International Journal of
Civil Engineering (IJCE)
ISSN(P): 2278-9987; ISSN(E): 2278-9995
Vol. 4, Issue 6, Oct - Nov 2015, 47-58

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

EXPERIMENTAL STUDY ON COLD FORMED STEEL SHORT COLUMN INFILLED WITH SILICA FUME CONCRETE

ANI MARY ALEX[1] & EAPEN SAKARIA[2]

[1]Research Scholar, Geomechanics and Structures, Saintgits College of Engineering, Kottayam, Kerala, India

[2]Professor, Department of Civil Engineering, Saintgits College of Engineering, Kottayam, Kerala, India

ABSTRACT

An experimental investigation on the behaviour of cold formed steel short column infilled with silica fume concrete under axial compression to failure is presented. The ultimate load carrying capacity and load versus strain graph for hollow section, hollow column infilled with normal M30 concrete and hollow column infilled with optimum silica fume concrete were examined. A total of 12 specimens with square cross section having length to breadth ratio as 7 and breadth to thickness ratio as 40 and 50 were tested. The results were compared with various codes of practices and also with some equations published in journal papers. Hollow column infilled with silica fume concrete with B/t ratio 40 increases its axial compressive load by 17% when compared with hollow column infilled with normal M30 concrete gives the best result. As B/t decreases the axial load carrying capacity of CFST infilled with silica fume concrete increases by 37%. In all the comparisons with the codes, CFST infilled with silica fume concrete were conservative.

KEYWORDS: Cold Formed Steel Tubes (CFST), Composite Members, Silica Fume (SF) Concrete

INTRODUCTION

An experimental study was conducted to understand the behavior of cold formed steel short column infilled with silica fume concrete under axial compression to failure. A total of 12 specimens having a square cross-section were tested to investigate the load carrying capacity in particular and behavior as a whole. The length-to-diameter ratios of the test specimens is 7. So the test specimen is a short column. The diameter-to-thickness ratio is 40 and 50. The steel pipes are made up of cold formed steel of grade 355 N/mm^2. Thickness of tube wall are 2 mm and 2.5 mm. Dimensions of square tubes are 100 mm x 100 mm and 700-mm long. Tests were carried out on the said steel tubes under axial compression. The aim of the project is to develop a high strength columns by combining concrete filled steel tubes and with the silica fumes. Concrete filled steel tubes having high load carrying capacity where as when silica fumes is mixed with concrete increases its performance. So here in this project, decide to conduct an experiment on concrete filled steel tubular columns infilled with silica fume concrete. The parameters of this project is the ultimate axial load carrying capacity, strain corresponding to the ultimate load and load strain relationship of CFST with silica fume concrete. The test results are also compared with various thickness of steel of CFST, with the hollow CFST and also with CFST with normal control concrete. Also test results were compared with the theoretical results obtained using different code of practices and also with some equations published in some journal papers. Some broad conclusions were made and areas of future research were indicated.

Objectives of the Work

- To determine the optimum percentage of silica fume in M30 grade of concrete.

- To determine the grade of the steel.
- To determine the ultimate axial load carrying capacity of cold formed steel short column infilled with the optimum percentage of silica fume concrete.
- To determine the load strain relationship of cold formed steel short column infilled with the optimum percentage of silica fume concrete.
- To compare with the results of cold formed steel short column infilled with silica fume concrete with various thickness of steel.
- To compare with the results of cold formed steel short column infilled with silica fume concrete, with normal M30 concrete and also with hollow CFST.
- To compare with the theoretical results of infilled columns in Georgios Giakoumelis and Dennis Lam's proposal to ACI committee, American code (ACI 318 – 1999) and Australian code (AS 5100 - 2004), Eurocode 4 (EC4 – 2004) and British code (BS5400 – 2005) code of practices and also compared with the theoretical values obtained by using the equation in the journal paper by Kenji Sakino et al.

EXPERIMENTAL PROGRAMME

The cold formed steel short column infilled with normal M30 grade concrete, infilled with optimum percentage of silica fume concrete and hollow section column were undergone the test in a Universal Testing machine with 1000 kN capacity. The optimum percentage of silica fume is obtained by conducting the cube test with various percentage of silica fume (5,10,15,20 and 25%) in compression testing machine.

Coupon Test

Coupon test was done to determine the grade of steel. This test was conducted as per the code ASTM 370 standards. Inorder to conduct the coupon test, the material which is used to conduct the experiment that is cold formed steel is to be fabricated as per the specification given in the code ASTM 370 standards. Tension test is conducted in UTM and test is continued till the failure. Fabrication details for coupon test as per ASTM 370 standards are shown in the figure 2.

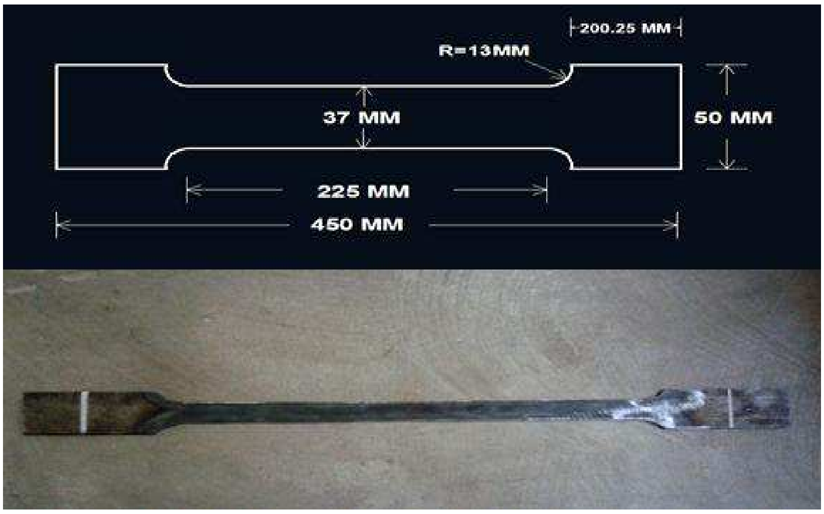

Figure 1: Fabrication Details for Coupon Test as Per ASTM 370 Standards

Preparation of CFST Specimens

Cold formed steel sheet specimen was cut in lengthwise direction. The cut sheets were welded using welding machine.Welding is done along the lengthwise direction. The both sides of the steel tubes are left opened. The steel tubes were placed in lengthwise position and the concrete were filled inside the steel tubes.Hand mixing is adopted. The test specimens were self cured for 28 days from the date of concreting. And the specimens were undone with the testing. Compression test is conducted in Universal Testing Machine with 1000 KN capacity. Column placed vertically with steel plates at top and bottom for providing fixed condition. The electrical strain gauges were used to measure the strain in steel surface of the column specimen. Strain guages were placed at bottom of the column. For every increment in the load value the corresponding strain values were noted. Test continued till failure. Ultimate axial load carrying capacity is obtained for all the specimens.

a) b) c)

Figure 2: Fabrication Details of CFST Specimens a) CFST with Different Thickness b) Hollow Specimen c) Infilled Column

RESULTS AND DISCUSSIONS

The optimum percentage of silica fume is obtained as 5% by conducting the cube test. The results of coupon test is determined and the grade of steel is obtained as 355N/mm^2. The results of coupon test is shown in the figure 6.

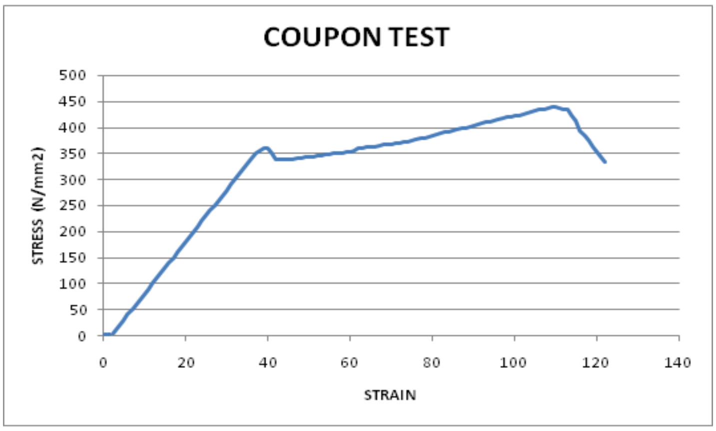

Figure 3: Stress Strain Graph for Coupon Test

Table 1: Description of Steel Sheets

Description	E (N/mm^2)	F_y(N/mm^2)	F_u(N/mm^2)
Steel Sheet	2.04x10^5	355	440

Comparison between Different CFST Columns

- Comparative study on hollow column and silica fume concrete short column (L/b = 7 < 12) with 2mm thick steel tube

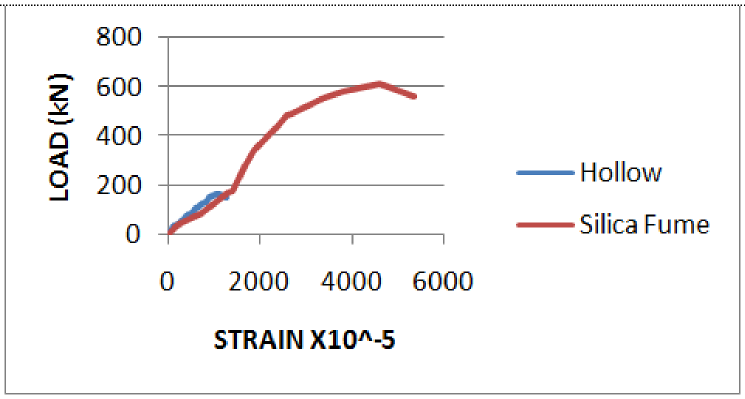

Figure 4: Load versus Strain Graph for Hollow and Silica Fume Column with 2 mm

The ultimate load carrying capacity of hollow column is 165kN and where as for silica fume concrete is 610 kN, i.e 270 % more increase in strength when hollow section column were filled with silica fume concrete. Strain corresponding to ultimate load of hollow column is 0.0105 and for silica fume concrete is 0.038.

- Comparative study on control M30 column and silica fume column (L/b = 7 <12) with 2mm thick steel tube

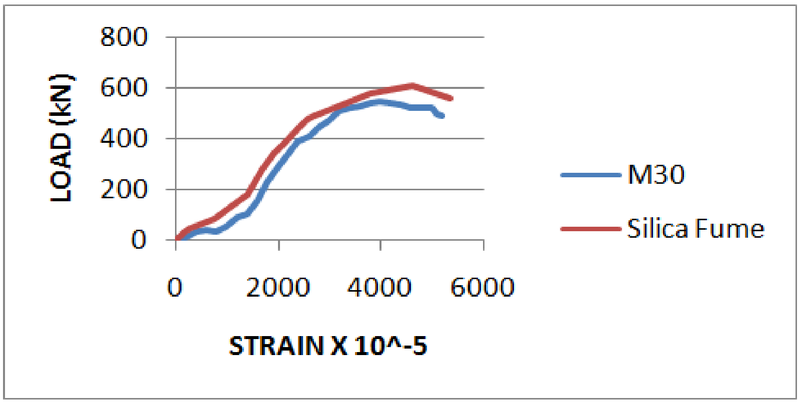

Figure 5: Load versus Strain Graph for M30 and Silica Fume Column with 2 mm

Ultimate load carrying capacity of control M30 column is 547 kN whereas for silica fume concrete column is 610 kN,i.e 12 % increase in the strength even with 5% replacement of cement with silica fume concrete. Strain corresponding to ultimate load of control M30 column is 0.038 and for silica fume concrete column is 0.0423.

- Comparative study on hollow, control M30 and silica fume concrete column (L/b = 7 < 12) with 2mm thick steel tube

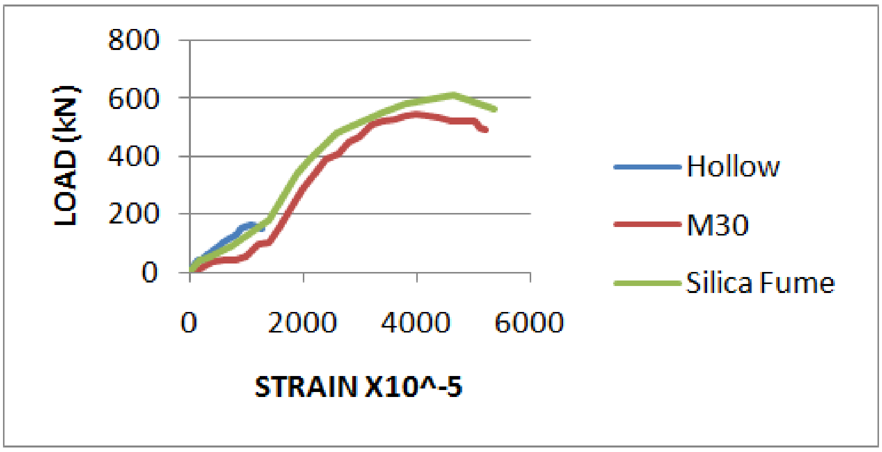

Figure 6: Load versus Strain Graph for Hollow, M30 and Silica Fume Columns with 2 mm

Silica fume concrete column gives the best result when compared to other. Ultimate load of silica fume concrete column is 1.12 times the ultimate load of control M30 column and 3.7 times that of hollow column. The strain corresponding to silica fume concrete column is 12 % more than the that of control M30 column.

- Comparative study on hollow column and silica fume concrete column (L/b =7 <12) with 2.5 mm thick steel tube

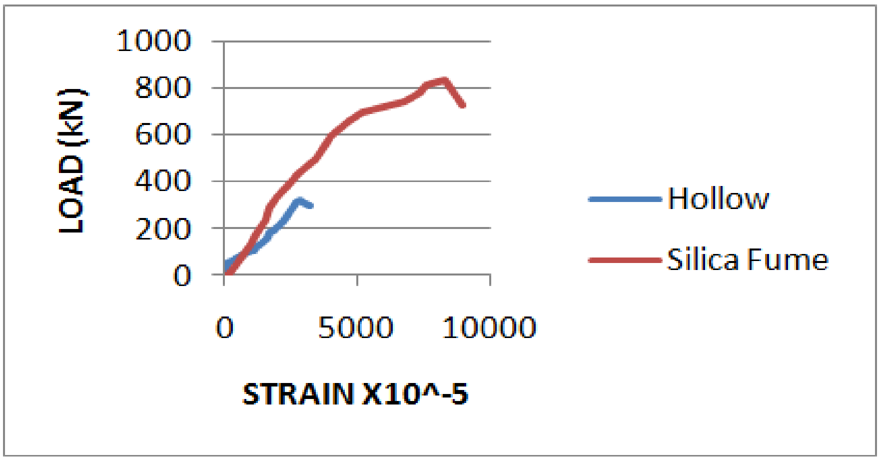

Figure 7: Load versus Strain Graph for Hollow and Silica Fume Column with 2.5 mm

Ultimate load capacity of hollow column with 2.5 mm thickness is 320 kN where as for silica fume concrete column is 835kN,i.e 161% more increase in strength when hollow section column were filled with silica fume concrete with 2.5 mm thickness. The Strain corresponding to the ultimate load of hollow column is 0.027 and for silica fume concrete column is 0.08

- Comparative study on control M30 column and silica fume concrete column (L/b = 7 <12) with 2.5 mm thick steel tube

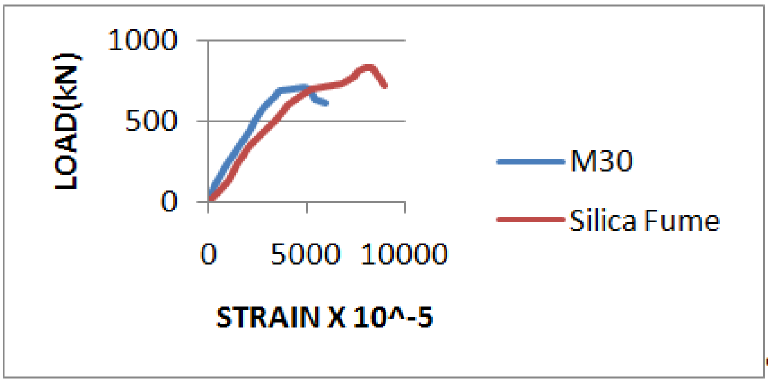

Figure 8: Load versus Strain Graph for M30 and Silica Fume Column with 2.5 mm

Ultimate load carrying capacity of control M30 column is 716 kN whereas for silica fume concrete column with 2.5 mm thickness is 835 kN, i.e 17 % increase in the strength even with 5% replacement of cement with silica fume concrete column with 2.5 mm thickness. The strain corresponding to ultimate load of control M30 column is 0.042 and for silica fume concrete column is 0.08.

- Comparative study on hollow, control M30 and silica fume concrete column (L/b = 7 < 12) with 2.5 mm thick steel tube

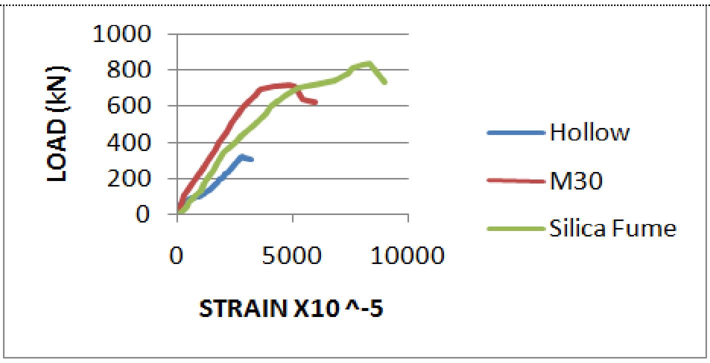

Figure 9: Load versus Strain Graph for Hollow, M30 and Silica Fume Column with 2.5 mm

Silica fume concrete column gives the best result when compared to others. Ultimate load of silica fume concrete column is 1.2 times the ultimate load of control M30 column and 2.6 times that of hollow column.

- Comparative study on hollow short column (L/b = 7 < 12) with 2 mm and 2.5 mm thick steel tube

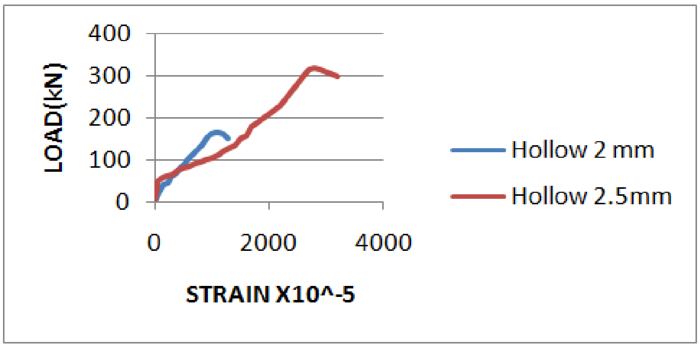

Figure 10: Load versus Strain Graph for Hollow Column with 2mm and 2.5 mm Thickness

Ultimate load for hollow column with 2mm thickness is 165 kN and for hollow column with 2.5 mm thickness is 320 kN, i.e 94 % more increase in the strength as the thickness increases from 2 to 2.5 mm. Strain corresponding to ultimate load of hollow column with 2mm thickness is 0.0105 and for 2.5 mm thickness is 0.027. Failures in hollow column is shown in the figure 11.

Figure 11: Failure Mode in Hollow Column

- Mode of failure in hollow column is local inward folding failure mechanism as well as local buckling in both the top and bottom of the column.
- Inward folding failure mechanism took place when the ultimate load reached 80%.
- Here failure is due to the failure of the steel tube. So, the ultimate load given by the hollow column is the load which can taken by the steel tube alone.
- Comparative study on control M30 short column (L/b = 7 < 12) with 2 mm and 2.5 mm thick steel tube

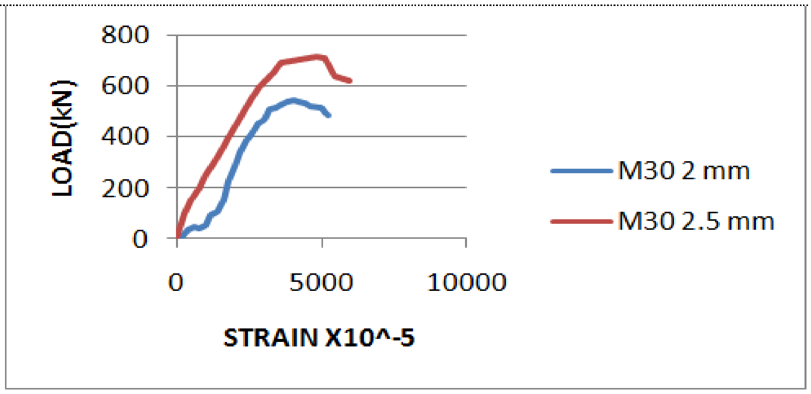

Figure 12: Load versus Strain Graph for Control M30 Column with 2 mm and 2.5 mm

The ultimate load for control M30 column with 2mm thickness is 547 kN and for control M30 column with 2.5 mm thickness is 716 kN, i.e 31 % more increase in the strength as the thickness increases from 2 to 2.5 mm. Strain corresponding to ultimate load of control M30 column with 2mm thickness is 0.038 and for 2.5 mm thickness is 0.042. Failures in hollow column is shown in the figure.

Figure 13: Failure Mode in M30 Infilled Column

- The bulging of column took place when the ultimate load reached 85% and at 90% of the ultimate load the separation of steel and concrete took place.
- The failure for hollow steel tube infilled with M30 grade of concrete was outward folding failure as well as local buckling in both top and bottom of the columns.
- Here the failure mode is mainly due to crushing failure mode i.e, the concrete crushes first thereby pushes the steel wall outwards.
- Comparative study on silica fume concrete short column (L/b = 7 < 12) with 2 mm and 2.5 mm thick steel tube.

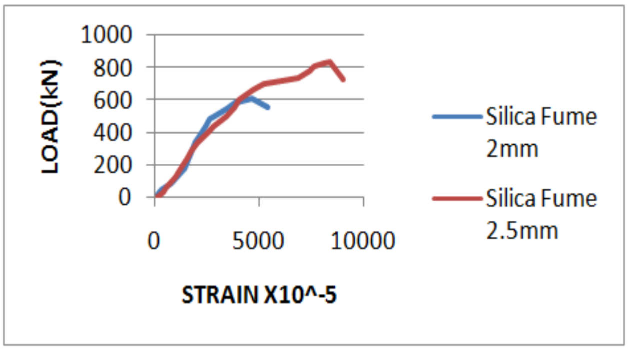

Figure 14: Load versus Strain Graph for Silica Fume Column with 2 mm and 2.5 mm

The ultimate load for silica fume concrete column with 2mm thickness is 610 kN and for silica fume concrete column with 2.5 mm thickness is 835 kN, i.e 37 % more increase in the strength as the thickness increases from 2 to 2.5 mm. Strain corresponding to ultimate load of silica fume concrete column with 2mm thickness is 0.038 and for 2.5 mm thickness is 0.08. Failures in hollow column is shown in the figure 15.

Figure 15: Failure Mode in Silica Fume Infilled Column

- Local buckling was delayed, when the ultimate load reached 88 % first bulging gradually occurred at the bottom of the column.
- When the ultimate load reached 95%, the buckling of the column took place at top of the column also.
- Here also the failure mode is mainly due to crushing failure mode i.e, the concrete crushes first thereby pushes the steel wall outwards.
- Local buckling occurs in the steel tube at a position of about 20 mm from the top and bottom of the column.
- As per literature, outward type local buckling is called Elephent foot type failure.
- The failure mode of almost all infilled columns at the bottom or at the top was a typical crushing failure mode where the steel wall was pushed out by the concrete core which was confined by the steel tube.
- When the steel tube is removed from the failured specimen, the concrete attains the shape of the deformed steel which implies the composite action of steel and concrete.
- Comparison with different codes and formulas published in journal papers

Table 2: Strength Comparison using Different Codes for Control Concrete Short Columns

	D or B mm	Aa mm^2	Ac mm^2	EC4	ACI and AS	BS	Dennis Lam Proposal Formula	Kenji Sakino Formula	Experimental KN
C2	100	784	9216	578	534	500	668	583	547
Nt/Nc	-	-	-	0.95	1.02	1.1	0.82	0.94	-
C2.5	100	975	9025	640	596	584	728	646	716
Nt/Nc	-	-	-	1.12	1.2	1.23	0.98	1.11	-

Table 3: Strength Comparison using Different Codes for Silica Fume Concrete Short Columns

	D or B mm	Aa mm^2	Ac mm^2	EC4	ACI and AS	BS	Dennis Lam Proposal Formula	Kenji Sakino Formula	Experimental kN
SF2	100	784	9216	628	572	523	733	628	610
Nt/Nc	-	-	-	0.97	1.06	1.17	0.83	0.97	-
SF2.5	100	975	9025	690	633	606	791	690	835
Nt/Nc	-	-	-	1.21	1.32	1.32	1.06	1.21	-

CONCLUSIONS

- Short column (L/b= 7 <12) infilled with silica fume concrete increases by 10-20% than short column (L/b= 7 <12) with normal M30 concrete.
- Short column (L/b= 7 <12) infilled with silica fume concrete increases by 150- 300 % than the short hollow column with the same dimension.
- When hollow column infilled with control M30 concrete and silica fume concrete increases the ultimate load carrying capacity and ultimate strain value.
- With decrease in aspect ratio (B/t) from 50 to 40, 20-40% increase in ultimate load carrying capacity.
- In comparison with ACI 318- 1999 and AS 5100- 2004, the ratio of experimental to theoretical failure loads are

conservative by 2 – 30 %

- In comparison with Eurocode 4 (2004), the ratio of experimental to theoretical failure loads are conservative by 11 – 22%
- In comparison with Georgios Giakoumelis, Dennis Lam's proposal to ACI committee, the ratio of experimental to theoretical failure load are conservative by 6%
- In comparison with British code BS5400 – 2005, the ratio of experimental to theoretical failure loads are conservative by 10 – 45 %
- In comparison with Kenji Sakino et al. Formula, the ratio of experimental to theoretical failure loads are conservative by 10 – 22 %
- The load carrying capacity of hollow section column infilled with optimum silica fume concrete is high when compared to hollow column with B/t ratio 50 and 40 is due to resistance offered by concrete, resistance offered by steel and interaction between the steel and concrete.
- Concrete core increases the axial capacity of CFST, for all B/t values but the rate of increase was found to increase with decrease in B/t ratio.
- In case of hollow column infilled with silica fume concrete, bulging of column at bottom occurred when 88%of ultimate load and when 95% of the ultimate load reached bulging occurs at top also.
- In hollow column, failure is mainly inward type local buckling where as in the case of infilled column the failure is outward type local buckling called elephant foot failure.
- The failure mode of almost all infilled columns at the bottom or at the top was a typical crushing failure mode where the steel wall was pushed out by the concrete core which was confined by the steel tube.

SCOPE OF FUTURE WORK

- Cold formed steel column infilled with silica fume concrete can be studied under cyclic loading and also use reinforcement.
- Cold formed steel long hollow columns can be tested using various concrete infills.
- Together with that different sizes of cold formed steel hollow section columns using concrete infill can be tested.
- Dynamic analysis of CFST can also be incorporated in the study.

REFERENCES

1. Dennis Lam, Georgios Giakoumelis, "*Axial capacity of circular concrete filled tube columns*", Constructional Steel Research 60 (2004) 1049–1068
2. J. Zeghiche, K. Chaouib, "*An experimental behaviour of concrete-filled steel tubular columns*", Constructional Steel Research 61 (2005) 53- 66
3. C.S. Cai, Zhi-wu Yu, Fa-xing Ding, "*Experimental behavior of circular concrete-filled steel tube stub columns*",

Constructional Steel Research 63 (2007) 165–174

4. Ben Young, Ehab Ellobody, "*Experimental investigation of concrete-filled cold-formed high strength stainless steel tube columns*", Constructional Steel Research 62 (2006) 484–492
5. Serkan Tokgoz, Cengiz Dundar, "*experimental study on steel tubular columns in-filled with plain and steel fiber reinforced concrete*", Constructional Steel Research 48 (2010) 414–422
6. Safwan A Khedr, Mohamed Nagib Abou Zeid, "*Characteristics of silica fumes*", Journal of Materials in Civil Engineering 6 (1994) 357–375
7. P. C. Aitcin, P. Laplante, "*Long-term compressive strength of silica-fume concrete*", Journal of Materials in Civil Engineering 2 (1990) 164–170
8. Des King, "*the effect of silica fume on the properties of concrete as defined in concrete society report 74, cementitious materials*", 37th Conference on Our World in Concrete & Structures 8 (2012) 184–190
9. Arnon Bentur, Ariel Goldman, "*Curing effects, strength and physical properties of high strength silica fume concretes*", Journal of Materials in Civil Engineering 1 (1989) 46–58