American Journal of Civil Engineering and Architecture, 2017, Vol. 5, No. 2, 35-39
Available online at http://pubs.sciepub.com/ajcea/5/2/1

DOI:10.12691/ajcea-5-2-1

Performance of Concrete Filled Steel Tubular Columns

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Abstract Recent advancements in the availability of higher strength steels, better coating materials for protection and high strengths/performance concretes have expanded the scope of concrete filled steel composite columns with wide ranging applications in various structural systems with ease of construction, highly increased strengths and better performance. This experimental study is carried out on the behavior of short, concrete filled steel tubular columns axially loaded in compression to failure. Three dimensional confinement effect of concrete along with support provided by concrete to the thin walls of steel tube to prevent local buckling had a composite effect on the strength of the composite column increasing the compressive strengths by almost 300 to 400%. In addition to the concrete core, the parameters for the testing were shape of the steel tube and its diameter-to-thickness ratio. It has been observed that ultimate strength of concrete filled steel tubes under concentric compression behavior is considerably affected by the thickness of the steel tube, as well as by the shape of its cross section. Confining effect in circular CFST columns improves their strength, appreciably. The axial load-deformation behavior of columns is remarkably affected by the cross-sectional shape, diameter/width-to-thickness ratio of the steel tube, and the strength of the filled concrete. The load deformation relationship for circular columns showed strain-hardening or elastic perfectly plastic behavior after yielding.

Keywords: *tubular columns, concrete filled steel tubes, confined concrete, braced tubes, high strength steels*

Cite This Article: T. Kibriya, "Performance of Concrete Filled Steel Tubular Columns." *American Journal of Civil Engineering and Architecture*, vol. 5, no. 2 (2017): 35-39. doi: 10.12691/ajcea-5-2-1.

1. Introduction

Due to their excellent structural performance, high strength and ductility, concrete filled steel tubular columns are extremely suitable as structural members for buildings, bridges, trussed structures and deep foundations. The advantages of the concrete filled steel tubular columns over other composite systems are that the steel tube provides formwork for concrete, prevents concrete spalling, environmental damage, tensile strength and protection from offensive agencies whilst concrete in the steel tube supports thin walls and prolongs/ prevents local buckling of the steel tubing. The steel tube acts as longitudinal and lateral reinforcement, and is thus subjected to biaxial stresses, longitudinal compression and hoop tension, whilst the enclosed concrete is stressed tri-axially. The composite column adds significant stiffness to the structure as compared to more traditional steel frame. The advent of higher strength steels, better coating materials for protection and high strengths/performance concretes have expanded the scope of this composite with wide ranging applications in various structural systems with highly increased strengths and better performance.

2. Research Methodology

To study the behavior of composite columns, a total of 36 specimen in four groups comprising two groups of circular shape and two square shapes were tested. 3 specimen in each group were hollow, 3 filled with concrete and 3 braced and filled with concrete. Braced tubes were hollow steel tubes cross braced internally with #3 deformed bars welded in transverse direction, alternately at a distance of 150mm centre to centre and filled with concrete. The height of all specimen was 750mm.

The dimensions of the square columns selected aimed at maintaining similar cross sectional area as of corresponding circular columns. Hence square columns of Group C has similar cross sectional area as of circular columns of Group A and similarly Group D has similar cross sectional area as of circular columns of Group B. Other details are given in Table 1. Steel Pipes used for this experimental investigation were made of 250MPa steel. Normal OPC was used with crushed limestone coarse aggregates and medium grading sand. 30Mpa concrete, as shown in Table 2, was used in this study. The test strengths of different columns were also compared with strengths given by various codes and also the design equation proposed by Georgios Giakoumelis and Dennis Lam (1).

2.1. Code Check for Minimum Thickness Requirement – Steel Tube

Minimum b/t requirements under LRFD, Eurocode and ACI are given in Table 3. The minimum steel requirement is given in Table 4 confirming that all columns have steel area more than 4%.

Table 1. Geometric properties of steel tubes used

Ser #	Group	Column Type	Outer Dia mm	Inner Dia mm	Thickness mm	D/t or b/t	L/D or L/b	λ
1	A	Circular	160	155	2.5	64	4.69	19
2	B	Circular	111.25	106.25	2.5	44.5	6.74	27
3	C	Square	125.66	120.66	2.5	50.26	5.97	21
4	D	Square	87.38	82.38	2.5	34.95	8.58	30

Table 2. Properties of concrete used

Specimen	Compressive strength $f_c^{/}$ (MPa)	Average $f_c^{/}$ (MPa)
1	32.61	31.82
2	29.74	
3	33.42	

Table 3. Limiting values of b/t

Type	LRFD	Eurocode	ACI code
Square	40	50.6	49.16
Circular	40	85	80

Table 4. Minimum steel check

Ser	Column type	Outer Dia mm	Inner Dia mm	Thickness mm	As sq mm	Ac sq mm	As %
1	A Circular	160	155	2.5	1237	18869	6.15
2	B Circular	111.25	106.25	2.5	854	8866	8.80
3	C Square	125.66	120.66	2.5	1231	14559	7.80
4	D Square	87.38	82.38	2.5	848	6786	11.11

Steel fy = 250 Mpa
Concrete fc=30 Mpa.

2.2. Testing Procedure

The columns were tested in a 200 tons capacity Universal compression testing machine. The specimens were centered in the testing machine in order to avoid eccentricity. The vertical displacement was measured by displacement transducers. The top and bottom faces of specimen were grinded and made smooth and leveled to remove surface imperfections and maintain uniformity of loading on the surface.

Figure 1. Photographs showing failure modes

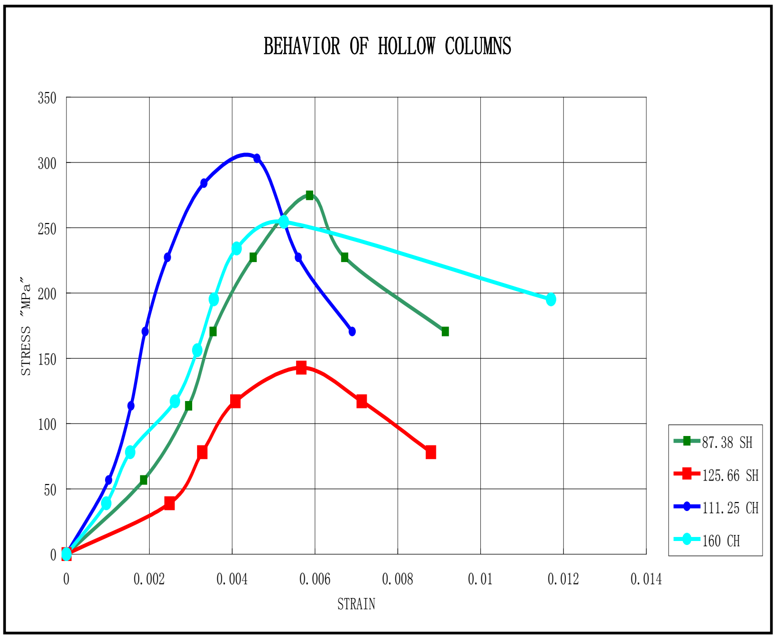

Figure 2. Stress – strain curve of hollow columns

3. Experimental Results

The stress – strain behaviour of specimen tested is shown in Figure 2 to Figure 4 and the test results are listed at Table 5.

3.1. Hollow Steel Columns

All columns behaved in almost similar way with yielding strain observed to be between 0.004 and 0.006 and stress in steel around 250MPa at failure. Deformation behavior was also similar. Circular columns failed at about 40% higher loads and deformations on yielding as shown in the stress-strain curves. Square columns started yielding at lower loads as compared to circular ones. Figure 2 shows the yielding of the columns.

3.2. Concrete Filled Columns

Almost 400% increased strengths were observed for circular columns with 160mm diameter whilst about 100% increase was observed for circular columns with 111.25mm dia. Almost 300% increase in strength was observed for square columns with 125.7 mm side as compared to 100% increase in square columns with 87.4 mm side clearly indicating that higher increase in strength of concrete filled columns was in those with higher concrete area with circular columns performing better than square ones.

Failure strains ranged up to 12mm whilst failure mode in all cases was observed to be due to crushing of concrete resulting into bulging of steel column, failing thereby in yielding as shown in Figure 3.

Table 5. Comparison of Results

Ser	Column type	Actual capacity kN	Pu LRFD kN	Pu ACI kN	Pu Eurocode kN	Georgios Equation kN
1	A circular hollow	290	341	341	309.25	309.25
2	-do- filled	1153	698	784	909	986.27
3	-do- filled & braced	1090	698	784	909	986.27
4	B circular hollow	237	235	235	213.50	213.50
5	-do- filled	526	380	443	454	531.61
6	-do- filled & braced	422	380	443	454	531.61
7	C Square hollow	179	339	339	307.75	307.75
8	-do- filled	594	551	681	788	830.13
9	-do- filled & braced	595	551	681	788	830.13
10	D Square hollow	215	234	234	212	212
11	-do- filled	450	293	393	428	455.48
12	-do- filled & braced	407	293	393	428	455.48

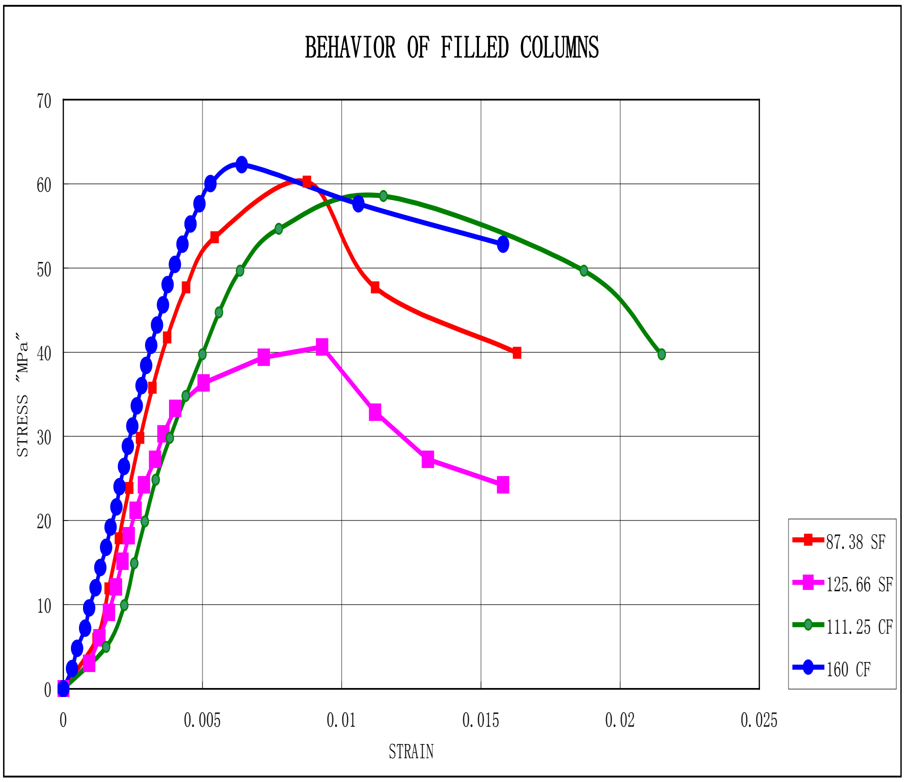

Figure 3. Stress – strain curve of filled columns

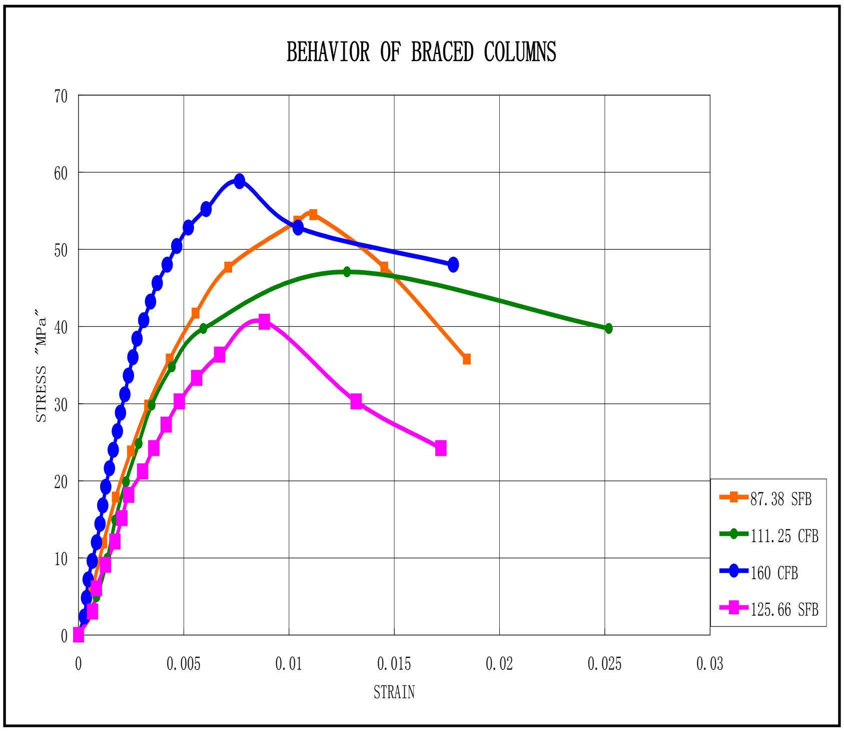

Figure 4. Stress – strain curve of braced columns

3.3. Concrete Filled and Braced Columns

Braced and concrete filled steel columns were observed to behave almost similar to the concrete filled columns without bracing. Bracing did not improve the strength because of improper filling of steel tubes due to presence of bracing at every 150mm distance along with the length of the column which falls into short columns category where slenderness effects did not come into play. The failure was due to crushing of concrete and thereby yielding of steel due to bulging out.

3.4. Strength Comparison by Design Codes

The values calculated by this method are listed at Table 5. It is observed that the capacities given by ACI code are too conservative whereas those calculated by using proposed equation are more realistic, especially for circular columns.

3.5. Modified equation

Since the above values are too conservative, a modification for ACI and AS equation proposed by Georgios Giakoumelis and Dennis Lam [1]. A coefficient is proposed for the ACI/AS equation to take into account the effect of concrete confinement on the axial load capacity of concrete filled circular steel tube, suggesting the revised equation as follows:- $N_u = 1.3 A_c f_c^{/} + A_s f_s$.

4. Discussion

4.1. Effect of concrete confinement

For concrete filled circular sections, the confinement effect of concrete increases the concrete strength. The effect of confinement is considered when the relative slenderness, $\bar{\lambda}$ is less than 0.5. Due to concrete confinement the stress bearing capacity of concrete increased to almost double in circular columns. It implies that when diameter is kept constant and steel thickness is increased, the confinement factor increases thereby increasing the compressive strength of concrete (9).

4.2. Failure Modes

Almost all columns failed due to local buckling and concrete crushing. Local buckling took place in inelastic range and after this concrete crushing followed. The failure mode of almost all columns at bottom or top was a typical crushing failure mode where the steel wall was pushed out by the concrete core, which in turn was confined by the steel. When the steel was removed from the specimen after failure, the concrete was found to have taken the shape of the deformed steel tube, which illustrates the composite action of the section.

4.3. Circular Columns

In the initial stages of loading of the circular CFT columns subjected to axial load, Poisson's ratio for the concrete is lower than that for steel; therefore a separation between steel tube wall and concrete core takes place. As the load increases, the longitudinal strain reaches a certain critical strain, the lateral deformation strength and the nominal ultimate load is provided by the confining effect on concrete strength, and this gain depends upon the tube strength. Figure 2 through Figure 4 indicate the behavior of circular columns as much better as compared to square ones for both hollow and filled series. At failure, ring shaped buckles developed outwards mostly near ends i.e top or bottom. Equation developed by Georgios Giakoumelis and Dennis Lam(1) predicts the ultimate strength almost accurate for circular columns.

4.4. Square Columns

In the case of square columns, it is necessary to take into consideration a capacity reduction due to local buckling of the steel tube wall of the column with large *B*/*t* ratio rather than the confinement effect of the steel tube. Also the compressive strength decreases as the size of square columns increases as shown in Figure 2 to Figure 4. An equation for square columns is suggested to be used for calculating the ultimate strength as: $N_u = 1.10 A_c f_c^{/} + A_s f_s$ which gives fairly safe results.

5. Conclusion

The experiments have shown that strength increase in circular concrete filled steel columns is more than that of square ones. Increase in strength of circular columns was observed to be 400% higher as compared to about 300% higher strengths for concrete filled square columns. Local buckling of steel tube was observed in both hollow and filled square columns. Almost all concrete filled steel columns behaved in a fairly ductile manner. Concrete filled steel columns with relatively higher concrete area proportionately increased the ultimate strength.

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