Analytical Study on high Strength Concrete Filled Steel Tubular Columns Subjected to ISO-834 Standard Fire

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ABSTRACT:

Concrete filled steel tubular columns have been extensively used in modern construction owing to that they utilise the most favourable properties of both constituent materials. The present study is a theoretical investigation on the fire performance of concrete filled steel tubular (CFST) columns under constant axial load. A 3-D finite element analysis model is developed to carry out both the numerical heat transfer and non-linear stress analysis and to predict the load versus deformation relationships of CFST columns subjected to a combination of temperature and axial compression. The structural responses of the columns, including critical temperature and fire-resisting time, are obtained for the ISO-834 standard fire. A parametric study is performed to investigate the behaviour and strength of CFST circular columns, viz., column dimensions, steel strength, concrete strength, etc. The temperature distribution, critical temperature and fire exposing time are extracted by using finite element package ABAQUS.

Keywords: Heat transfer analysis, non-linear stress analysis, FEA model, Concrete filled steel tubular column, ISO-834 standard fire, Abaqus.

1. INTRODUCTION

A concrete-filled tube (CFT) column consists of a steel tube filled with concrete. The concrete core adds stiffness and compressive strength to the tubular column and reduces the potential for inward local buckling. Conversely, the steel tube acts as longitudinal and lateral reinforcement for the concrete core helping it to resist tension, bending moment and shear and providing confinement for the concrete. Due to the benefit of composite action of the two materials, the CFT columns provide excellent seismic event resistant structural properties such as high strength, high ductility and large energy absorption capacity. Also, circular hollow sections possess many advantages over open sections, including aesthetic appearance and economy in terms of material costs.

Concrete –filled steel tubular (CFST) columns has been widely used in the construction of framed structures in high rise buildings due to their fine looking appearance, high bearing capacity and ductility, fast construction and cost- saving features. However the main disadvantage of the CFST column is that steel tube is exposed thus leading to a lower fire resistance compared with concrete cased steel composite column or even conventional reinforced concrete columns.

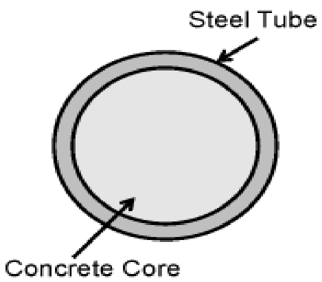

Fig1.1.Typical cross section of CFST column

1.1. Concrete filling of the section

Filling hollow sections with concrete is a verysimple and attractive way of enhancing fire resistance. The temperature in the unprotected outer steel shell increases rapidly. However, as the steel shell gradually loses strength and stiffness, the load is transferred to the concrete core.

Apart from the structural function, the steel section also acts as a radiation shield to the concrete core. In combination with a steam layer between the steel and the concrete core, this leads to a lower temperature rise in the core compared to reinforced concrete structures.

2. FIRE RESISTANCE

As far as building construction is concerned, it is important that the construction elements can withstand a fire for a specified amount of time. In this respect, one should bear in mind that the strength and deformation properties of the commonly used building materials deteriorate significantly at the temperatures that maybe expected under fire conditions. Moreover, the thermal expansion of most of the building materials appears to be considerable. As a result, the structural elements and assemblies may deform or even collapse when exposed to fire conditions.

The amount of time that a construction element canresist a fire depends largely on the anticipated temperature development of the fire itself. This temperature development depends, among other things, on the type and amount of combustible materials present. In practical fire safety design, however, it is conventional to use a so-called "standard fire curve", defined in ISO 834.

The amount of time a building component is able to withstand heat exposure according to the standard fire curve, is called the "fire resistance". In order to be able to determine the fire resistance of a building component, proper performance criteria have to be determined.

As far as the determination of the fire resistance is concerned, there are basically two possibilities: an experimental approach and an analytical or fire engineering approach. The experimental approach, i.e. the determination of the fire resistance of columns on the basis of standard fire tests, is the traditional approach. Although based on different national testing procedures, the concept of fire testing is by and large the same in the various countries. The fire engineering approach is a relatively new development that has become possible by the recent development of computer technology. On an international level, calculation rules for the fire resistance of both steel and composite steel concrete columns, including concrete filled circular columns, are available. There are significant advantages to the analytical approach, when compared with the experimental one.

3. DESIGNING CONCRETE FILLED STEEL CIRCULARCOLUMNS FOR FIRE RESISTANCE

3.1. Basic Principles

A CFST column is normally considered to be exposed to all-around fire when its fire resistance is studied. Investigations on the fire response of CFST columns were limited and only numerical studies have been attempted to date with no available test evidence. The calculation of the fire resistance of concrete filled circular steel tubularcolumns comprises two steps:

- the determination of the temperature at which the column fails, the so called "critical steel temperature"; this is the mechanical response
- the determination of the temperature developmentin the steel section; this is thethermal response.

Both assume a uniform temperature distribution acrossthe cross section and along the length of the steelmember.

Combining the two calculation steps gives thenumber of minutes after which failure of the columnwould occur if exposed to standard fire conditions. Thisamount of time is the fire resistance of the column.

3.2. Thermal response

For unprotected steel sections it can be shown that – forstandard fire exposure - the temperature developmentof a steel section depends only on the relativegeometry of the profile. This effect is taken into account by means of the shape factor, Am/V, where:

Am = exposed surface area of the member per unitlength [m^2/m]

V = volume of the member per unit length [m^3/m]

The analysis was performed by first conducting a pure heat transfer analysis, using the standard ISO-834 fire curve applied to the exposed surface of the column, for computing the temperature field. Afterwards structural analysis was performed for calculating the structural response.

4. ANALYTICAL SEQUENCE IN ABAQUS

4.1. Pre-processing (Abaqus/CAE)

In this stage, the model of the physical problem was modeled, and an Abaqus input file was created. The model is usually created graphically using Abaqus/CAE or another pre-processor, although the Abaqus input file for a simple analysis can be created directly using a text editor.

4.2. Simulation (Abaqus/Standard or Abaqus/Explicit)

The simulation which normally runs as a background process is the stage in which Abaqus/Standard or Abaqus/Explicit solves the numerical problem defined in the model. Examples of output from a stress analysis include displacements and stresses that are stored in binary files ready for post processing. Depending on the complexity of the problem being analyzed and the power of the computer being used, it may take anywhere from seconds to days to complete an analysis run.

4.3. Post processing (Abaqus/CAE)

We can evaluate the results once the simulation has been completed and the displacements, stresses or other fundamental variables have been calculated. The evaluation is generally done interactively using the visualization module of Abaqus/CAE or another post processor. The visualization module, which reads the neutral binary database file, has a variety of options for displaying the results, including color contour plots, animations; deformed shape plots X-Y plots.

5 .MATERIAL PROPERTIES

For the heat transfer calculations, the thermal properties of steel and concrete in Lie and Stringer[11] are used.

5.1. Steel:

- Density =7850 kg/m^3
- Poisson ratio=0.3
- E=2.1 x10^{5}MPa
- Coefficient of thermal expansion=12 x 10^{-6}/°C
- Thermal conductivity, Ks= 54-(Ts/300) [W/mK]for 20°C ≤ Ts≤ 800°C
- Ks=27.3[W/mK] for Ts>800°C
- whereTsdenotes temperature of steel.
- Specific heat=425+0.773 Ts-0.00169Ts^2+2.22 x10^{-6}Ts^3 for 20 °C≤ Ts≤ 600°C
- =666-(13002/ (Ts-738)) for600°C<Ts<900°C
- =650 for Ts>900°C

5.2. Concrete:

- Density =2400 kg/m^3
- E= 5000√(f_{ck})cu Mpa
- Poisson ratio=0.2
- Coefficient of thermal expansion- 6x 10^{-6}/°C
- Specific heat= 900+ 80(T/120) – 4(T/120)^2 J/kg/K for 20°C<T<1200°C
- Thermal conductivity λ_c = 1.6– 0.16(θ_c / 120) + 0.008(θ_c / 120)^2[W/mK] for 20°C ≤ θ_c ≤ 1200°C
- whereθ_c is the temperature of concrete.

Table5.1.Thermal properties of steel and concrete

Specimen	Diameter (Mm)	Thickness Of The Steel Tube(Mm)	F_{ck} (N/Mm^2)	Load Ratio	Load P (Kn)
S1	400	13.33	30	0.3	1622
S2	400	13.33	30	0.5	2703
S3	400	13.33	50	0.3	1760
S4	400	13.33	50	0.5	2933
S5	200	5	30	0.3	295
S6	200	5	30	0.5	492
S7	200	5	50	0.3	327
S8	200	5	50	0.5	545

6. ANALYTICAL PROGRAM

It is proposed to do the analytical study for finding fire resistance behaviour of columns for the specimen shown in table 6.1. Then after validation of the above results the study will be extended further by changing the various parameters such as

- Thickness of the steel tube
- Diameter of the column
- Concrete grade
- Boundary conditions

Table6.1. Available experimental data.

Specimen	Diameter (Mm)	Thickness Of Tube (Mm)	F_{ck} (N/Mm^2)	Boundary Conditions	Standard Fire Exposure Time (Min)
S 1	300	8	50	P-P	30
	300	8	60	P-P	30
	300	8	80	P-P	30
	300	8	50	P-P	60
	300	8	60	P-P	60
	300	8	80	P-P	60
S2	300	8	50	F-P	30
	300	8	60	F-P	30
	300	8	80	F-P	30
	300	8	50	F-P	60
	300	8	60	F-P	60
	300	8	80	F-P	60

Sample specimen details and its parameters to be proposed is shown in table 6.2.

Table6.2.Parameters used

Temp (^{O}c)	Thermal Conductivity Of Concrete[W/Mk]	Thermal Conductivity Of Steel[W/Mk]	Specific Heat Of Concrete(J/Kg/K)	Specific Heat Of Steel(J/Kg/K)
200	1.355	53.33	1022.22	529.76
300	1.25	53	1075	564.74
400	1.156	52.67	1122.22	605.88
500	1.072	52.33	1163.89	666.5
600	1	52	1200	759.92
700	0.939	51.67	1230.56	899.46
800	0.889	51.33	1255.56	1098.44
900	0.85	51	1275	1370.18
1000	0.82	50.66	1288.89	1728
1100	0.806	50.33	1297.22	2185.22
1200	0.8	50	1300	2755.16

7.FINITE ELEMENT MODEL USING ABAQUS

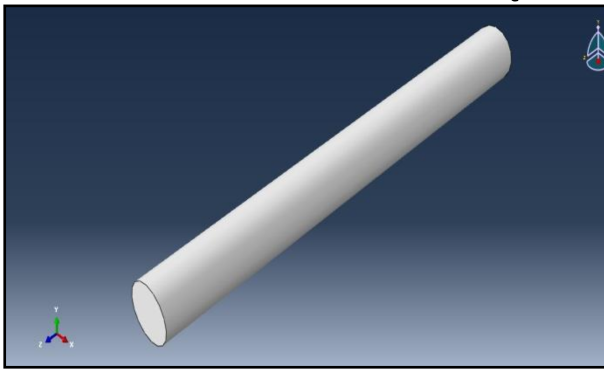

Fig 7.1.Part module

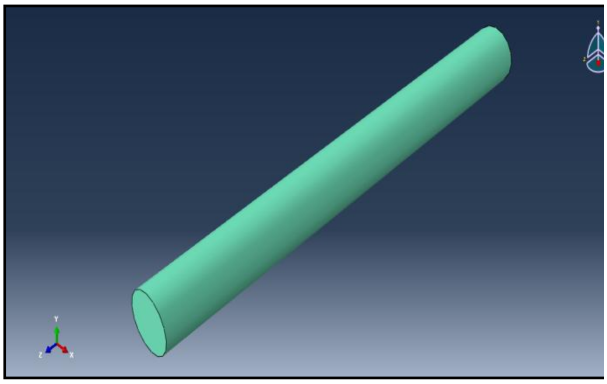

Fig 7.2.Property module

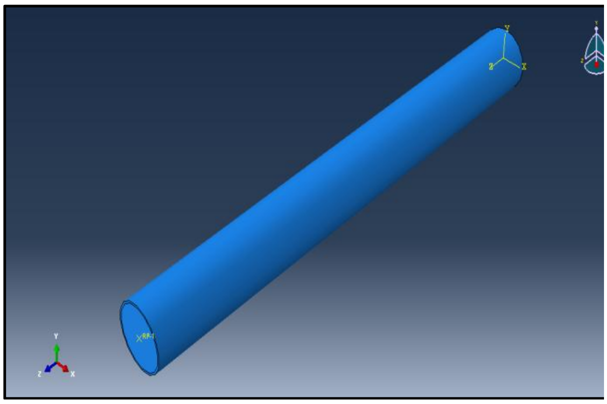

Fig 7.3.Assembly module

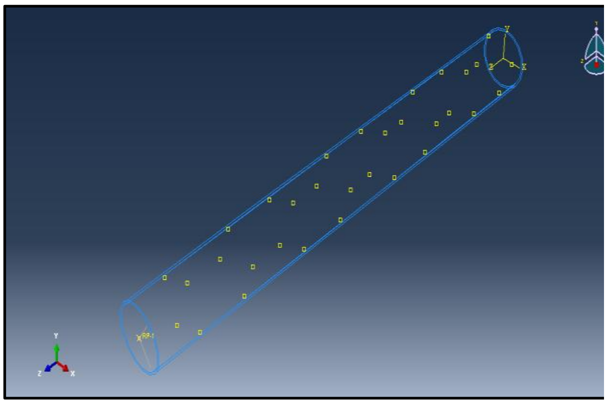

Fig 7.4.Interaction module

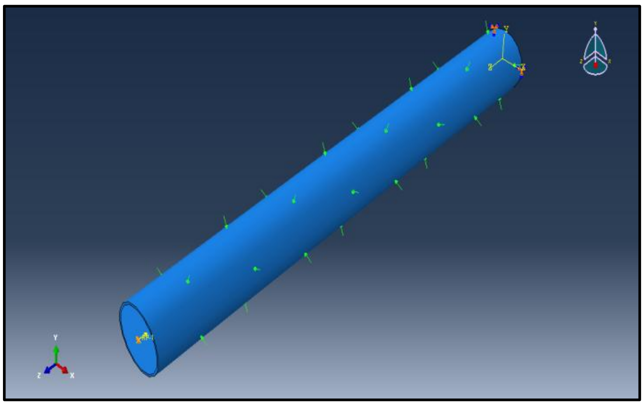

Fig 7.5 .Load and boundary conditions

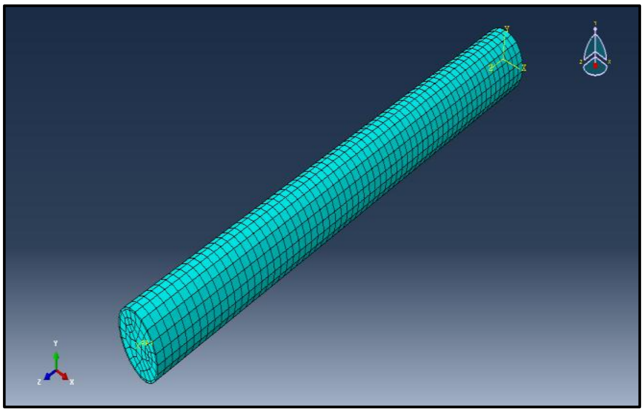

Fig 7.6.Mesh module

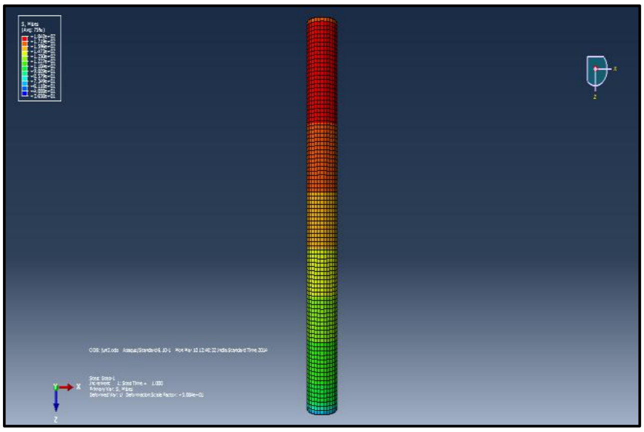

Fig 7.7.Visualization module

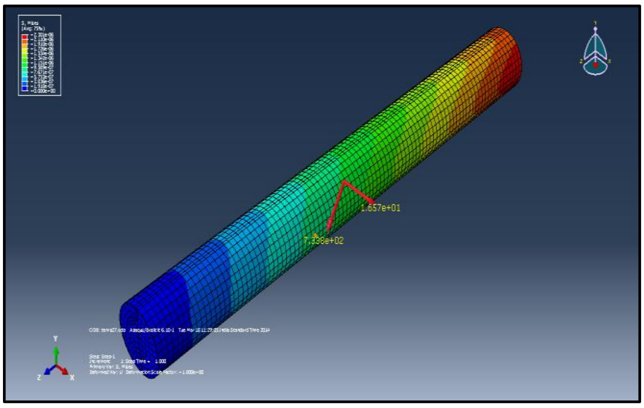

Fig 7.8.Stress contour

8.THEORETICAL PROGRAM

8.1. Fire Resistance Rating:

$$t = f\,\frac{(f_{ck}+20)}{(L_e-1000)}\,D^2\sqrt{D/P}$$

D=outside diameter of the column
f=empirical factor = 0.07 for CFST column
P=applied load during fire
L_e= effective length of the column
f_{ck}= compressive strength of concrete

8.2. ISO-834 Standard fire:

$$T=T_0+345\log_{10}(8t+1)$$

t = time in fire
T= temperature (^{O}C) at time t
T_0= initial temperature = 20^{O}C

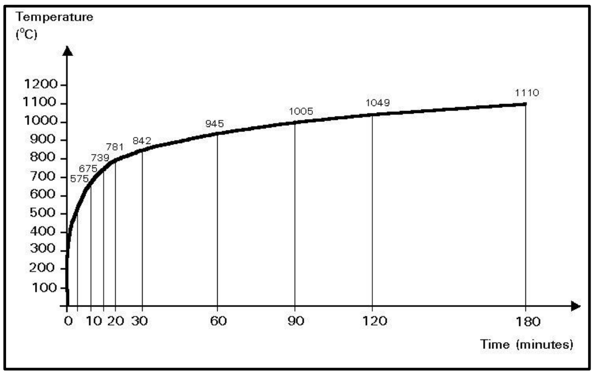

Fig 8.1.ISO standard fire curve

Initial Temperature,T_0 (^{O}c)	Time In Fire (Min)	Standard Fire Temp, T(^{O}c)
20	30	841.8
20	60	945.34
20	90	1005.98
20	120	1049.04

Table8.1 Standard fire table

9. CONCLUSION

The behaviour of CFST columns in fire has been investigated by finite element analysis.The basic steps of ABAQUS and its approaches were discussed. Finite element model using ABAQUS found to be computationally efficient. Concrete filling improves the behaviour of CFST columns when there is a fire. The interaction between the steel and concrete in the columns is found to be a key factor responsible for the good fire performance of the composite columns.

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