THERMO-STRUCTURAL BEHAVIOUR OF CONCRETE ENCASED CONCRETE FILLED STEEL TUBE COLUMNS SUBJECTED TO FIRE

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Abstract - *RCC composite structure such as a concrete-encased CFST column consists of a concrete filled steel tube (CFST) embedded in reinforced concrete. The CFST core utilizes high strength concrete to provide enough axial compressive strength, while the peripheral RC encasement utilizes normal or high strength concrete to resist most of the lateral loads. In this study, a parametric study has been carried out, in which the column shape, material and core changes were made, modeled and analyzed using ANSYS WORKBENCH 16.1. The parametric study on concrete encased CFST column is carried out by providing modifications in its inner core by replacing it with I sections and double I sections. The section with better fire resistance property is adopted as the inner core for specimen with material changes at outer core. Then parametric study is conducted with exterior changes like Steel tube and FRP tube with varying thicknesses. Here it's decreasing moment capacity on exposure to fire and its ability to resist the fire during that time can also be found out. The columns with higher loss in load carrying capacity are provided with intumescent fire coatings. Its fire performances and structural behavior is studied. Here the results shows as thickness of exterior encasements were increased results in increasing load carrying capacity, intumescent coatings provided can reduce loss of load carrying capacity during exposure to fire. The mode of deformation observed in all column is global buckling with smooth residual bending deformation.*

Key Words: Concrete encased CFST, Steel tube, FRP tube, Intumescent Coating, FEA, Fire behaviour, Thermal behaviour, Structural behaviour

1. INTRODUCTION

Composite columns are constructed using various combinations of structural steel and concrete in an attempt to utilize the beneficial properties of each material. Composite columns were generally developed after steel columns and reinforced concrete columns. The interactive and integral behavior of concrete and the structural steel elements makes the composite column a very stiff, more ductile, cost effective and consequently a structurally efficient member in building and bridge constructions. It is used in high rise buildings in order to increase the usable floor space area for given strength. It has great fire and corrosion resistance where in concrete encased columns. It has economic advantages over steel columns and concrete columns. It governs the non-residential high storey building sector. Its recognition is due to its strength and stiffness that can be achieved with minimum use of material. The reason behind using composite construction is excellent is good in compression and steel is good in tension. By combining these two materials together structurally, their strengths can be exploited to result in a highly efficient and light weight design. Composite system also offers benefits in terms of time saving in construction, fire resistance and better strength.

Concrete-encased concrete-filled steel tube (CFST) columns are a type of composite structure are type of innovative composite column comprising an inner CFST component and an outer reinforced concrete (RC) component as encasement. Branching from conventional CFST columns, concrete-encased CFST columns inherit the advantages of CFST columns. They are used as the load bearing members in high-rise buildings and large-span structures. This type of composite member was initially designed to achieve an enhanced seismic performance by applying concrete of higher strength grade inside the steel tube and constructing the inner CFST component first so that it can serve as a structural member bearing the construction loads. Therefore, the inner CFST component exhibits a higher load level in service stage than the outer RC component, thus allowing the latter, especially the outermost concrete fibre, to gain more capacity to develop compression under seismic action.

2. OBJECTIVES OF WORK

In this study the structural and thermal behavior of concrete encased CFST columns were studied. In all the parametric studies conducted the weight of steel tube is kept constant for all variations in the models. The parametric studies were conducted by changing the inner core CFST by I section and Double I section steel profiles, by providing an exterior encasements by Steel tubes and FRP tubes of varying thickness, in the higher reduction in load carrying capacity columns an intumescent coatings were provided over the encasement tubes.

3. GEOMETRICAL MODEL

A non-linear static analysis was done in ANSYS workbench 16.1 software for the Concrete-encased CFST column. A column specimen of 3800mm height and outer RC cross section of 300mm × 300mm consisting of M30 concrete and consist of an inner CFST tube of 159mm diameter consisting of M60 concrete. The FE model mainly includes four components, namely in-filled and peripheral concrete, steel tube and reinforcement steel bars. Here in the thermal analysis inner core and outer RC is modeled with SOLID70, steel tube with SHELL131 and reinforcements with LINK33. In the structural analysis inner core and outer RC is modeled with SOLID185, steel tube with SHELL181 and reinforcements with LINK180.

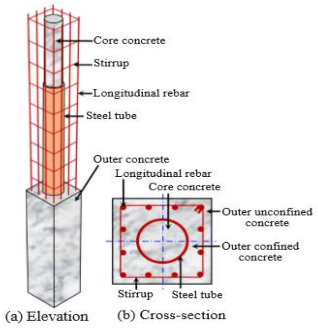

Fig -1: Concrete encased CFST column

3.1 Finite Element Analysis Model

The models of columns were done using the software ANSYS WORKBENCH 16.1.Here the columns were exposed to fire according to ISO-834 fire curve with varying temperature of 22˚C to 1089˚C for about 120min exposure to fire.Its thermal behavior and structural behaviors were studied along with the parametric studies carried out in columns. The bottom surface of the column was restrained against all degrees of freedom. The axial loading was applied from the top surface by restraining the bottom surface against all degrees of freedom.

In the paper, Experimental performance of concrete-encased CFST columns subjected to full-range fire including heating and cooling given by Kan Zhou, Lin-Hai Han in 2018 studied about the thermal and structural behavior of columns. Most of columns undergo fail in ductility and global buckling Most resembles structural and thermal behavior of conventional CFST. Thermally robust insulating properties of concrete infill lag behind temperature of steel core. Reduction in structural performances and lack of protective coverings In that study the load carrying capacity is less and there is lack of protective coverings provided to columns and behaviors of columns by providing encasement tubes were not studied. So this paper deals with study of structural and thermal behavior of columns provided with various parametric studies enhancing its behavior.

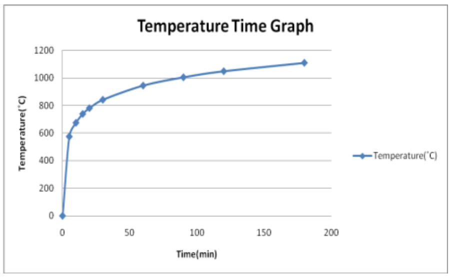

Fig-2: ISO-834 Standard fire Curve

4. PARAMETRIC STUDIES

In this study parametric studies were conducted on the concrete encased CFST columns subjected to fire. In all the further studies conducted the area of steel tube is kept constant. In the first parametric study the columns were provided with inner steel core changes by providing I section steel profile as core and double I section steel profile as core in two columns as named RC-I and RC-2I.The column providing better strength as compared to validated model of concrete encased column is chosen and kept as inner core in all columns for further parametric studies. In the second parametric study conducted the columns were provided with outer steel tube encasements and with FRP tube encasements. The columns were provided with outer steel tube encasements of varying thicknesses 1.5mm, 3mm,4mm and 5mm where columns with FRP tube encasements of varying thicknesses 3mm,4mm and 5mm are also provided. Its thermal and structural behaviour is studied. Then the columns having greater decreasing load carrying capacity is provided with intumescent coating of 1.2mm in order to enhance its performance since there is loss in the load carrying capacity of columns when exposed to fire. In all these studies its temperature distribution, load carrying capacity and deformation is observed. The table-1 shows the geometrical details of all columns. RC-I denotes Reinforced Concrete with I section core column, STE-t1.5 denotes Steel tube encased column of tube thickness 1.5mm, FRP-t3mm denotes FRP tube encased column of tube thickness 3mm and STE-t1.5-coating denotes Steel tube encased column of tube thickness 1.5mm provided with intumescent coating.

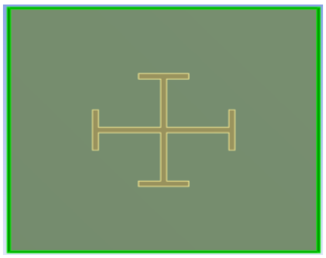

Fig-3: Cross section of column

Table-1: Geometric Details of Columns

Column	Tube thickness (mm)	Coating thickness (mm)	Details of steel core		
			Lf (mm)	tf =tw (mm)	Lw (mm)
RC-I	-	-	140	7	126
RC-2I	-	-	50	6.5	127
STE-t1.5	1.5	-	50	6.5	127
STE-t3	3	-	50	6.5	127
STE-t4	4	-	50	6.5	127
STE-t5	5	-	50	6.5	127
FRP-t3	3	-	50	6.5	127
FRP-t4	4	-	50	6.5	127
FRP-t5	5	-	50	6.5	127
STE-t1.5 - coating	1.5	1.2	50	6.5	127
STE-t3-coating	3	1.2	50	6.5	127
FRP-t3-coating	3	1.2	50	6.5	127

5. RESULTS AND DISCUSSIONS

Total of 12 columns were modeled to study its thermal and structural behavior when it is subjected to a temperature range of 22˚C to 1089˚C for about 120min exposure to fire as per ISO-834 fire curve. The columns are long with total height of 3800mm provided with axial loading. Its load carrying capacity, temperature distribution and deformation of column is found out.

5.1 Temperature Distribution

The columns were subjected to fire for about 120min.The columns were exposed with an initial temperature of 22˚C to an final temperature of 1089.7˚C for about 120min. Since the column is having reinforced concrete as its outer it could withstand at higher temperature .The inner steel core section could impart better strength in varying time and temperature. Here the outer concrete posses higher temperature when exposed to fire for120min.The temperature distributions at various points on section is almost similar. The temperature measured at various positions position 1 is at the end of cover provided, position 2 is at top of flange and position 3 is at middle of column were added to the tabular column shown in Table-2.

The maximum temperature is obtained at the outer core concrete compared to other sections of the columns. On increasing the thickness the temperature at the inner middle section of column decreases. So the conventional column on providing with outer steel or FRP encasement and with and without coating the transfer of heat to the inside cores decreases as a result the column subjected to fire can show better thermal performances.

Table-2: Temperature distribution in columns

Column	Temperature(˚C) after exposure for 120min		
	1	2	3
RC-I	629.01	191.34	178.08
RC-2I	628.97	183.6	178.09
STE-t1.5	639.43	185.68	177.61
STE-t3	630.83	188.08	176.46
STE-t4	646.08	183.73	175.54
STE-t5	667.93	185.38	174.57
FRP-t3	610.56	174.94	163.5
FRP-t4	582.1	169.2	159.59
FRP-t5	544	166.54	156.66
STE-t1.5-coating	654.18	183.09	175.05
STE-t3-coating	645.5	181.62	174.6
FRP-t3-coating	639.93	181.82	174.74

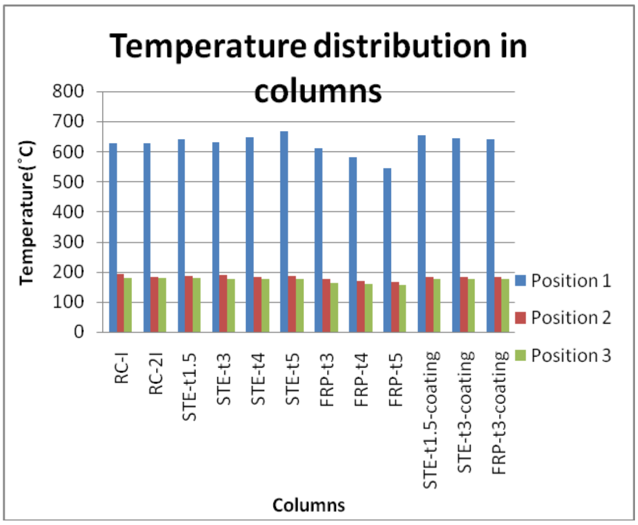

Chart -1: Temperature distribution in columns

5.2 Load Carrying Capacity of Columns

The columns were subjected to axial loading. The load carrying capacity of column under thermal conditions and structural conditions are studied. The Table 3 given below shows the values obtained and its graphical representation is given below in Chart-2.The ultimate load carrying capacity of column is greater than ultimate load carrying capacity of column exposed to fire for 120min.The ultimate load carrying capacity of columns decreases when column is exposed to fire for 120min.

From the table RC-2I column shows lesser decrease in strength of 32.34% comparing RC-I column. On considering the columns provided with encasement tubes the STE-t3 and

STE-t1.5 shows decrease in strength of 45.86% and45.88% whereas FRP-t3 has decrease in strength of 7.26%.In the next study the intumescent coatings were provided over these columns since there is reduction in load carrying capacity hence provided coating of1.2mm thickness. Then the reduction in load carrying capacity of columns is reduced.

Table-3: Load –Deflection of Columns

Column	Ultimate Load(kN)		Deformation of Column(mm)		Decrease in strength after exposure to fire (%)
	0min	120min	0 min	120 min	
RC-I	5020	3003.7	16.51	18.52	40.17
RC-2I	4941	3342.8	23.88	44.08	32.34
STE-t1.5	4942.2	2682.4	36.26	22.47	45.88
STE-t3	6364.9	3445	43.03	17.52	45.86
STE-t4	7196.2	3958.6	41.73	21.62	44.99
STE-t5	7586.9	4427.8	42.25	16.46	41.63
FRP-t3	4755.9	4410.6	92.71	65.49	7.26
FRP-t4	5718.9	5415.7	130.12	57.04	5.30
FRP-t5	6736.1	6392.9	120.13	49.17	5.09
STE-t1.5-coating	4946.1	2682.4	40.96	34.06	45.76
STE-t3-coating	6025.4	3462.4	35.93	17.27	45.86
FRP-t3-coating	4804.9	4566	89.62	69.25	4.95

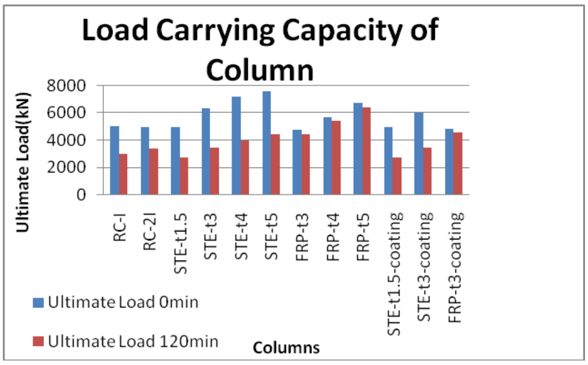

Chart -2: Load Carrying Capacity of Columns

5.3 Deformation of Columns

Any column provided with axial loading it undergoes deformations. Here the CFST column is long column with height of 3800mm provided with axial loading it undergoes deformation with mode of failure as buckling. Global buckling was observed for all the columns and failure modes of fire resistance test exhibited smooth residual bending deformation. On comparing all columns it is seen that deformation on conventional CFST column and coated columns shows same failure modes. On comparatively the deformation value decreases on providing intumescent coatings over the exterior encasements of steel tubes and FRP tube columns.

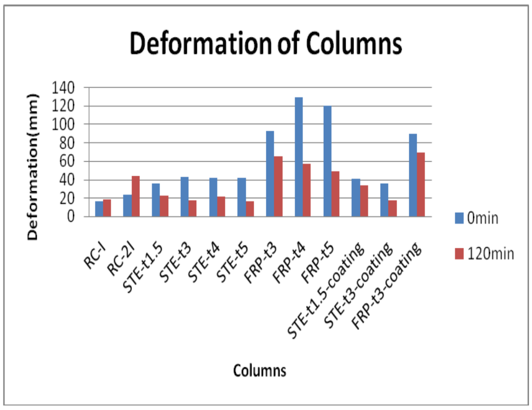

Chart -3: Deformation of Columns

6. CONCLUSIONS

In the study conducted on concrete encased CFST column subjected to fire its thermal and structural analysis is conducted. Then in order to enhance the behavior of columns parametric studies are conducted with inner steel cores, exterior encasement of steel tubes and FRP tubes of varying tube thicknesses and the exterior intumescent coatings were provided over exterior encasement tubes. Then comparative studies were conducted between columns with and without intumescent coatings, at last all the modeled columns are compared with respect to its temperature distributions, load carrying capacity and deformation of columns. From the studies conducted it is concluded that:

- The Columns are subjected to fire for a time period of 120min having varying temperature with initial temperature of 22˚C to maximum temperature of 1089˚C. The maximum temperature is obtained at the outer core concrete compared to other sections of the columns.
- On increasing the thickness the temperature at the inner middle section of column decreases. So the conventional column on providing with outer steel or FRP encasement and with and without coating

the transfer of heat to the inside cores decreases as a result the column subjected to fire can show better thermal performances.

- The load carrying capacity of column increase as the thickness of outer encasement tube is increased In case of pure column without exposure to fire, increase in strength is about 22.352% when thickness varies from 1.5-3mm and for 3-4mm and 4-5mm the increase in strength is about 11.55% and 5.149% respectively. In case of FRP tube encased columns increase in strength is about 16.83% when thickness varies from 3-4mm and for 4-5mm the increase in strength is about 15.10% respectively. It is preferable to use steel tube of thickness 1.5-3mm and FRP tube of thickness 3-4mm for composite columns to provide better load carrying capacity.
- On comparing columns with and without intumescent coatings the loss in load carrying capacity is reduced and the maximum temperature is distributed over the outer concrete lag behinds the transfer of temperature to inner sections. In case of STE-t3 Coating column has decrease in strength of 42.53% lesser than STE-t3 column having decrease in strength of 45.86%.In case of FRP-t3 Coating column has decrease in strength of 4.953% lesser than FRP-t3 column having decrease in strength of 7.260%.
- On comparing all columns, considering the load carrying capacity of pure column without exposures to fire the inner core of column provided with double I section which posses an increase in strength of 61.202% on comparing with the validated concrete encased CFST model.
- In case of parametric study conducted with exterior encasement of steel tube and FRP tube of varying thicknesses there is increase in strength of 34.87% for STE-t5 Column and 26.64% for FRP-t5 column on comparing with RC-2I column.
- In case of coatings provided there is increase in strength of 17.99% and 2.83% for STE-t3-Coating and FRP-t3-Coating columns on comparing with RC-2I column respectively.
- Column provided with axial loading undergoes deformation with mode of failure as buckling. Global buckling was observed for all the columns and failure mode exhibited smooth residual bending deformation

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