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STUDY ON EFFECT OF COLUMN SHAPE ON FIRE RESISTANCE OF CFST COLUMN WITH SOLID STEEL CORE

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Abstract - *Concrete filled steel tube (CFST) columns with steel core are innovative composite columns that exhibit high load bearing capacity and exceptional structural fire behaviour. In high rise building practice, these features allow relatively slender design solutions under high load levels and fire resistance requirements. Besides their structural advantages, they are also appealing architecturally and economically. High fire ratings can be achieved without the use of fire protection materials, which increases the floor space in high rise buildings and eliminates an in-situ work step in comparison to conventional fire protected steel columns or reinforced concrete columns. The CFST columns also take the advantages of combined effect of steel and concrete working together. In this study a non dimensional finite element modal analysis is done through ANSYS16.0 to study the fire resistance, structural behaviour and temperature distribution of CFST columns with a solid steel core. A comparative study is done on different shapes of columns (circular, square and rectangular) with and without solid steel core to find the best CFST column with excellent structural behaviour and fire resistance. From the results obtained it was clear that circular concrete filled steel (CFCST) columns with steel core provide better performance.*

***Key Words*: Concrete Filled Steel Tube (CFST) columns, Temperature distribution, Finite element analysis**

1. INTRODUCTION

1.1 GENERAL

A column can be defined as a vertical structural member designed to transmit a compressive load. In other words, a column is a compression member. A column transmits the load from ceiling or roof slab and beam, including its own weight to the foundation. Hence it should be realized that the failure of a column results in the collapse of the entire structure. The design of a column should therefore receive importance. Concrete-filled steel tube (CFST) columns are type of steel columns which are used in high-rise building practice due to their high load-bearing capacity and exceptional structural fire behaviour.

1.2 CONCRETE FILLED STEEL TUBULAR (CFST) COLUMNS

Concrete filled steel tubular (CFST) members utilize the advantages of both steel and concrete. They comprise of a steel hollow section of circular or rectangular shape filled with plain or reinforced concrete. They are widely used in high-rise and multi-storey buildings as columns and beam-columns, and as beams in low-rise industrial buildings where a robust and efficient structural system is required. There are a number of distinct advantages related to such structural systems in both terms of structural performance and construction sequence.[1] The inherent buckling problem related to thin-walled steel tubes is either prevented or delayed due to the presence of the concrete core. Furthermore, the performance of the concrete in-fill is improved due to confinement effect exerted by the steel shell. The distribution of materials in the cross section also makes the system very efficient in term of its structural performance. The steel lies at the outer perimeter where it performs most effectively intension and bending. It also provides the greatest stiffness as the material lies furthest from the centroid. This, combined with the steels much greater modulus of elasticity, provides the greatest contribution to the moment of inertia. The concrete core gives greater contribution to resisting axial compression.

The use of concrete filled steel tubes in building construction has seen resurgence in recent years due to its simple construction sequence, apart from its superior structural performance. Typically, it was used in composite frame structures. The hollow steel tubes that are either fabricated or rolled were erected first to support the construction load of the upper floors. The floor structures consist of steel beams supporting steel sheeting decks on which a reinforced concrete slab is poured.

Such structural system has the advantage of both steel and reinforced concrete frame. It has the structural stiffness and integrity of a cast-on-site reinforced concrete building, and the ease of handling and erection of a structural steelwork. The hollow tubes alone were designed in such a way that they are capable of supporting the floor load up to three or four storey height. Once the upper floors were completed, the concrete was pumped into the tubes from the bottom. To facilitate easy pumping the tubes were continuous at the floor level. Modern pumping facility and high performance concrete make pumping three or four storey readily achievable.[3] Due to the simplicity of the construction sequence, the project can be completed in great pace. Fig 2.1. shows plan and section of CFST columns.

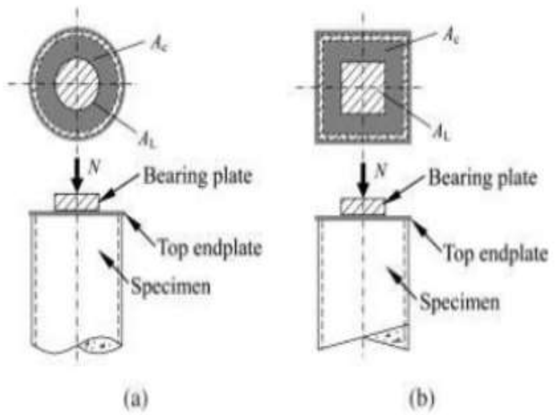


Fig – 1: Plan and section of CFST columns

1.3 OBJECTIVES

- To study the behavior of the CFST columns with solid steel core when exposed to fire, based on the section shape of the column
- To measure the variation of temperature with time along the surface of column, for varying cross sections
- To find out the section shape of the column which will have maximum resistance to fire

2. FINITE ELEMENT ANALYSIS

2.1 GENERAL

In order to study the temperature distribution of the CFST column with solid steel core, three dimensional finite element models were modelled in ANSYS (version 16). The different shapes analysed in this study are concrete filled circular steel tube (CFCST) columns, concrete filled square steel tube(CFSST) columns and concrete filled rectangular steel tube (CFRST) column, all with soild steel core of corresponding shape.The column length is 3000mm and steel tube thickness is 6mm with steel yield strength 350 MPa.

2.2 MATERIAL PROPERTIES AND THERMAL PARAMETERS

Table -1: Material properties and thermal properties of concrete

Material	Steel	Concrete
Young's Modulus	E= 209×10^9 Pa	E= 1.5×10^9 Pa
Poisson's Ratio	0.30	0.2
Density	7900 kg/m^3	1900 kg/m^3
Specific heat	460 J /(kg·K)	970 J /(kg·K)
Yield strength	350 MPa	30 MPa
Conductivity	45.00 W/m^2·K	1.14 W/m^2·K
Convection	25.00 W/m^2·K	20.0 /m^2·K

Table 1 shows the material properties and thermal properties of the concrete and steel respectively. After the analysis the best section shape is found out and a multi-storey steel frame is analyzed by using that shape.

2.3 MODELLING AND ANALYSIS

The elements in the model are discretized using SOLID 90. It is a higher order version of the 3-D eight node thermal element. The element has 20 nodes with a single degree of freedom, temperature, at each node. The 20-node elements have compatible temperature shapes and are well suited to model curved boundaries. The 20-node thermal element is applicable to a three-dimensional, steady-state or transient thermal analysis.

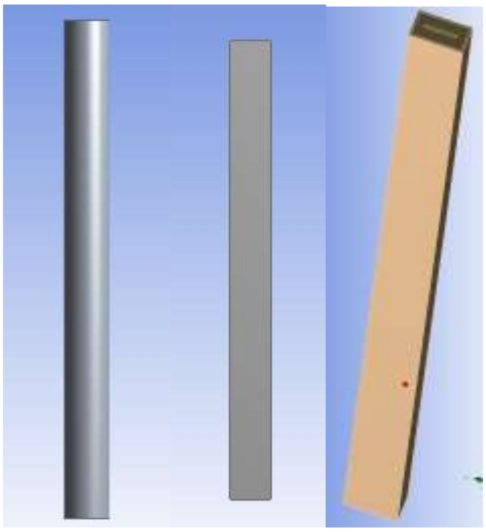
Fig.2 shows the ANSYS model of different sections.(a) circular column, (b) square column and (c) rectangular column. The dimension details of the columns are given below. The dimensions of different sections are calculated by keeping the volumes of the sections constant.

2.3.1 Circular Section

The length of the column is 3000mm and the thickness of the steel tube and steel core are 6mm and 74 mm respectively. The diameter of the column is 270mm.

2.3.2 Square Section

The length of the column is 3000mm and the thickness of the steel tube is 6mm. The size of the steel core is 65mm × 65mm. The size of the column is 230mm × 230mm.



a b c

FIG - 2 : Cross section of columns (a) circular column (b) square column (c) rectangular column.

2.3.3 Rectangular Section

The length of the column is 3000mm and the thickness of the steel tube is 6mm. The size of the steel core is 92mm × 45mm. The dimension of the rectangular column is335mm × 167mm.

Table – 2 : Standard fire time temperature curve (ISO-834)

TIME (Sec)	TEMPERATURE °C
0	0
600	500
900	700
1200	780
2400	900
3600	950
4800	1000
6000	1050
7200	1075
8400	1100

2.4 STATIC ANALYSIS

The static analysis of the columns is done by using static structural in ANSYS. The columns are fixed at bottom end and free at top. A gravity load is also applied to the columns in downward direction.

2.5 THERMAL ANALYSIS

The standard ISO 834 fire curve was applied to the surface of CFST column specimen as thermal load, through convection and radiation heat transfer mechanisms. The entire length of the column was exposed to fire. The thermal analysis is done by using the transient thermal analysis.

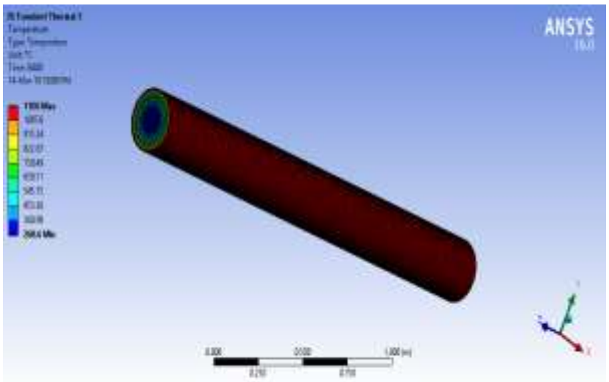


FIG - 3: Temperature applied on circular section

2.5.1 Temperature Applied

The applied loading temperature is based on ISO-834 standard fire, and the fire curve drawn based on table 2 the temperature is applied on the outer surface of the columns. Fig 3 shows the circular column, fig 4 shows the square column and fig 5 shows the rectangular column.

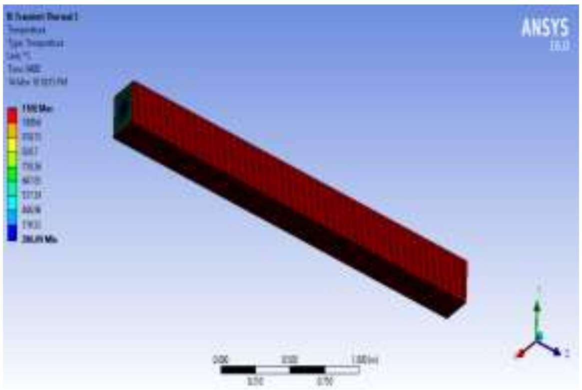


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FIG – 4: Temperature applied on square section

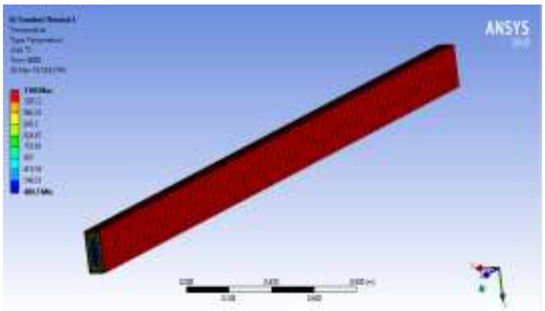

FIG – 5: Temperature applied on rectangular section

3.RESULTS AND DISCUSSION

3.1 GENERAL

The main objective of this research work is to study the temperature distribution of the CFST columns with solid steel core when exposed to fire, based on the section shape of the column (circular square and rectangular) and to find out the section shape of the column which will have maximum resistance to fire. A three dimensional finite element analysis was done by using ANSYS. Three different section shapes(circular, square and rectangular) are analyzed.

3.2 CIRCULAR SECTION

After the analysis the total deformation for the circular column with steel core is 28.141mm.The deformed shape of the circular column is shown in fig 6 The maximum deformation is at the top of the column and minimum at bottom.The maximum stress developed after the application of the temperature is 5.3277×10^{9} Pa and minimum is 6.6987×10^{6} Pa. Fig 7 shows the stress variation of the circular column. The temperature distribution at the inner surface is shown in the fig 8. The maximum temperature is distributed at the middle of the column and the minimum temperature is at the two ends of the column. The maximum temperature at 8400 s is 331.84 °c and minimum is 270 .76 °c

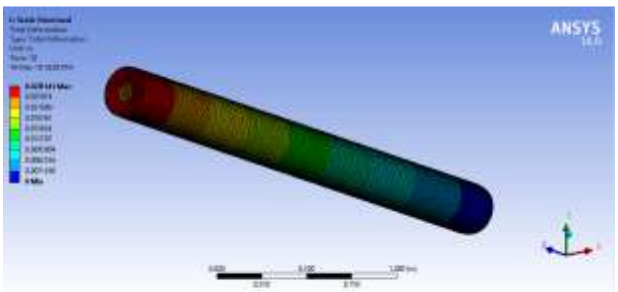

FIG -6 : Total deformation of circular section

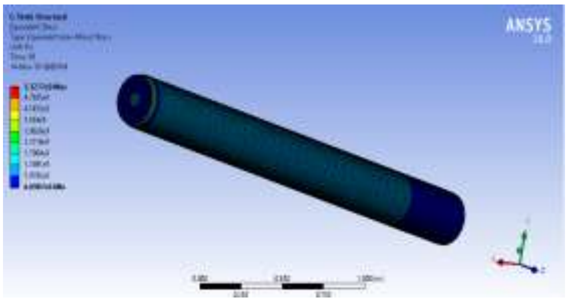

FIG -7: Equivalent stress of circular section

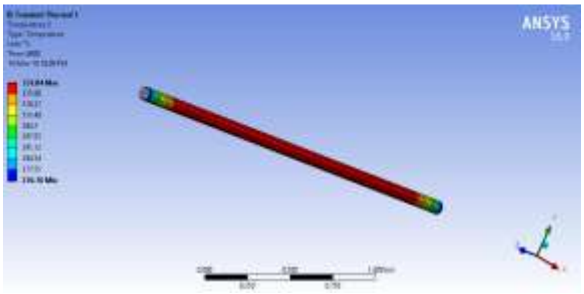

FIG – 8: Temperature distribution at 98 mm from the surface

3.3 SQUARE SECTION

After the analysis the total deformation for square column with steel core is 34.713mm.The deformed shape of the square column is shown in fig 9. The maximum deformation is at the top of the column and minimum at bottom. The maximum stress developed after the application of the temperature is 8.986×10^{9} Pa and minimum is 9.989×10^{8} Pa. Fig 10 shows the stress variation of the square column. The temperature distribution at the inner surface is shown in the fig 11. The maximum temperature is distributed at the middle of the column and the minimum temperature is at the two ends of the column. The maximum temperature at 8400 s is 374.06 °c and minimum is 297.22 °c.

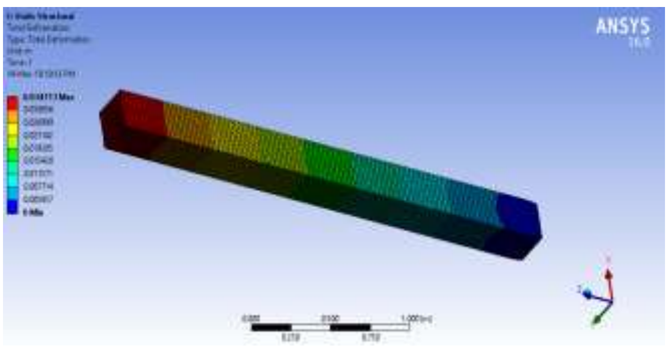

FIG – 9: Total deformation of square section

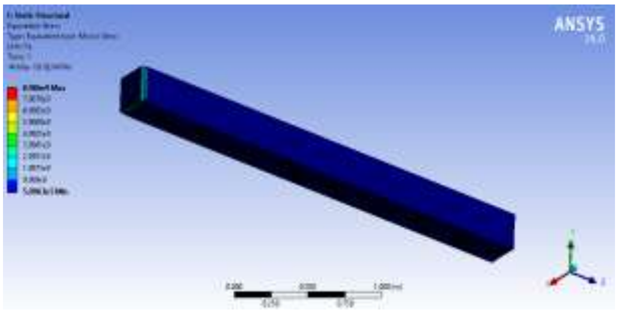

FIG – 10: Equivalent stress of square section

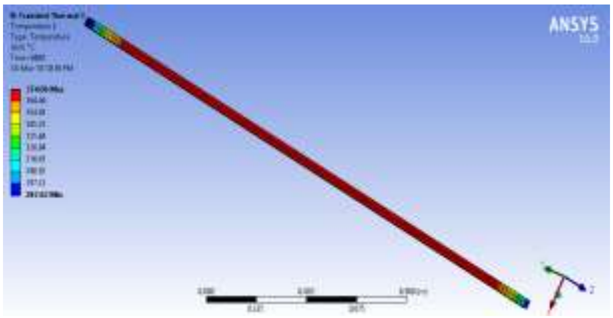

FIG – 11: Temperature distribution at 98 mm from the surface

3.4 RECTANGULAR SECTION

After the analysis the total deformation for rectangular column with steel core is 34.43mm. The deformed shape of the rectangular column is shown in fig 12. The maximum deformation is at the top of the column and minimum at bottom. The maximum stress developed after the application of the temperature is 7.452×10^{9}Pa. Fig 13 shows the strees variation of the rectangular column. The temperature distribution at the innersurface is shown in the fig 14. The maximum temperature is distributed at the middle of the column and the minimum temperature is at the two ends of the column. The maximum temperature at 8400 s is 603.4 °c and minimum is 540.39 °c

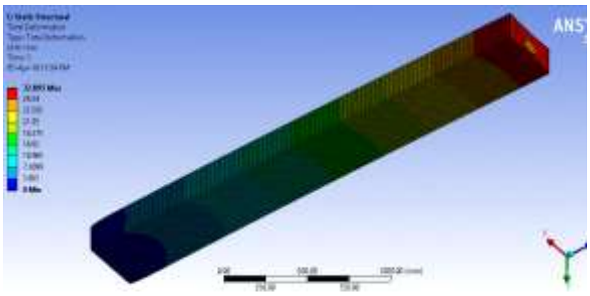

FIG -12: Total deformation of rectangular section

From the results, it is apparent that the circularcross-section shows slightly better fire resistance period than the square and rectangular cross sections. The lower fire resistance in square and rectangle columns can be explained by the fact that the corners are heated from two sides, which lead to an increased supply of heat, higher loss of strength and thus the failure happens earlier.

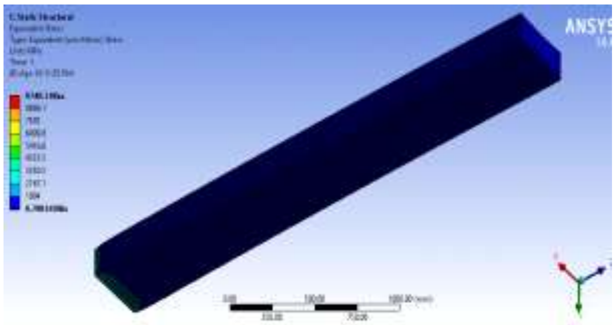

FIG – 13: Equivalent stress of rectangular section

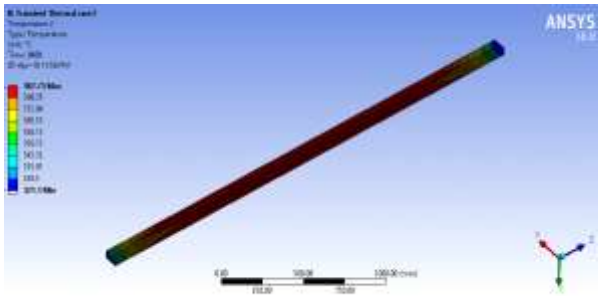

FIG – 14: Temperature distribution at 98 mm from the surface

In the case of square and rectangular columns, the temperature at a given distance from the edge is higher at the corner than that along the sides. This is caused by the heat transfer from two sides. The circular cross-section shows a uniform temperature distribution.

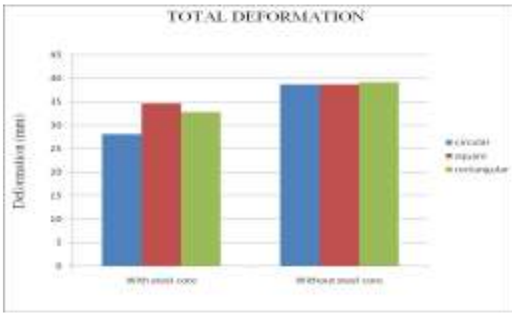

Chart – 1: Graph showing the total deformation of columns with and without steel core

Thus the use of the solid steel core inside CFST columns can increase the structural fire behaviour. High fire ratings can be achieved without the use of any fire protection material.

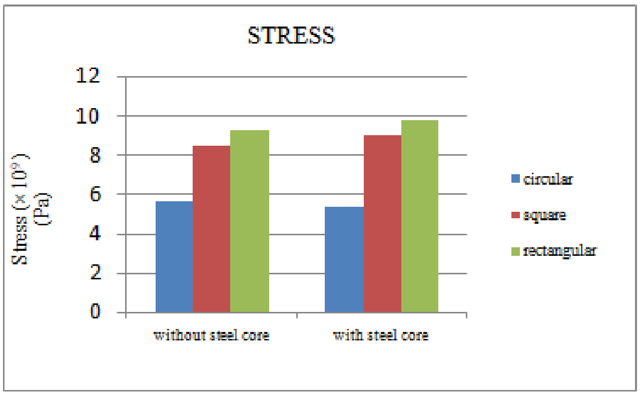

Chart – 2: Stress of the columns with and without steel core

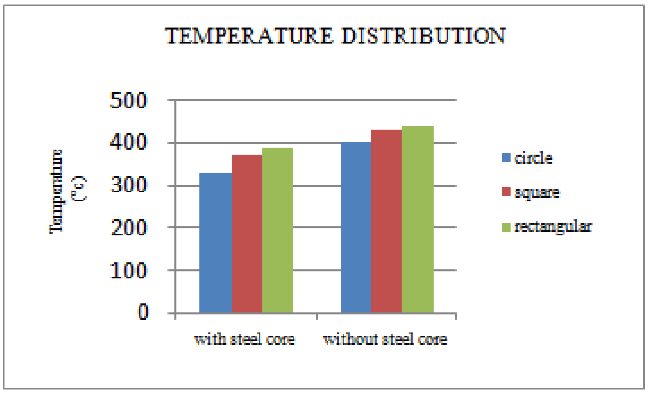

Chart – 3: Temperature distribution of columns with and without steel core

4.CONCLUSIONS

Concrete filled steel tubular columns utilize the advantages of both steel and concrete. They proved to provide excellent structural performance and fire resistance. Analysis done on CFST columns with steel core reveal that providing steel core furthermore enhances the performance of the conventional CFST columns.

Thermal analysis was done to compare fire resistance of different column shapes; with steel core. The circular section with solid steel core inside was found to have maximum fire resistance.Thus it can be concluded that by using CFST columns with steel core, high fire rates can be achieved without the use of any fire protection materials.

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