EXPERIMENTAL INVESTIGATION ON CFST COLUMNS UNDER CYCLIC LOADING SUBJECTED TO ELEVATED TEMPERATURE

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***Abstract*:**The effect of thermal stresses and deformations on the performance of structure due to increase in temperaturehas been studied by experimental investigations carried out on the behavior of self-compaction Concrete Filled Steel Tube (CFST) under cyclic loading at elevated temperatures. The raise in temperature due to fire causes the structural elements to expand and if the expansion is restrained, the internal stresses are introduced which intern effects the expectedload carrying capacity of the structure also results in decrease of stiffness and strength which significantly influences the structural performance. The study includes experimental investigation on a total of 128 specimens that includes 32 specimens of hollow and 96 specimens filled with SCC of grades M20, M30, and M40. The various parameters such as geometry of the specimen – circular section, different L/D ratios, and different grades of self-compaction concrete infill have been selected. The specimens including four L/D ratios and having 33.7 mm outer diameter and constant thickness 3.2 mm,which were subjectedtodifferentelevatedtemperature(i.e.,30°C. 60°C,90°C,120°C, 150°C, 180°C, 200°C and 300°C) and tested. The experimental column strengths are compared with values obtained by Euro code -4. The experimental results indicates that with increase in temperature, the load carrying capacity of CFST decreases. The ultimate load carrying capacity is higher for SCC filled tubes than the hollow tubes and higher for higher grade ofSCC. The required mathematical formula has been proposed to reduce the variation of experimental results in comparison with Euro code-4 formula.

***IndexTerms* - CFST, cyclic loading, elevated temperature, self-compactionconcrete,buckling load**

I. INTRODUCTION

Concrete filled steel tubes (CFST) are composite structures of steel tube and in filled concrete these members are suitable for all applications because of effective usage of construction materials. CFST columns posses earth quake resistant properties such as high strength, ductility, large energy absorption capacity and high fire resistance as well as fast construction[1, 2]. The behavior of CFST members in bending, shear, compression and fatigue resistance under cyclic seismic loading are also superior over reinforced members[3, 4]. The development of CFST members adds structural properties to the composite action i.e. concrete core stiffened the steel tube and prevents the inward buckling. The use of CFST columns has become wide spread in construction of tall buildings. The presence of concrete in with in a hollow steel column section has a beneficial effect on the fire resistance of the steel section. The CFST column has high fire resistance capacity without fire protection due to heat storage of the concrete filling inside the steel tube. In many cases the required period of fire resistance can be obtained by concrete filling without the need of external protection. Concrete filled steel tubes (CFST) are composite structures of steel tube and in filled concrete. These members are suitable for all applications because of effective usage of construction materials. CFST columns posses earth quake resistant properties such as high strength, ductility, large energy absorption capacity and high fire resistance as well as fast construction [5, 6]. The behavior of CFST members in bending, shear, compression and fatigue resistance under cyclic seismic loading are also superior over reinforced members [7, 8]. The development of CFST members adds structural properties to the composite action i.e. concrete core stiffened the steel tube and prevents the inward buckling. The use of CFST columns has become wide spread in construction of tall buildings. The presence of concrete in with in a hollow steel column section has a beneficial effect on the fire resistance of the steel section [9, 10]. The CFST column has high fire resistance capacity without fire protection due to heat storage of the concrete filling inside the steel tube [11-13]. In many cases the required period of fire resistance can be obtained by concrete filling without the need of external protection.

II. MATERIALS AND METHODS

Steel Tubes

Steel tubes are the outer casing for the composite element where it holds the concrete still and strong in its place. In this experiment total of 128 specimens where prepared and those dimensions are shown in table 1.

Table 1. Dimensions of the specimens

Diameter D in mm	Thickness t in mm	L/D ratio	length L in mm	Number of specimens
33.7	3.2	6	202.2	32
		8	269.6	32
		12	404.4	32
		16	539.2	32

Mix design for different grades of SCC

The mix design for the Self-compaction concrete (SCC) used to fill in the prepared specimens is done as per IS 10262: 2009. The coarse aggregate used in between 6mm to 10mm in size because of small diameter of availability of steel tubes. Mix design is a process of selecting suitable ingredients and determining their relative proportions with the objective of producing concrete of having certain minimum workability, strength and durability as economically as possible concrete. A mix design can be designed to develop workability super plasticizer add about 2% of cement quantity.

Properties of steel and concrete

The concrete cubes casted and Compression test carried out on different grades of concrete, the average ultimate compressive strength of concrete obtained for design mix grades of SCC M20, M30 and M40 are 23.66 Mpa, 34.8 Mpa and 45.6 Mpa respectively and yield strength obtained for test 333.33 Mpa. Poisson's ratio of concrete and steel are 0.16 and 0.3 respectively. Properties shown in table 2. Also the properties of concrete and steel shown in table 3 due elevated temperature according to Euro code [15]

Table 2 Propertied of materials.

Area of steel section (mm^2) $\mathbf{A_s}$		306.62
Area concrete core (mm^2) **Ac**		585.27
Yield Strength of Steel $\mathbf{f_{y0}}$at 20ºC (N/mm^2) (Experimental)		310
Young's modulus of steel $\mathbf{E_o}$ or $E_s$at 20ºC (N/mm^2)		210000
Moment of Inertia of Steel section $\mathbf{I_s}$ (mm^4)		36028
Moment of Inertia of Concrete section $\mathbf{I_c}$ (mm^4)		27252
Young's modulus of Concrete $\mathbf{E_{co}}$ **or Ec** at 20ºC (N/mm^2)	SCC M20	22360.7
	SCC M30	27386
	SCC M40	31623

Table 3 Material constants for Young's modulus and Strength of materials at elevated Temperatures [15]

Temperature ºC	**Material constant for Steel**		**Material constant for Concrete**	
	Constant for Young's modulus K_{EST}	**Constant for Yield strength K_{ST}**	**Constant for Young's modulus K_{ECT}**	**Constant for Compressive strength K_{CT}**
30	1	1	1	1
60	1	0.985	0.8125	0.975
90	1	0.974	0.672	0.957
120	0.98	0.9624	0.587	0.94
150	0.95	0.951	0.5285	0.925
180	0.92	0.9396	0.465	0.91
200	0.9	0.932	0.432	0.9
300	0.8	0.895	0.3036	0.85

The prepared specimens are tested using cyclic loading compressive testing machine capacity of 2000 KN in order to determine ultimate load and its corresponding deformation for a different L/D ratios with constant thickness and also by varying the grades of concrete. After doing the basic tests on the materials a suitable design for Self-compaction concrete is done according to the ACI code. Then the basic tests on the fresh concrete are done before casted in to the steel tubes. The filling material which is SCC concrete is tested for 7 and 28 days respectively where the aggregates used is 6mm to 10mm in. Total of 128 to required dimensions and cleaned to remove it from dirt and any type of grease and the corners are leveled in order to maintain the even leveled surface. A plate is welded one side in order to seize expel of fresh concrete while filling in steel tubes. After filling the concrete the top of the surface is leveled and excess concrete is expelled out and placed for curing.

Experimental work carried out by preparing a total of 128 specimens which include 96 CFST column specimens as infill with different grades of SCC (i.e.' M20, M30 & M40) and 32 hollow tube column specimens of 33.7 mm outer diameter and 3.2 mm thickness of various lengths of different L/D ratios (i.e., 6,8,12,and16) are selected for the investigation. The specimens were tested at room temperature 30°C and at elevated temperature of 60°, 90°, 120°, 150°, 180°, 200°C and 300°C which are heated in the oven and initialized the free expansion due variation of temperature and tests are carried out in 2000KN cyclic testing machine using SCADA software. To know the ultimate load carrying capacity of the steel tube under cyclic loading subjected to elevated and its equivalent deflection for different lengths and for different grade of concrete.

Euro code 4

The Ultimate or buckling resistance of cross section subjected to axial load is given by equation given below with combined effect of steel, concrete, slenderness factor, confinement effect and temperature effect . The confinement effect not considered when slenderness factor is greater than 0.5 and eccentricity is greater than D/10.

Buckling or Ultimate load, $P_{b\_EU} = A_s.K_{ST}.f_{yo}.\eta_2 + A_c.K_{CT}.f'_c\left(1+\eta_1 \frac{t.\ fyo}{D.\ f'c}\right)$

Where $\eta_1 = 4.9 - 18.5\,\lambda_T + 17\,\lambda_T^2$, $(\eta_1 \geq 0.0)$

$\eta_2 = 0.25(3+2\,\lambda_T)$, $(\eta_2 \leq 1.0)$

Slenderness factor, $\lambda_T = \sqrt{\frac{As.KST.fyo + Ac.KCT.f'c}{Pe}} \leq 2.0$

Euler buckling load , $Pe = \frac{(EI)e.\ \Pi^2}{(kl)^2}$

Effective or equivalent bending stiffness $(EI)_e = \varnothing_s.K_{EST}.E_s.I_s + \varnothing_c.K_{ECT}.E_c.I_c$

Where $\varnothing_s$=1 and $\varnothing_c$ =0.8are reduction factors due elevated temperatures or exposed to fire

Net ultimate or buckling load carrying capacity of CFST column due to elevated temperature

$P_{b\_EUT} = \chi.\ P_{b\_EU}$

Reduction factor for buckling load due to temperature

$$\chi = \frac{1}{\phi + \sqrt{\phi - \lambda_t^2}}$$

$\phi = 0.5(1 + \alpha(\lambda_T - 0.2) + \lambda_T^2)$, α=0.21 (buckling curve 'a' given in Euro code, 2005)

Predicted or proposed formula in comparison with experimental buckling load at elevated Temperature for CFST infill with SCC.

Buckling load due to elevated temperatures,

$P_{b\_PFT} = \chi.\ (P_{b\_EU})^k$

Power factor $k= (1+ (\lambda_T^2.\beta^x/S^y)$

Where x=0.3 and y= 0.33 at T<300°C & y=0.66 at T≥300°C for L/D<12,

y=0.52 at T<300°C & y=1.04 at T≥300°C for 12≤ L/D ≤14

y=0.75 at T<300°C & y=1.5 at T≥300°C for L/D ≥16

Buckling load capacity of CFST column specimens due experimental test results subjected to cyclic loading and buckling load using proposed formula for CFST column shown in table 4. Graphs are plotted for Temperature vs. buckling load, deformations vs. load for experimental values subjected cyclic loading shown in figure 1 to figure 6.

Table 4. Comparison of buckling load of experimental and predicted formula of Euro code

Grade of SCC	Length L mm	S= L/D	Temperature T in °C	P_{b_EU}	$P_{b\_EUT}= \chi .P_{b\_EU}$	k	$P_{b\_PLT} = \chi.(P_{b\_EU})^k$	Exp. Load Pb_cyc	Pb_cyc /Pb_pLt
M30	202.2	6	30	134.65	133.18	1.03	154.66	157	1.015
			60	130.05	128.64	1.025	145.07	154	1.062
			90	126.74	125.37	1.022	139.34	152	1.091
			120	123.2	121.82	1.02	134.31	149	1.109
			150	119.74	118.33	1.019	129.83	143	1.101
			180	116.33	114.88	1.019	125.61	139	1.107
			200	114.09	112.62	1.018	122.92	131	1.066
			300	103.47	101.81	1.01	106.56	110	1.032
	269.6	8	30	125.63	121.83	1.049	154.61	154	0.996
			60	121.44	117.78	1.04	142.66	150	1.051
			90	118.41	114.85	1.035	135.92	145	1.067
			120	115.17	111.65	1.033	130.45	140	1.073
			150	112.02	108.49	1.031	125.78	135	1.073
			180	108.90	105.38	1.03	121.5	130	1.07
			200	106.86	103.34	1.03	118.81	126	1.061
			300	97.18	93.62	1.014	100.02	104	1.04
	404.4	12	30	122.49	113.26	1.061	151.51	146	0.964
			60	118.43	109.54	1.049	138.41	142	1.026
			90	115.50	106.84	1.043	131.24	138	1.051
			120	112.66	104.11	1.04	125.9	134	1.064
			150	109.87	101.33	1.038	121.41	128	1.054
			180	107.10	98.58	1.037	117.34	123	1.048
			200	105.28	96.77	1.037	114.79	120	1.045
			300	96.59	88.10	1.01	92.087	99	1.075
	539.2	16	30	122.55	105.83	1.049	133.92	134	1.001
			60	118.53	102.40	1.04	123.75	129	1.042
			90	115.62	99.92	1.035	118.02	124	1.051
			120	112.66	97.16	1.033	113.32	119	1.05
			150	109.87	94.39	1.031	109.26	115	1.053
			180	107.10	91.64	1.03	105.51	109	1.033
			200	105.28	89.839	1.03	103.14	103	0.999
			300	96.58	81.1	1.004	82.428	80	0.971

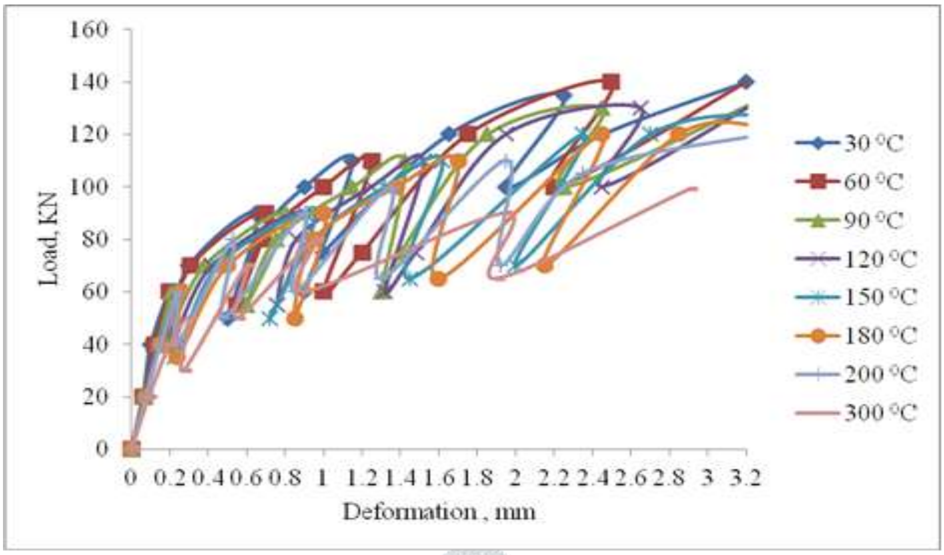

Figure.1 Deformation vs loadcurves for CFST column as infill SCC M30 For L/D=12 at different temperatures due to cyclic loading

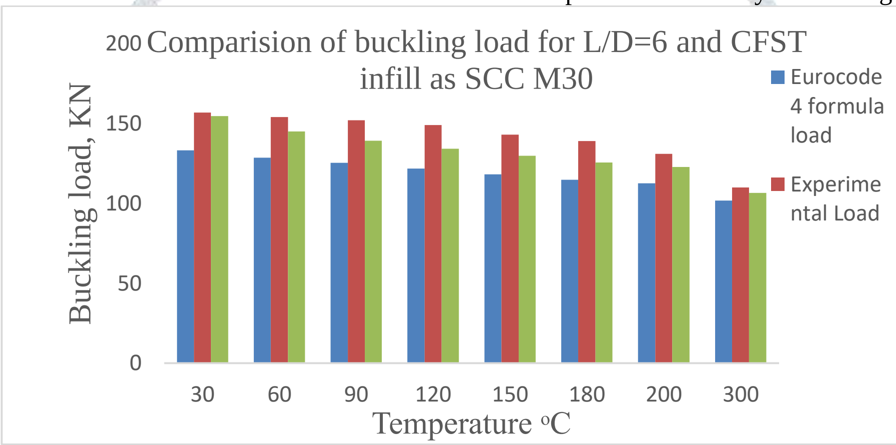

Figure.2 Comparison of buckling load due to Euro code 4, Experimental load and Predicted formula for L/D =6 and CFST infill as M30

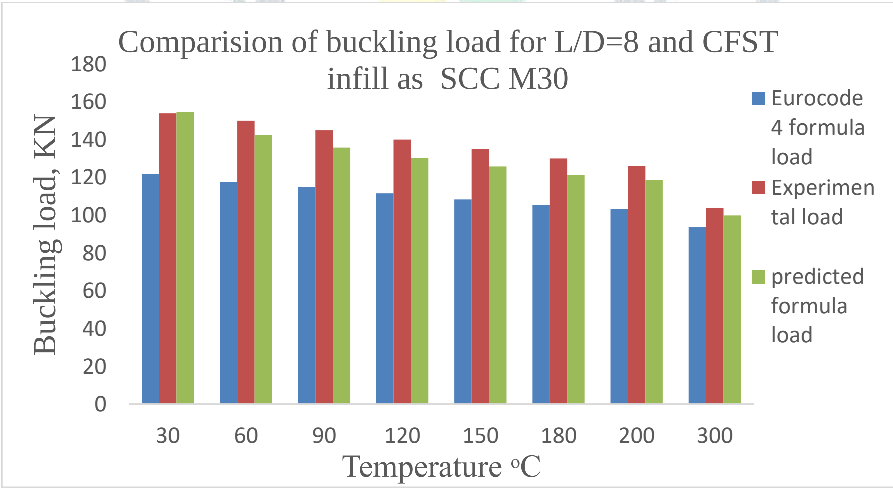

Figure.3 Comparison of buckling load due to Euro code 4, Experimental load and Predicted formula for L/D =8 and CFST infill as M30

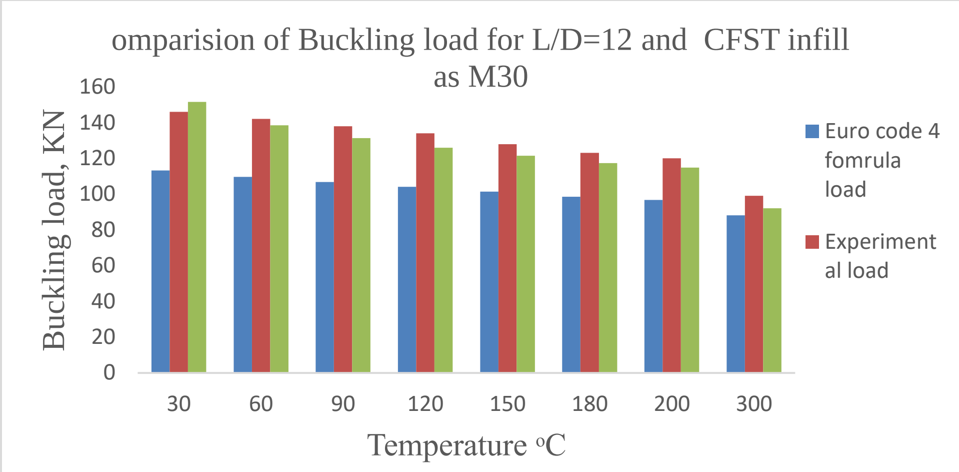

Figure. 4 Comparison of buckling load due to Euro code 4, Experimental load and Predicted formula for L/D =12 and CFST infill as M30

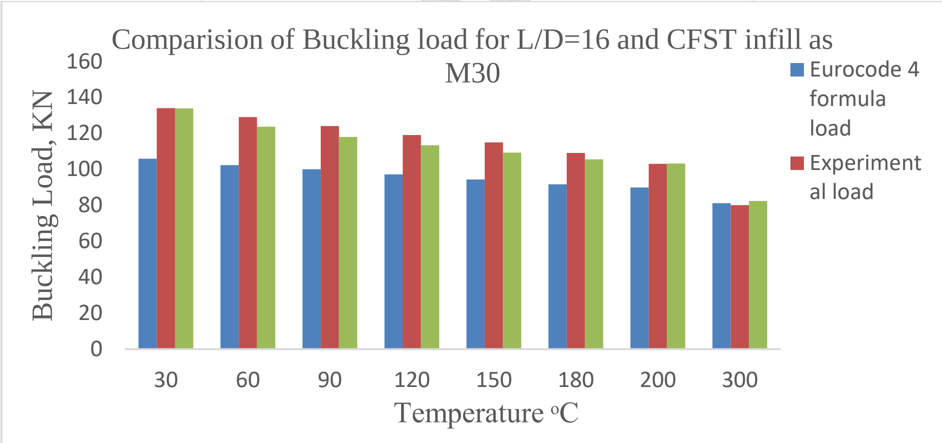

Figure. 5 Comparison of buckling load due to Euro code 4, Experimental load and Predicted formula for L/D =16 and CFST infill as M30

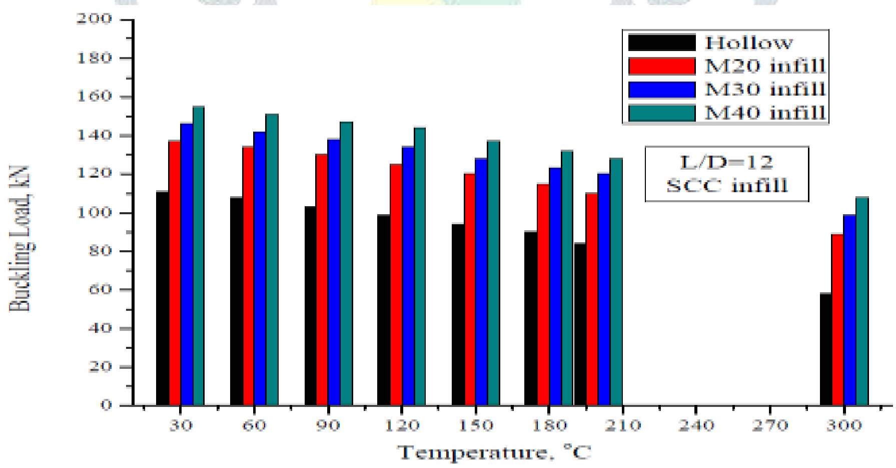

Figure 6Buckling Load vs. Temperature for CFST column with different SCC grades infill For L/D=12 due to cyclic loading

III. CONCLUSIONS

1. The buckling load capacity of CFST columns increases as the grade of infill increases.
2. The buckling load capacity of CFST columns decreases as the temperature increases.
3. It is observed that, for hollow columns the buckling load decreases by 14.75% and 32.2% at temperatures 200^{O} C and 300^{O} C respectively, when compared to normal temperature of 30 ^{O} C.
4. For CFST columns with infill as M20concrete, the buckling load decreases by 12.75% and 26.17% at temperatures 200^{O}

C and 300^{O} C respectively, when compared to normal temperature of 30 ^{O} C.

5. For CFST columns with infill as M30concrete, the buckling load decreases by 12.5% and 24.37% at temperatures 200^{O} C and 300^{O} C respectively, when compared to normal temperature of 30 ^{O} C.
6. For CFST columns with infill as M40concrete, the buckling load decreases by 12. 5% and 23.8% at temperatures 200^{O} C and 300^{O} C respectively, when compared to normal temperature of 30 ^{O} C.
7. The deformations at buckling load with various parameters of CFST columns were observed to be marginal.
8. Variation of buckling load carrying capacity from experimental load to Euro code formula is about 20% to 26% and Experimental load to load calculated from predicted formula is about 2% to 7% and an average variation of about 4%.

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