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Analytical Study of Single Skin Steel Tube Confined Reinforced Concrete Columns Exposed to Different Fire Conditions

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***Abstract*—Steel tube confined reinforced concrete (STCRC) columns, are a kind of composite column in which the outer steel tube acts predominantly as hoop reinforcement. This is achieved by the provision of breaks to the longitudinal continuity of the steel tube. In this arrangement, better confinement effect is offered by steel tube to concrete which enhances the strength and ductility of the in-filled concrete. This reduces the chances of local buckling and increases the fire resistance. This paper highlights the performance of single skin STCRC column under fire exposure. Such columns consists of a steel section, in which the reinforced concrete is cast. The load carrying capacity of single skin STCRC column without fire exposure and with fire exposure for sixty minute and one twenty minute retention are compared with that of RC column. The results obtained from this study have shown that, single skin STCRC columns offers better load carrying capacity than the conventional RC column, when exposed to fire.**

Keywords*—Single skin STCRC column; Fire exposure; Load carrying capacity

I. INTRODUCTION

RCC and steel frames have been the most common frame systems for long times whereas composite frame system has also emerged as popular system for high rise buildings for few decades. Multi-storey composite frames are generally composed of structural steel members made composite with concrete. A type of reinforced concrete columns confined by steel tubes, are known as steel tube confined reinforced concrete (STCRC) columns. This type of column is achieved by the provision of breaks to the longitudinal continuity (gaps) of the steel tube. They are a kind of composite column in which the outer steel tube acts predominantly as hoop reinforcement and such columns exhibits high load-bearing performance. The breaks present at the member ends limit the longitudinal stresses in the steel and maximise the level of confinement afforded to the concrete through the generation of hoop stresses in the tube. Thus, the steel tube is pressure free from the longitudinal force and applies a considerable radial constraint to the concrete which consequently increases the strength as well as the ductility of the concrete.

II. LITERATURE REVIEW

The performance of STCRC columns subjected to standard fire conditions was evaluated to determine the fundamental behaviour of these columns in fire and obtain essential information to underpin their fire safety design. STCRC column with beam connection is shown in Fig.1. In order to prevent load being applied to the tube directly, the steel tube is usually terminated at the beam to column connections rather than being continuous, thus reducing the chances of local buckling of the steel tube in STCRC columns.

Faqi Liu et al. presents the results of an experimental study on STCRC columns exposed to fire and it was observed that, despite some crushing occurred in concrete, the concrete remained largely intact due to the confinement of the outer steel tube, which prevented falling off of the concrete cover [1]. Faqi Liu et al. conducted experimental and numerical study on the behaviour of STCRC columns after fire exposure and concluded that longer heating time results in lower residual load-bearing capacity and compressive stiffness due to decrease of strength and elastic modulus after fire exposure [2]. Hua Yang et al. investigated the fire behaviour of such columns and found that the temperature was not uniform across the cross section and decreased from the outer steel tube to the concrete centre [3]. The delay of temperature rise is attributed to the high thermal capacity of concrete and the protection from the surrounding material. In the post fire behaviour study of columns, all the specimens exhibited a fairly ductile behaviour on exposure to longer heating times and hence the possibility of rehabilitation [4]. In this study, the performance of single skin STCRC column under fire has been investigated.

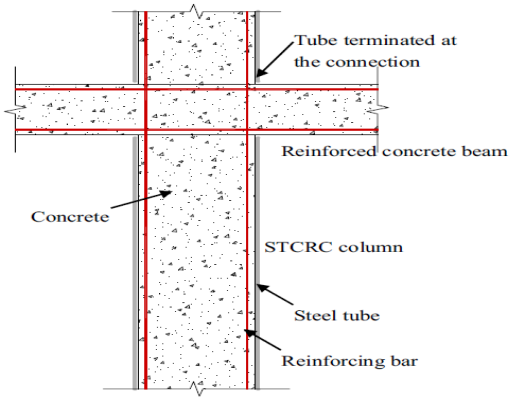

Fig. 1.A schematic view of STCRC column [1]

III. NUMERICAL STUDY ON SINGLE SKIN STCRC COLUMN

Single skin STCRC columns consists of a steel section and the reinforced concrete is cast in between this steel section. The fire exposure to the specimens is as per ISO 834 (ISO

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1999) standard fire curve. The analysis of columns were done using ANSYS 16.1 Workbench, a finite element software for mathematical modelling and analysis. The analytical study includes the development of finite element model to evaluate the performance of single skin STCRC column, at different fire exposure times. single skin STCRC column specimen is circular. Outer diameter of the single skin STCRC column is 300 mm and steel tube thickness is 2.75 mm. Length of specimen is 3770 mm with concrete cover of 25 mm. The reinforcing cages were fabricated by tying eight longitudinal reinforcing bars with stirrups at intervals of 200 mm. The diameter of longitudinal bars and stirrups were 20 and 6.8 mm respectively. The specimens were fixed at the bottom end and pinned at the top end. The material properties (Table 1, 2 and 3) were assigned to the models and analysis of columns has been performed under normal condition, fire exposure condition for 60min and 120 min. The exposure time were chosen for the ease of solving. The reinforced concrete column was modelled with the same dimensions to that of the single skin STCRC column, expect there was no steel tube in the column. The outer diameter, length of column and the reinforcing bars were same as that of single skin STCRC column.

TABLE I. MATERIAL PROPERTIES

Material	Fe 415 steel	M 30 grade concrete
Modulus of elasticity	1.93 x 10^5 N/mm^2	2.518 x 10^4 N/mm^2
Poisson's ratio	0.3	0.12
Density	7850 kg/m^3	2400 kg/m^3

TABLE II. THERMAL CONDUCTIVITY AND SPECIFIC HEAT CAPACITY OF STEEL

Material	Temperature(ºC)	Thermal conductivity (W/m.ºC)	Specific heat capacity (J/kg. ºC)
Steel	21	53.3	431
	100	50.7	471
	200	47.3	522
	300	41.4	573
	400	39.2	624
	500	37	675
	600	34.8	760
	700	32.6	1008
	800	30.4	799
	900	28.2	650

TABLE III. THERMAL CONDUCTIVITY AND SPECIFIC HEAT CAPACITY OF CONCRETE

Material	Temperature (ºC)	Thermal conductivity (W/m. ºC)	Specific heat capacity (J/kg. ºC)
Concrete	21	1.36	913
	100	1.35	963
	200	1.34	1022
	300	1.32	10755
	400	1.22	1122
	500	1.10	1164
	600	0.97	1200
	700	0.85	1231
	800	0.72	1256
	900	0.6	1275

IV. RESULTS AND DISCUSSION

The results of numerical analysis such as load carrying capacity and deflection of single skin STCRC column and RC column are shown in Table 4 and 5. Load carrying capacity of single skin STCRC specimen under normal condition shows 3101.3 kN, whereas that of RC column shows 1954.2 kN, which is 60% lesser than that of single skin STCRC column. The deflection of RC column is more than that of STCRC column under normal condition. The single skin STCRC specimen withstand up to 972.17 ºC when subjected to fire exposure for 60 min and shows a reduced load carrying capacity of 2594.4 kN with 20.07 mm deflection. The load carrying capacity of RC column reduced to 1850.70 kN and deflection increased to 24.79 mm at 60 min of fire exposure. Under fire exposure for 120 min, single skin STCRC column shows load capacity as 2565.2 kN at 1079.6 ºC and deflected to 22.79 mm. In case of RC specimen, only a small reduction in load capacity is observed (1848.20 kN with a deflection of 24.39 mm) compared to that at 60 min fire exposure. The load deflection curve of STCRC and RC columns is shown in Fig.2 and 3 respectively. Temperature distribution in y direction can be visualized in Fig.4,5,6 and 7.

TABLE IV. ULTIMATE LOAD AND DEFLECTION OF SINGLE SKIN STCRC COLUMN

Specimen	Ultimate load (kN)	Deflection (mm)
SS STCRC/0	3101.3	18.5
SS STCRC/60	2594.4	20.07
SS STCRC/120	2565.2	22.79

TABLE V. ULTIMATE LOAD AND DEFLECTION OF RC COLUMN

Specimen	Ultimate load (kN)	Deflection (mm)
RC/0	1954.2	24.11
RC/60	1850.70	24.79
RC/120	1848.20	24.39

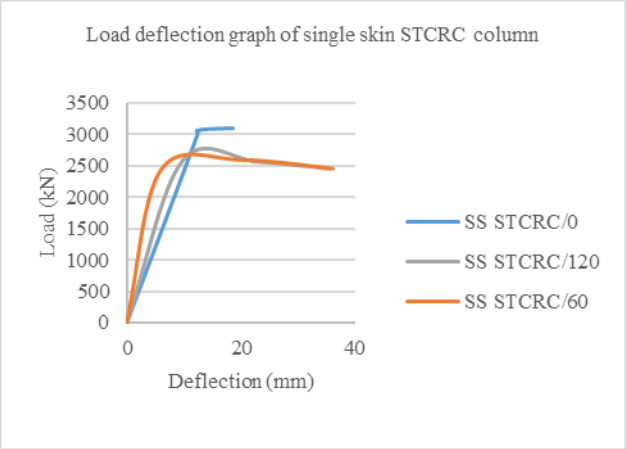

Fig. 2.Load-deflection graph of single skin STCRC column

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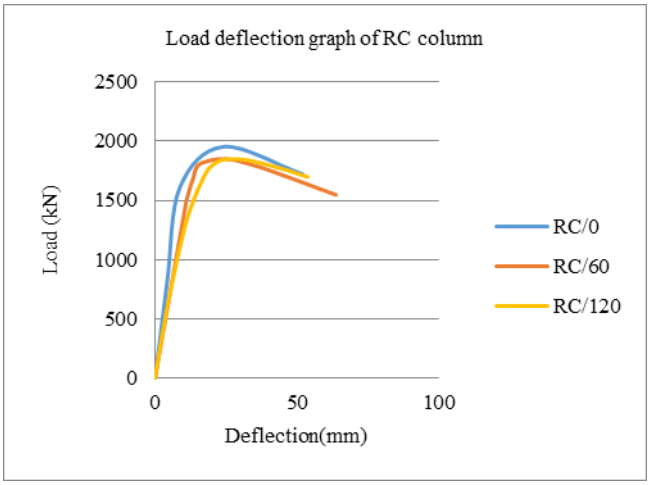

Fig. 3.Load-deflection graph of RC column

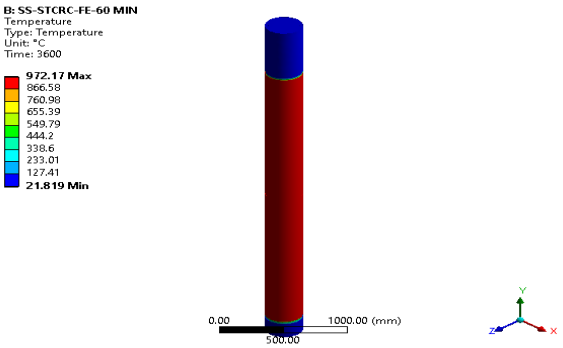

Fig. 4.Temperature in the STCRC column at 60 min of fire exposure

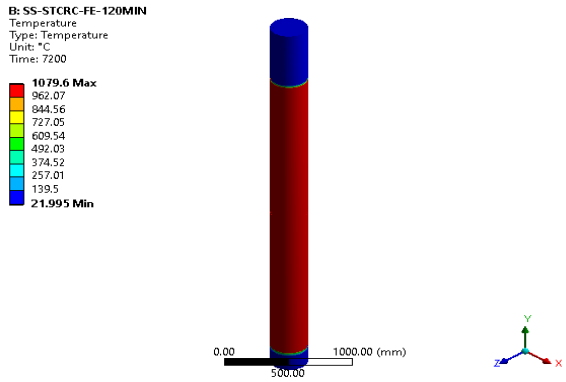

Fig. 5.Temperature in the STCRC column at 120 min of fire exposure

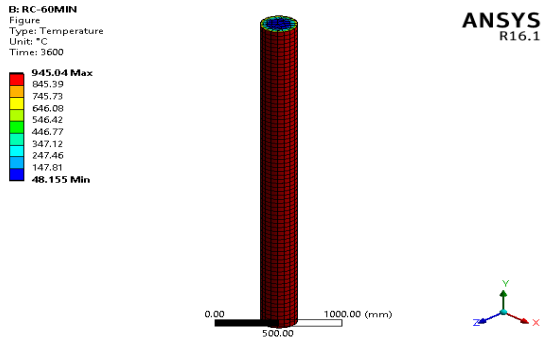

Fig. 6.Temperature in the RC column at 60 min of fire exposure

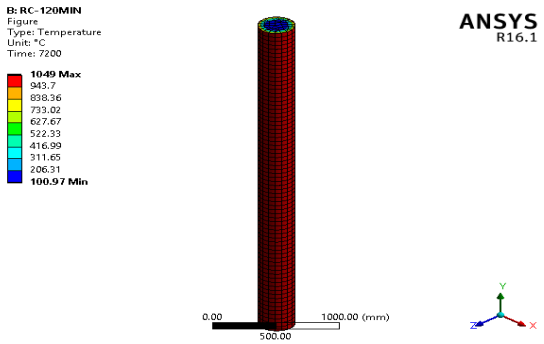

Fig. 7.Temperature in the RC column at 120 min of fire exposure

The temperature variation in the concrete and steel tube of the specimen across the cross section is given in Table 6 and 7. Maximum at the exterior and minimum at the inner portions are observed.

TABLE VI. TEMPERATURE DISTRIBUTION IN SINGLE SKIN STCRC COLUMN

Specimen	Time	Outer tube	Outer concrete	Middle concrete
SS STCRC Column	60 Min	111.63	56.812	54.222
	120 Min	164.8	116.15	108.65

TABLE VII. TEMPERATURE DISTRIBUTION IN RC COLUMN

Specimen	Time	Outer concrete	In b/w center	Middle concrete
RC Column	60 Min	146.81	67.198	56.706
	120 Min	248	121.17	111.86

V. CONCLUSIONS

Present study evaluates the performance of single skin STCRC column, at different fire exposure conditions and compared with RC column. Tests on specimens with boundary conditions of bottom end fixed and top end pinned through numerical analysis. The load carrying capacity of single skin STCRC column was observed higher than that of RC column. The deflection of single skin STCRC column was lower than that of RC column, when it is exposed to longer heating times. The main conclusions are summarized as follows;

- In normal condition, load carrying capacity of single skin STCRC column is 3101.3 kN with 18.5 mm deflection and that of RC column is 1954.2 kN with a deflection of 24.11 mm.
- Under fire exposure for 60 min, the load carrying capacity of single skin STCRC column was observed as 2594.4 kN at 972.17 ^{o}C and that of RC column as 1850.7 kN at 945.04 ^{o}C.
- During 120 min of fire exposure condition, single skin STCRC and RC column show reduced load capacity as 2565.2 kN at 1079.6 ^{o}C and 1848.20 kN at 1049 ^{o}C respectively.
- Single skin STCRC column shows high load carrying capacity with low deflection compared to conventional RC column when subjected to such extreme temperatures.

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