62×3.72	142×62×3.72	.5
		9	RH1-1	240×160×3.62	240×160×3.62	186×106×3.72	186×106×3.72	0.75
		10	E1-1	240×160×3.62	240×160×3.62	186×106×3.72	186×106×3.72	0.75
		11	E2-2	240×160×3.62	240×160×3.62	142×62×3.72	142×62×3.72	0.5
		12	EH1-1	240×160×3.62	240×160×3.62	186×106×3.72	186×106×3.72	0.75
		13	TC1-1	197×197×3.62	220×220×3.62	136×136×3.72	159×159×3.72	0.75
		14	TC2-2	197×197×3.62	220×220×3.62	83 × 83 × 3.72	106×106×3.72	0.5
		15	TCH1-1	197×197×3.62	220×220×3.62	136×136×3.72	159×159×3.72	0.75
		16	TS1-1	197×197×3.62	220×220×3.62	136×136×3.72	159×159×3.72	0.75
		17	TS2-2	197×197×3.62	220×220×3.62	83 × 83 × 3.72	106×106×3.72	0.5
		18	TSH1-1	197×197×3.62	220×220×3.62	136×136×3.72	159×159×3.72	0.75
		19	TR1-1	215×135×3.62	240×160×3.62	161×81×3.72	186×106×3.72	0.75
		20	TR2-2	215×135×3.62	240×160×3.62	117×37×3.72	142×62×3.72	0.5
		21	TRH1-1	215×135×3.62	240×160×3.62	161×81×3.72	186×106×3.72	0.75
		22	TE1-1	215×135×3.62	240×160×3.62	161×81×3.72	186×106×3.72	0.75
		23	TE2-2	215×135×3.62	240×160×3.62	117×37×3.72	142×62×3.72	0.5
		24	TEH1-1	215×135×3.62	240×160×3.62	161×81×3.72	186×106×3.72	0.75

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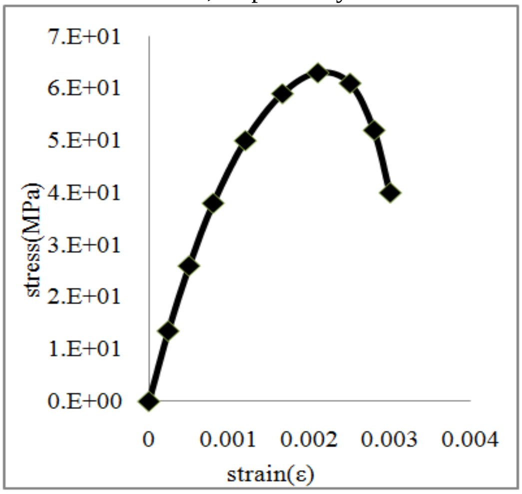
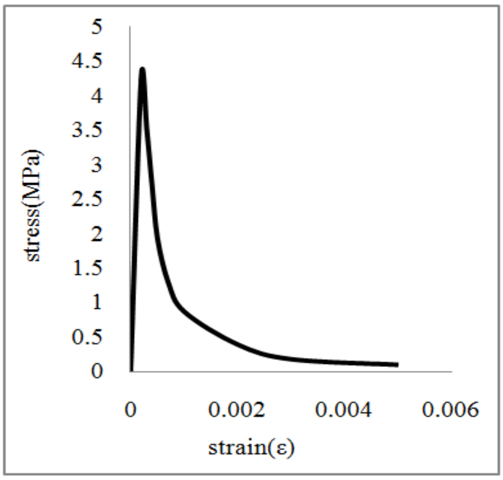
Concrete:

A mixture of Scc with a cubic sample compressive strength of 60 Mpa is designed approximately in 28 days. Elastic modulus scc (Es) is equal to 33,000 N per square millimeter. Scc combination of properties is as following: Cement: 440 kg/m3, slag, iron maidens: 143 kg/m3 of water: 194 kg/m3, 683 kg/m3 of sand, coarse aggregate: 855 kg/m3, a lubricant (HRWR): 5.83 kg/m3. In figure (3), (a) and (b) show the stress - strain of concrete in compression and tension, respectively.



(a)



(b)

Fig.3. a) diagram of the stress - strain of concrete in compression, b) diagram of the stress - strain of concrete in tension

IV. Presenting the ABAQUS Software Analysis Results for Torsion

In Figures (5) to (7) Von Mises stress distribution, amount and location of maximum stress for column C1 -1 is shown in the last stage of loading under torsion in ABAQUS. Moment-torsion axis from the ABAQUS analysis is shown for the intended column under torsional moment about the z axis.

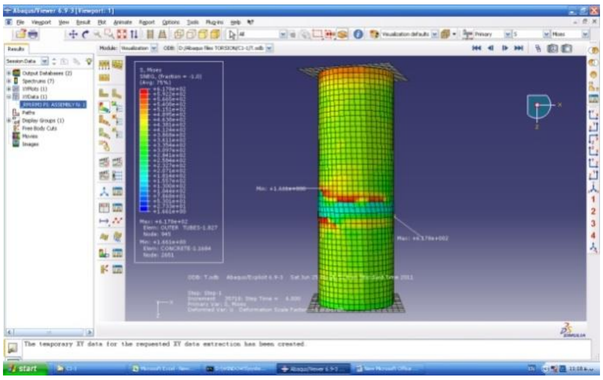


Fig.5. Schematic view of Von Mises stress distribution in column C1-1 under torsional moment

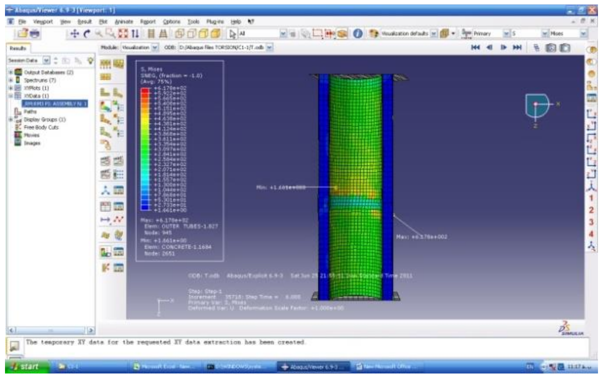


Fig.6. Schematic view of Von Mises stress distribution in vertical incision of column C1-1 under torsional moment

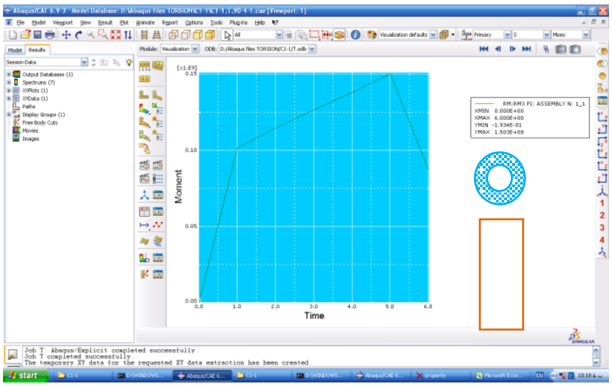


Fig.7. torsional moment axis at the foot of the column against the torsion applied to the free end of the column in ABAQUS for column C1-1 (x=0.75)

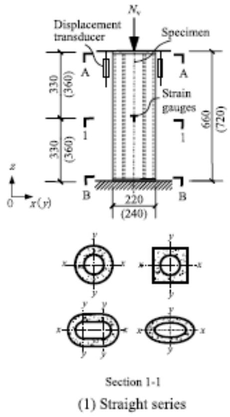
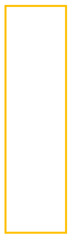
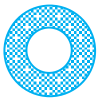
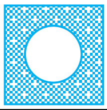
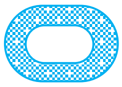
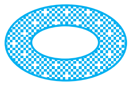
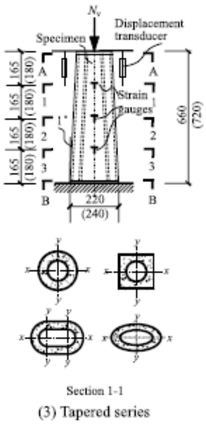
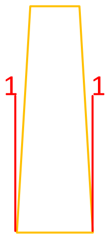
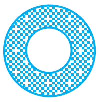
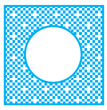
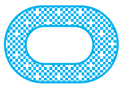
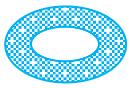
V. Analysis of Results and Comparison of Graphs for Bending

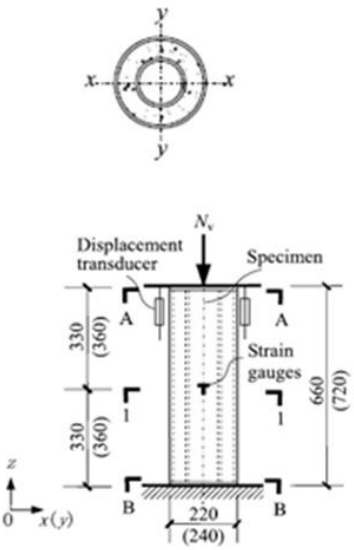
The results of numerical analysis for DST composite short columns for torsion are listed in Table 3. In the first and second columns of the table, the column type and section are shown and in the third and fourth columns of the table the column name and values for the ratio of hole are illustrated and finally the last column gives the ultimate torsional capacity of DST composite short column, respectively.

As it can be seen, torsional moment graph against the free end torsion for straight columns with circular section modeled by ABAQUS software are plotted in Figure (8).

Finally, the ultimate torsional capacity of DST short columns for both straight and tapered series for different sections are shown in Figures (9) and (10).

Table 3: Determining the ultimate capacity of DST short columns under torsion

Series	section	Specimen label	χ	Mut (KN.m)
 		C1-1	0.75	1.50E+02
		C2-2	0.50	1.25E+02
		CH1-1	0.75	8.07E+01
		S1-1	0.75	1.18E+02
		S2-2	0.50	1.89E+02
		SH1-1	0.75	8.35E+01
		R1-1	0.75	1.15E+02
		R2-2	0.50	1.04E+02
		RH1-1	0.75	6.66E+01
		E1-1	0.75	1.05E+02
		E2-2	0.50	9.31E+01
		EH1-1	0.75	7.00E+01
 		TC1-1	0.75	1.19E+02
		TC2-2	0.50	1.03E+02
		TCH1-1	0.75	6.66E+01
		TS1-1	0.75	1.39E+02
		TS2-2	0.50	1.20E+02
		TSH1-1	0.75	7.07E+01
		TR1-1	0.75	8.97E+01
		TR2-2	0.50	7.73E+01
		TRH1-1	0.75	5.17E+01
		TE1-1	0.75	8.09E+01
		TE2-2	0.50	7.02E+01
		TEH1-1	0.75	4.64E+01



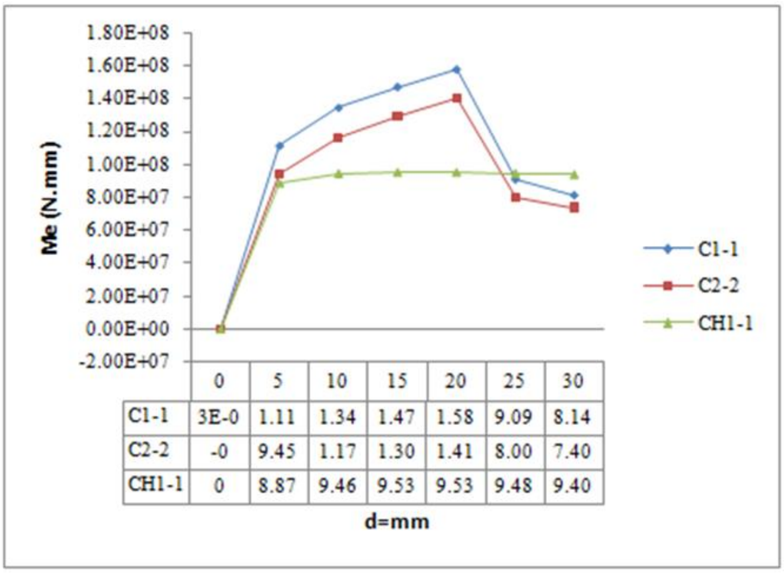


Fig.8. Torsion – moment curve for straight columns CH1-1, C2-2, C1-1

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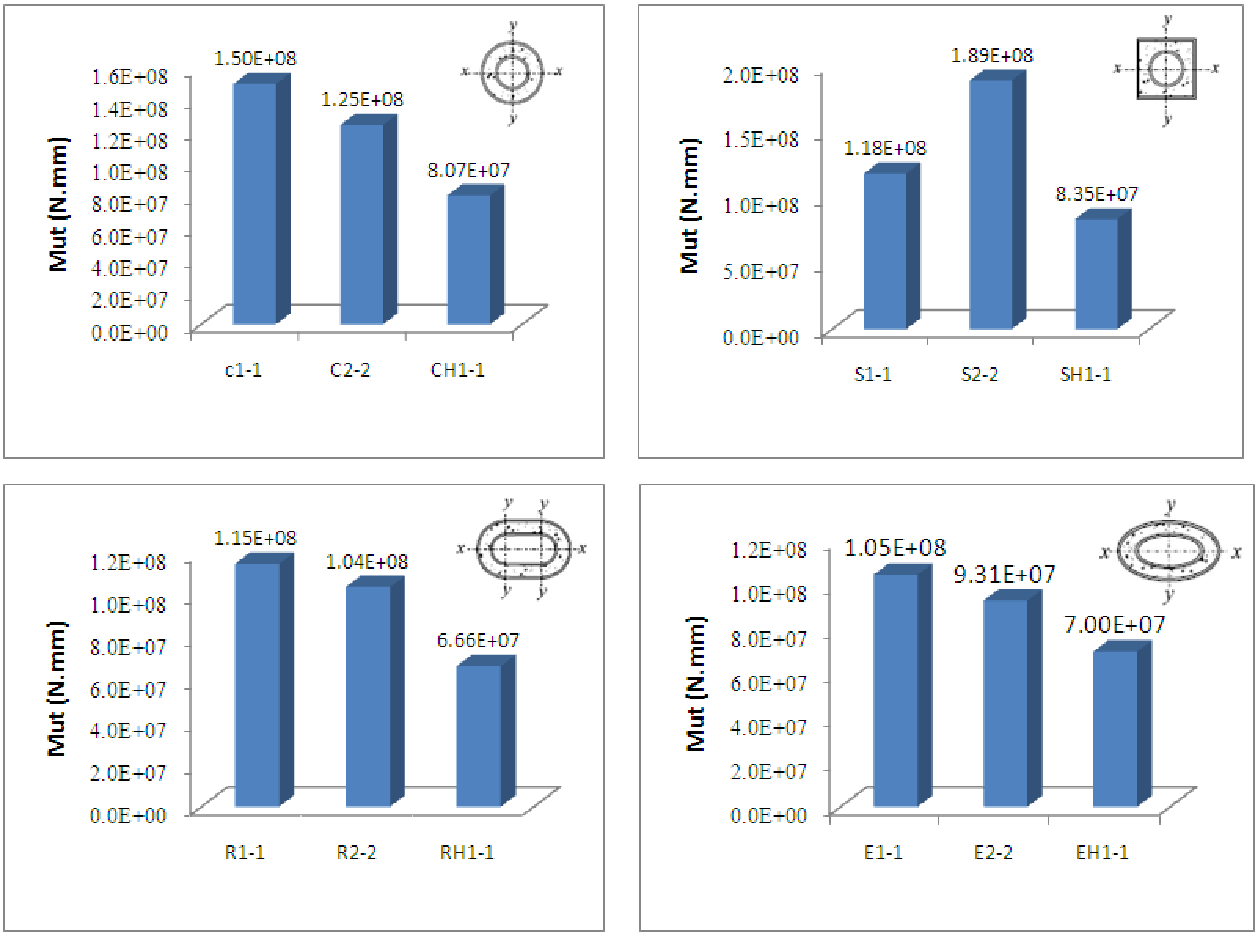
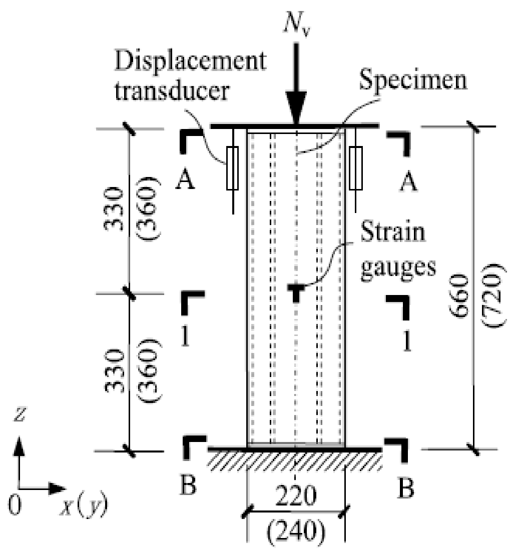
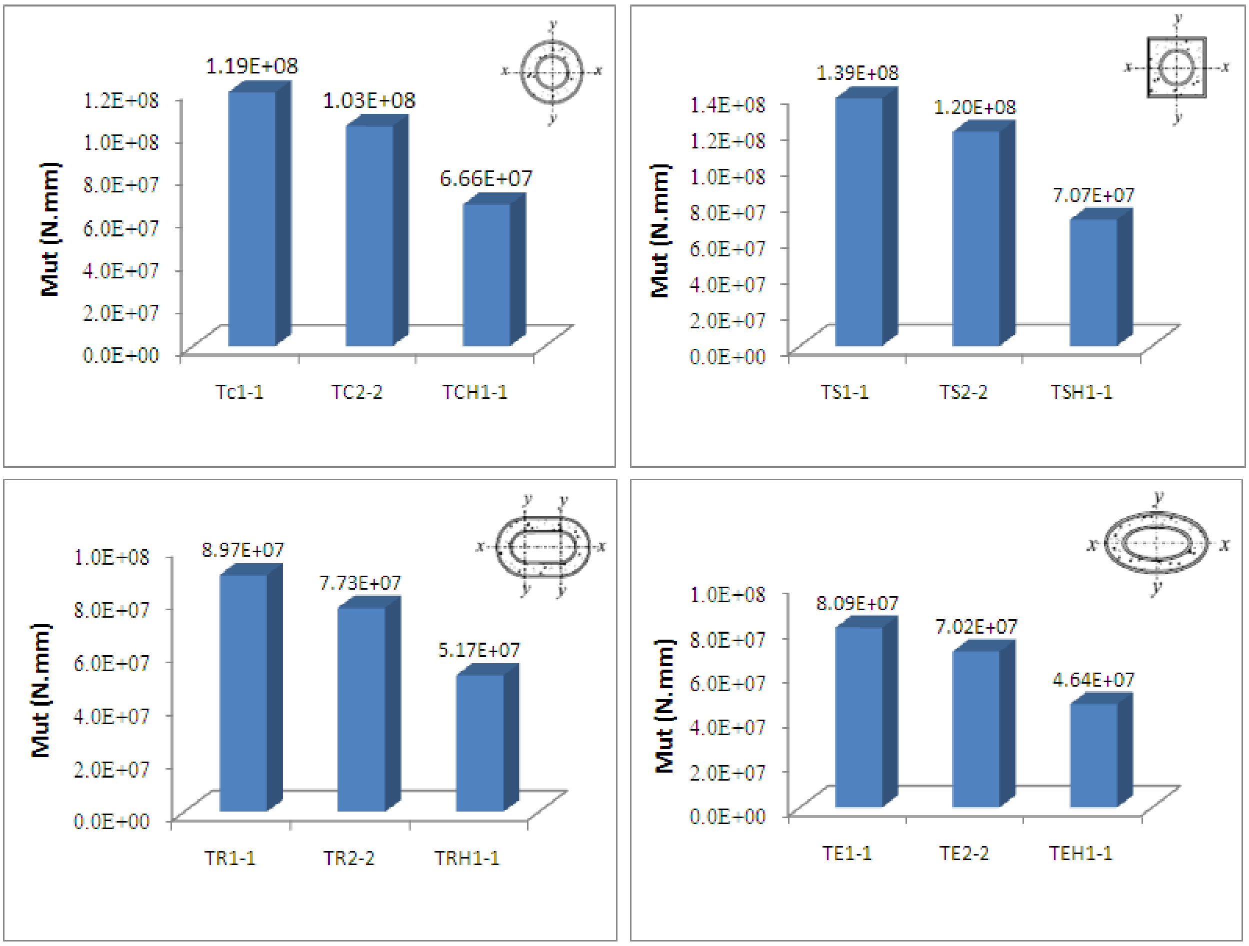


(a)

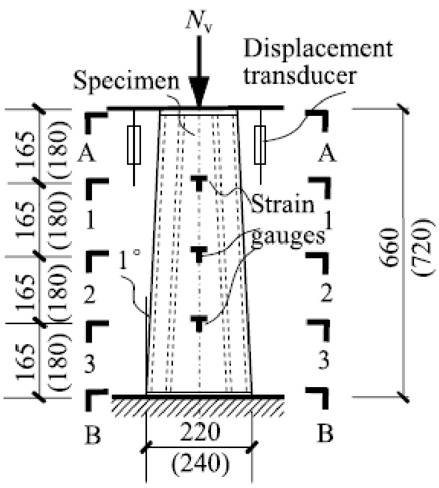


(b)

Fig.9. (a) Column charts for torsional capacity of DST columns for straight series (N.mm), (b) Straight series



(a)

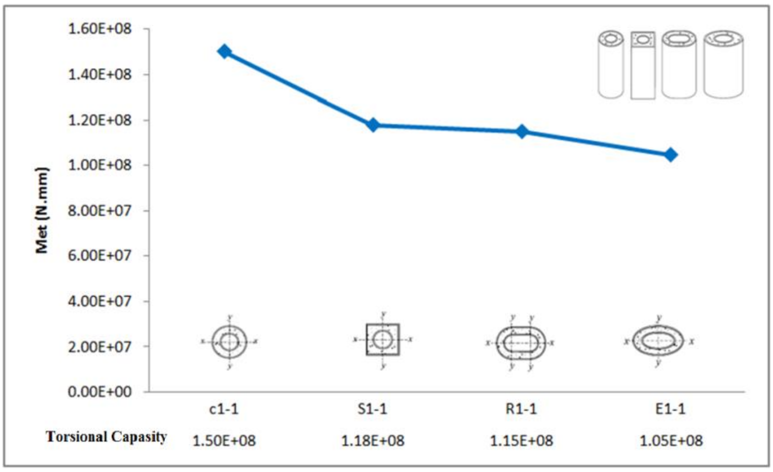


(b)

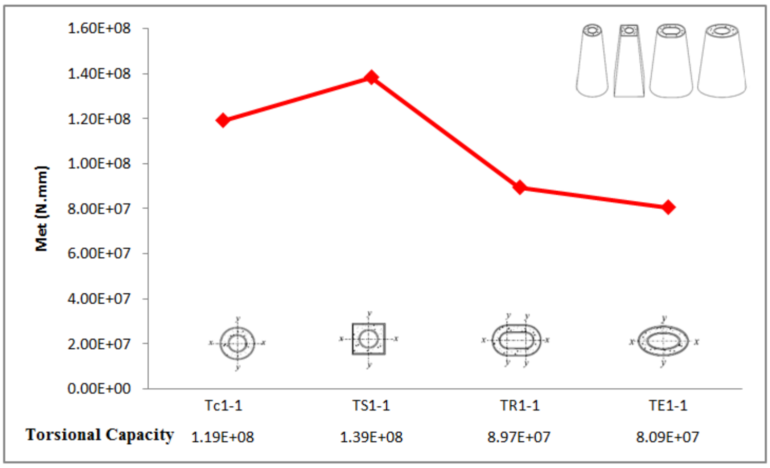
Fig.10. (a) column charts for torsional capacity of DST columns for tapered series (N.mm), (b) Tapered series

Ultimate torsional capacity of straight and tapered filled DST columns with the hole ratio of x=0.75 and x=0.50 are illustrated in figure 11 and 12, respectively. As it can be seen by the graphs, Ultimate torsional capacity of both straight and tapered columns is in the highest level for Circular cross section.

$$x = \frac{d}{D-2t_{so}} \qquad (3)$$

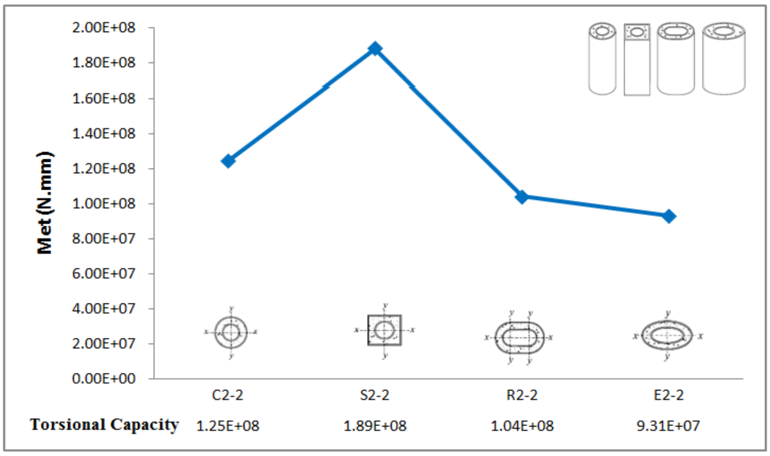


(a)

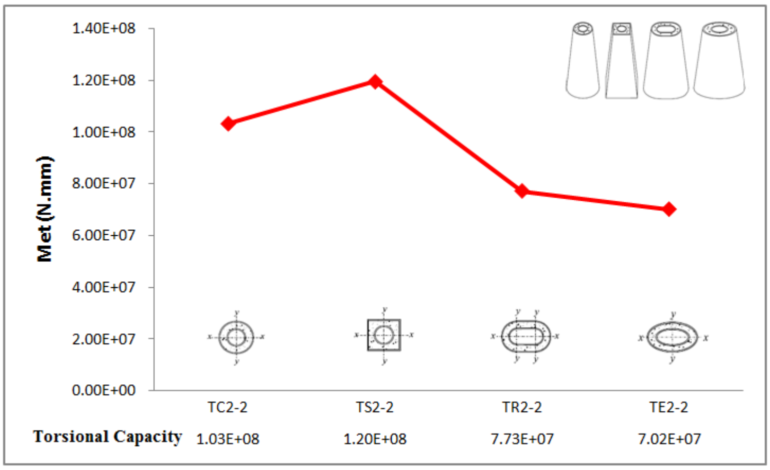


(b)

Fig.11. Ultimate torsional capacity of filled DST columns with the hole ratio of x=0.75



(a)



(b)

Fig. 12 Ultimate torsional capacity of filled DST columns with the hole ratio of x=0.50

To verify the performance of DST columns, ultimate torsional capacity for the straight and tapered columns are shown in figure 13 and also ultimate torsional capacity of DST filled columns with sandwich concrete and hollow both for straight have been illustrated in figure 14.

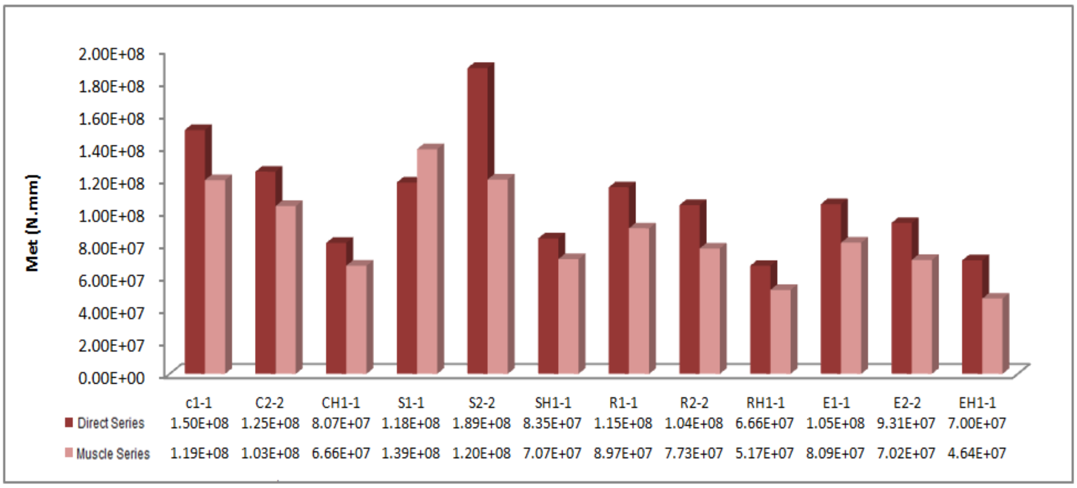


Fig.13. Torsional capacity of columns for both straight and tapered series

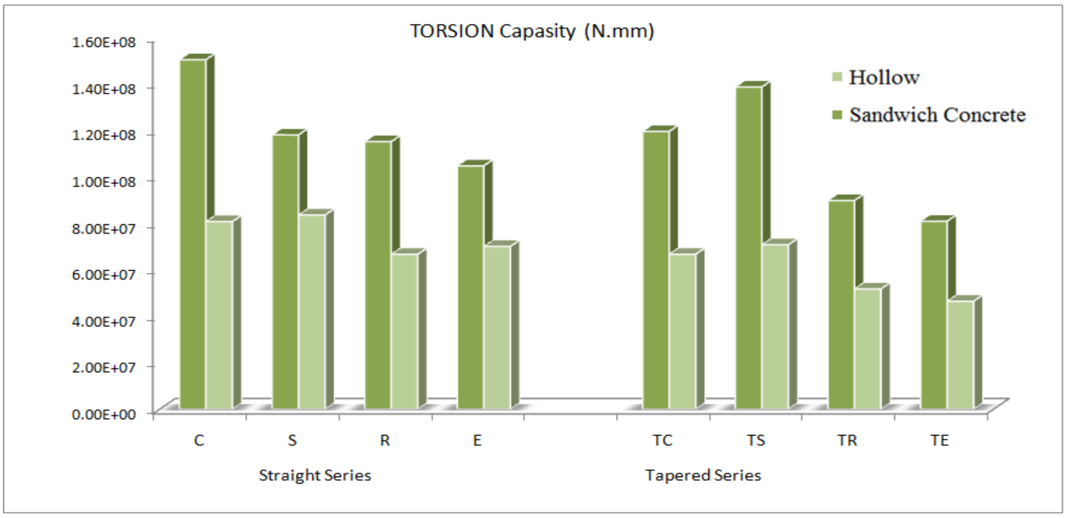


Fig.14. Torsional capacity of DST filled columns with sandwich concrete and hollow both for straight and tapered series

VI. Conclusion

In this study, the performance of DST columns with straight and tapered section was evaluated under the force of bending moment. The results are as following:

- Torsional resistance of cross sections (Mut) and the torsional stiffness of the direct column increases with the increase of the hole ratio(X) Aside from square section and increases markedly by filling the sandwiched concrete.
- Bending strength of transverse sections (Mut) and torsional stiffness of muscular column increases with the hole ratio(X) and increases markedly with filling the sandwiched concrete.
- Among the DST short columns (the ratio of the larger dimension of the cross section to the column height equal to 1.3) from the series of hollow muscular and direct with the hole ratio(X) equal to 0.75, the cross section has the maximum torsional capacity at the twist around the longitudinal axis of the column.
- DST short columns filled with concrete with hole ratio(X) equal to 0.75 of circular section, columns in direct series and square section for columns in muscular series have the maximum torsional capacity.
- DST short columns filled with concrete with hole ratio(X) equal to 0.50 of square section, columns in direct and muscular series have the maximum torsional capacity.
- DST muscular columns, torsional resistance decreases markedly with the increased muscular angle. Resistance of cross sections for circular, square, rectangular, and elliptical columns decreases by changing the angle from 0 to 1 degree to 27.0%, 21.0%, 25.0%, 18.3%. Apart from the square cross section with the hole ratio of 0.75, we are faced with the increase of torsional resistance by 18%.
- Torsional resistance of the cross-section (Mut) in DST olumns filled with concrete and DST hollow empty reference columns. It can be observed that the Torsional resistance of composite columns is mainly increased due to the filling with sandwich concrete. For direct members, the torsional resistance of DST circular, square, rectangular, or elliptical columns filled with concrete is 1.86, 1.41, 1.73 and 1.50 times the hollow pipes.
- For short muscular columns, the , torsional resistance of DST circular, square, rectangular, or elliptical members sandwiched with concrete are 1.79, 1.97, 1.74 and 1.74 times the hollow pipes.

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