Analysis of Composite Steel (CFST) Columns - FRC Infilled at Elevated Temperature Using MATLAB

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Abstract: - Combining different materials in a single structural member to take advantage of the good qualities that they both have separately has always been a recognized strategy in building industry. Concrete filled steel tubular columns (CFST) are a type of composite columns in which the combined action of steel and concrete leads to an exceptional structural behavior. In this case, the compressive strength of the element increases due to the passive confinement that the steel tube generates on the concrete core. Simultaneously, the local buckling of the steel tube is improved due to the support of the concrete core which prevents it from suffering this phenomenon inwards. In concrete filled tubular columns (CFST) the combined action of steel and concrete results in many positive attributes at ambient temperature: high load-bearing capacity with smaller cross-section size, aesthetics, high stiffness and ductility and reduced construction cost.

Keywords: Genetic Algorithm, MATLAB, VBA, Composite steel Column.

1. INTRODUCTION

This chapter introduces the structural technology of concrete filled steel tubular columns and their fire resistance characteristics. The benefits of using these composite columns over the other alternatives are also described. The three problems which constitute the whole fire analysis of a CFST column are explained: the fire dynamics, the thermal and the structural analysis

1.1. Background

Combining different materials in a single structural member to take advantage of the good qualities that they both have separately has always been a recognized strategy in building industry. Concrete filled steel tubular columns (CFST) are a type of composite columns in which the combined action of steel and concrete leads to an exceptional structural behavior. In this case, the compressive strength of the element increases due to the passive confinement that the steel tube generates on the concrete core. Simultaneously, the local buckling of the steel tube is improved due to the support of the concrete core which prevents it from suffering this phenomenon inwards.

Structural hollow sections (SHS) are the most efficient steel sections in resisting compression loads. Generating a new composite section by filling the hollow tube with concrete allows not only retaining all the advantageous features of the empty section but also developing new excellent properties. This fact reveals the synergy existing when these two elements work in conjunction. Figure 1.1 shows the behavior of a steel tubular column, a reinforced concrete (RC) stub column and a concrete filled steel tubular stub column without reinforcing bars. As it can be observed, the summation of the steel tube and the RC columns ultimate strength is less than that achieved by the CFST column Han et al. 2014.

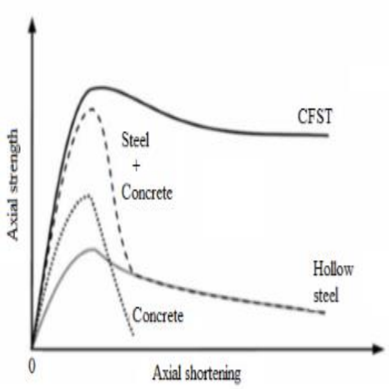


Figure 1-1 Axial compressive behavior of stub columns Han et al. 2014.

Concrete filled steel tubular (CFST) columns have many positive attributes at ambient temperature for building industry: high load-bearing capacity with smaller cross-section size, attractive appearance, high stiffness and ductility, high seismic resistance and reduced construction cost and time since no formwork is necessary.

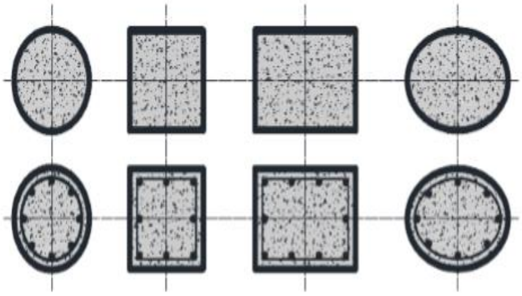


Figure 1-2 Possible shapes of CFST cross-sections Han et al. 2014

Among the most commonly used shapes of CFST columns, it can be found circular and rectangular cross-sections Figure 1.2, although new shapes, such as elliptical profiles, are appearing. A wide variety of concrete infills can be used such as plain concrete, bar-reinforced concrete or fiber reinforced concrete. As mentioned above, the combination of these elements permits the design of columns with reduced cross-section. However, when free spaces and higher net usable surfaces are desirable, the cross-section of the CFST column can be even smaller if high strength materials are employed, solution which is hugely applied by high-rise buildings designers.

2. Fire behavior of CFST columns

The use of concrete filling offers a practical alternative for providing the required fire resistance in steel hollow structural section columns without the need of additional protection Kodur and Lie 1995 and Twilt et al.1996.This is due to the heat sink effect produced in the composite section because of the low thermal conductivity of concrete and the mechanical contribution of the concrete core, which helps to support the applied load and also prevents the inward local buckling of the steel.

The increment in the fire resistance rate (FRR) can be magnified with the use of internal reinforcement. The fire resistance reached by bar-reinforced concrete (RC) filled tubular columns is higher than that achieved by steel tube columns filled with fiber reinforced concrete (FRC), which, at the same time, is higher than the FRR shown by plain concrete filled hollow steel section columns.

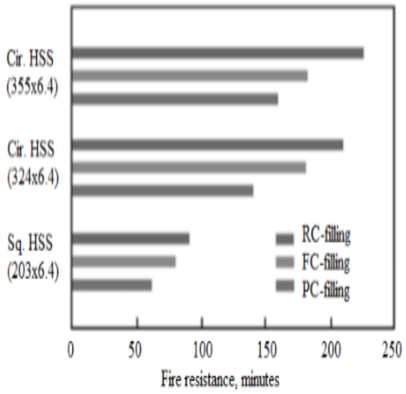


Figure 1-3 Effect of using different types of concrete infill on the fire resistance of CFST columns Kodur 2007.

3 Properties of fiber reinforced concrete column at elevated temperature

In recent years, the construction industry has shown significant interest in the use of fiberreinforced concrete due to the advantages it offers over traditional plain concrete. The use of steelfibers as reinforcement in plain concrete not only enhances the tensile strength of the composite system but also reduces cracking under serviceability conditions. Further, steel-fibers improve resistance to material deterioration as a result of fatigue, impact, shrinkage and thermal stresses. The improvements in material properties, which improve structural performance, have extended the use of fiber-reinforced concrete to applications in the area of fire.

A number of experimental investigations have been conducted up to date with the aim to observe the fire response of concrete composites. Particularly, the studies have focused on the effect of a type, shape and content of fibers on the mechanical properties of concrete composites, mostly compressive and tensile strength including elastic modulus. Namely, it concerns steel fibers, synthetic fibers and a mix of steel and polypropylene fibers which are widely used in the concrete industry. There are also a few investigations which deals with carbon fibers and glass fibers.

The mechanical properties that determine the fire resistance of structural members are the strength and deformation properties at elevated temperatures of the materials of which the members are composed. For concrete, the important mechanical properties are the compressive and tensile strength of the concrete and the deformations caused by load, creep and thermal expansion. These properties are usually expressed in stress-strain relations, which are used as input data in mathematical models for the calculation of the fire resistance of concrete members.

4 Material properties

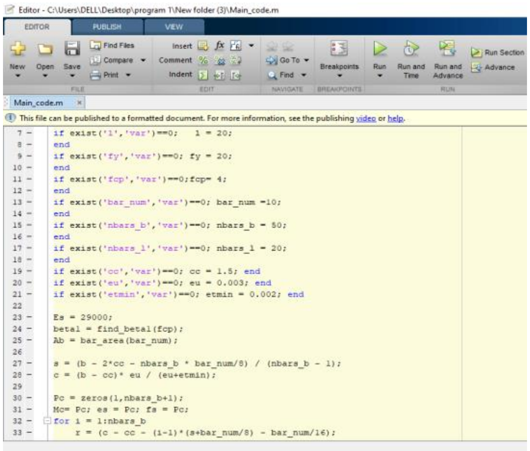
The properties of the fiber reinforced concrete which were used in the model were determined by an experimental test within the framework of “Models of Fiber reinforced concrete columns in case of fire”. The amount of steel fibers used in the fiber concrete mix was 1.7% by mass. Experimental tests were performed on conventional bodies at normal temperatures and elevated temperatures of 200 ° C, 400 ° C and 600 ° C. On the basis of the acquired knowledge a material model was made, which is to serve for numerical simulations of composite steel columns on the spatial model.

Table 4-1 Material properties of Fiber reinforced concrete at different temperatures

Parameter		Properties at(20°C)	Properties at(200°C)	Properties at(400°C)	Properties at(600°C)
Material Model					
Basic	Young modulus [MPa]	36000	34000	14000	4500
	Poisson ratio [-]	0.2	0.2	0.2	0.2
	Tension strength [MPa]	4.4	3.8	3.6	1.4
	Compression strength [Mpa]	-62	-57	-52	-29
Tensile	Fracture energy [KN/m]	0.103	0.103	0.103	0.02
	Fixed crack	1	1	1	1
	Activate crack spacing	No	No	No	No
	Activate tension stiffening	No	No	No	No
	Activate aggregate interlock	0.02 m	0.02 m	0.02 m	0.02 m
	Activate shear factor	No	No	No	No
	Activate unloading factor	No	No	No	No
Compressive	Plastic strain- EPS CP	-0.0009	-0.0009	-0.0011	-0.0012
	Onset of crushing – FCO [MPa]	-9.21	-9.21	-9.21	-9.21
	Critical Comp disp-WD [mm]	-0.15	-0.17	-0.3	-0.35
	Fc reduction	0.8	0.8	0.8	0.8
Miscellaneous	Excentricity-EXC	0.51	0.51	0.51	0.51
	Direc of pl flow-BETA	0	0	0	0
	Rho density $[kg/m^3]$	2300	2300	2300	2300
	Thermal expansion-alpha $[C^{-1}]$	0.000012	0.000012	0.000012	0.000012
Element geometry	Geometrical non linearity	Linear	Linear	Linear	Linear
	Idealisation	3D	3D	3D	3D
	Non-quadratic element	No	No	No	No

WORK FLOW

- Defining Structural problem.
- Determination of Objective Function, Design Variables and Constraints.
- Development of VBA (visual basic application) code for design.
- Development of MATLAB programme.
- Solving problem Using MATLAB.



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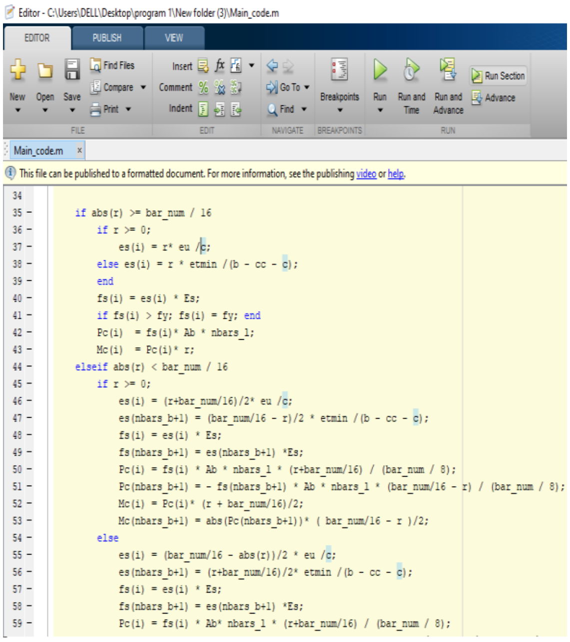
```
if exist('l','var')==0;    l = 20;
end
if exist('fy','var')==0; fy = 20;
end
if exist('fcp','var')==0;fcp= 4;
end
if exist('bar_num','var')==0; bar_num =10;
end
if exist('nbars_b','var')==0; nbars_b = 50;
end
if exist('nbars_l','var')==0; nbars_l = 20;
end
if exist('cc','var')==0; cc = 1.5; end
if exist('eu','var')==0; eu = 0.003; end
if exist('etmin','var')==0; etmin = 0.002; end

Es = 29000;
betal = find_betal(fcp);
Ab = bar_area(bar_num);

s = (b - 2*cc - nbars_b * bar_num/8) / (nbars_b - 1);
c = (b - cc)* eu / (eu+etmin);

Pc = zeros(1,nbars_b+1);
Mc= Pc; es = Pc; fs = Pc;
for i = 1:nbars_b
    r = (c - cc - (i-1)*(s+bar_num/8) - bar_num/16);
```



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    if abs(r) >= bar_num / 16
        if r >= 0;
            es(i) = r* eu /c;
        else es(i) = r * etmin /(b - cc - c);
        end
        fs(i) = es(i) * Es;
        if fs(i) > fy; fs(i) = fy; end
        Pc(i)  = fs(i)* Ab * nbars_l;
        Mc(i)  = Pc(i)* r;
    elseif abs(r) < bar_num / 16
        if r >= 0;
            es(i) = (r+bar_num/16)/2* eu /c;
            es(nbars_b+1) = (bar_num/16 - r)/2 * etmin /(b - cc - c);
            fs(i) = es(i) * Es;
            fs(nbars_b+1) = es(nbars_b+1) *Es;
            Pc(i) = fs(i) * Ab * nbars_l * (r+bar_num/16) / (bar_num / 8);
            Pc(nbars_b+1) = - fs(nbars_b+1) * Ab * nbars_l * (bar_num/16 - r) / (bar_num / 8);
            Mc(i) = Pc(i)* (r + bar_num/16)/2;
            Mc(nbars_b+1) = abs(Pc(nbars_b+1))* ( bar_num/16 - r )/2;
        else
            es(i) = (bar_num/16 - abs(r))/2 * eu /c;
            es(nbars_b+1) = (r+bar_num/16)/2* etmin /(b - cc - c);
            fs(i) = es(i) * Es;
            fs(nbars_b+1) = es(nbars_b+1) *Es;
            Pc(i) = fs(i) * Ab* nbars_l * (r+bar_num/16) / (bar_num / 8);
```

MATLAB Programming

5. Predicted and experimental results:

Table 4-3 Comparison of compressive and tensile strength of a FRC cube at elevated temperatures

Item	Temperature, °C	Compressive Strength (MPa)		Tensile Strength (MPa)		% of Tensile strength to Compressive strength
		Max.	% decrease	Max.	% decrease	
Cube 150x150x150mm	20	86.76	0.0	4.03	0.0	4.65
	200	82.48	-4.9	3.51	-12.9	4.26
	400	65.58	-24.4	3.11	-22.9	4.74
	600	36.20	-58.3	1.06	-73.7	2.93

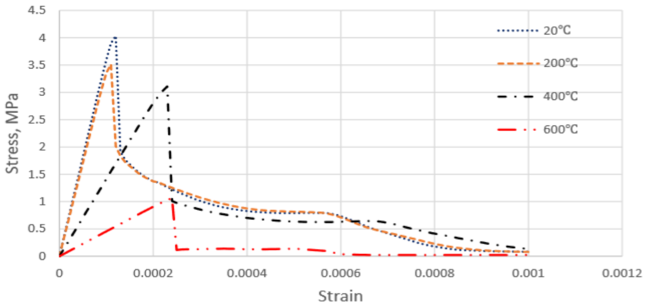


Figure 4-8 Tensile stress-strain curve of a FRC cube at different elevated temperatur

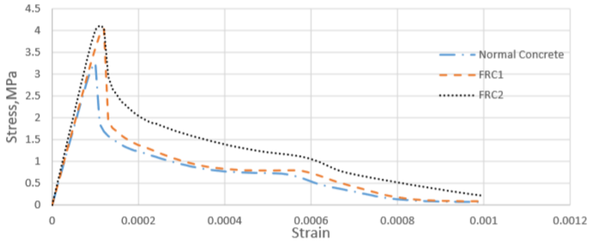


Figure 4-10 Tensile stress-strain curve of different concrete materials at ambient temperatures

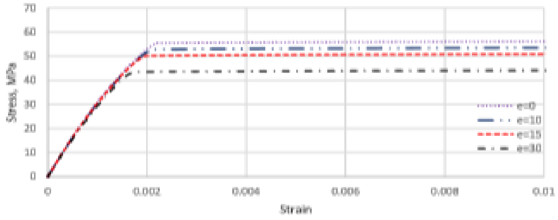


Figure 4-23 Effect of eccentricity of the load on compressive strength of a FRC column at 20°C

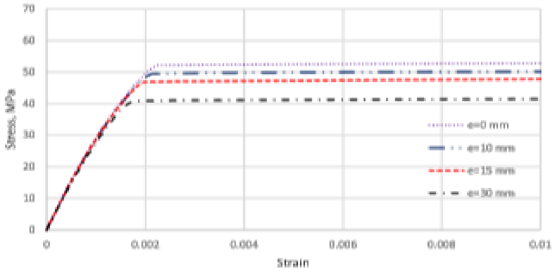


Figure 4-24 Effect of eccentricity of the load on compressive strength of a FRC column at 200°C

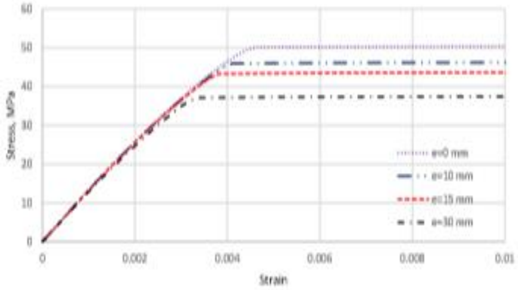


Figure 4-25 Effect of eccentricity of the load on compressive strength of a FRC column at 400°C

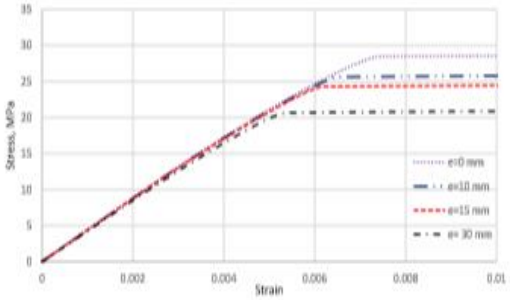
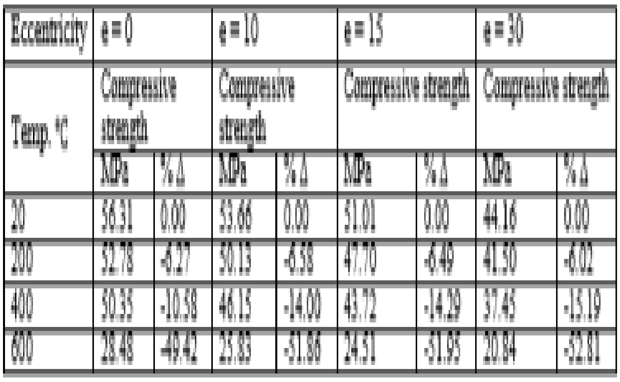


Figure 4-26 Effect of eccentricity of the load on compressive strength of a FRC column at 600°C

CONCLUSIONS AND FUTURE WORKS 5

Table 4-9 Compression strength of FRC column at different temperatures



Eccentricity	e = 0		e = 10		e = 15		e = 30	
Temp. °C	Compressive strength		Compressive strength		Compressive strength		Compressive strength	
	MPa	% Δ	MPa	% Δ	MPa	% Δ	MPa	% Δ
20	56.31	0.00	53.66	0.00	51.01	0.00	44.16	0.00
200	52.78	-6.27	50.13	-6.58	47.70	-6.49	41.50	-6.02
400	50.35	-10.58	46.15	-14.00	43.72	-14.29	37.45	-15.19
600	28.48	-49.42	25.83	-51.86	24.51	-51.95	20.84	-52.81

CONCLUSIONS AND FUTURE WORKS:

- The ultimate shear strength of FRC is less than the ultimate tensile capacity of FRC. It is less than by about 33%, 39% and 53% for temperatures of 200°C, 400°C and 600°C respectively.
- The steel fibers improves the post crack behavior of FRC significantly.
- Thecompressive strengthof the cube is about 20% higher than the compressive strength of the cuboid made from the same material. Unlike the compressive strength, the tensile strength of the cube and cuboid are almost the same.

- FRC column fails in compression by crushing when the axial load is applied without any eccentricity at any temperature. FRC column experiences a combined failure under the application of the load with some eccentricities.
- The orientation of cracks in the FRC column models with eccentric loading are aligned in a diagonal manner which indicates that the presence of a shear stress along with the flexural and compressive stresses.
- The failure modes of a column is greatly affected by the boundary condition and loading environment

REFERENCES:

[1] Espinos A, Romero ML, Hospitaler A. 2013. Fire design method for bar-reinforced circular and elliptical concrete filled tubular columns.Engineering Structures 56:384-395.
[2] Espinos A, Romero ML, Portolés JM, Hospitaler A. 2014. Ambient and fire behavior of eccentrically loaded elliptical slender concrete-filled tubular columns. Journal of Constructional Steel Research 100: 97:107.
[3] Espinos A, Romero ML, Serra E, Hospitaler A. 2015a. Experimental investigation on the fire behavior of rectangular and elliptical slender concrete-filled tubular columns. Thin-Walled Structures 93:137–148.
[4] Espinos A, Romero ML, Serra E, Hospitaler A. 2015b. Circular and square slender concrete-filled tubular columns under large eccentricities and fire. Journal of Constructional Steel Research 110: 90–100.
[5] Espinos, A., Gardner, L., Romero, M.L., Hospitaler, A. (2011). Fire Behavior of Concrete Filled Elliptical Steel Columns Thin-Walled Structures 49(2011) 239–255.
[6] Espinos, A., Romero, M.L., Hospitaler, A. (2010). Advansed Model for Predicting the Fire Response of Concrete Filled Tubular Columns. Journal of Constructional Steel Research 66 (2010) 1030–1046.
[7] Espinos, A., Romero, M.L., Hospitaler, A. (2012). Simple calculation model for evaluating the fire resistance of unreinforced concrete filled tubular columns. Engineering Structures 42 (2012) 231–244.
[8] Han LH, Chen F, Liao FY, Tao Z, Uy B. 2013. Fire performance of concrete filled stainless steel tubular column.Engineering Structures 36: 165-181.
[9] Han LH. 2001. Fire performance of concrete filled steel tubular beam-columns. Journal of Constructional Steel Research 57(6):697-711
[10] Han, L-H., Huo, J-S. (2003). Concrete-filled hollow structural steel columns after exposure to ISO-834 fire standard. Journal of Structural Engineering (ASCE) 129(1):68-78.
[11] Han, L-H., Huo, J-S. (2003). Concrete-filled hollow structural steel columns after exposure to ISO-834 fire standard. Journal of Structural Engineering (ASCE) 129(1):68-78.
[12] Han, L-H., Huo, J-S. (2003). Concrete-filled hollow structural steel columns after exposure to ISO-834 fire standard. Journal of Structural Engineering (ASCE) 129(1):68-78.
[13] Han, L-H., Li, W., Bjorhovde, R. (2014) Developments and advanced applications of concrete-filled steel tubular (CFST) structures: Members. Journal of Constructional Steel Research 100 (2014) 211–228.
[14] Han, L-H., Yang, Y-F, Xu, L. (2003). An experimental study and calculation on the fire resistance of concretefilled SHS and RHS columns. Journal of Constructional Steel Research 59 (2003) 427–452. 15. Hicks SJ, Newman GM. 2002. Design guide for SHS concrete filled columns. Corus Tubes.
[15] Hong, S., Varma, A.H. (2009). Analytical modeling of the standard fire behavior of loaded CFST columns. Journal of Constructional Steel Research 65 (2009) 54-69.
[16] Hu X, Guo H, Yao Y. 2015. Interaction approach for concrete filled steel tube columns under fire conditions. Journal of Building Engineering 3:144-154.