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Burning Influence on Load Capacity of Steel - Reinforced Concrete (SRC) Column

Ahmed Hussein Ali[1], Amjad Hameed Al-Mudhafer[2]

[1]Post Graduate Student at Faculty of Engineering, Kufa University, Kufa-Annajaf Road, Annajaf, Iraq
[2]Assistant Professor of Structural Engineering, Department of Civil Engineering, Faculty of Engineering, Kufa University, Kufa-Annajaf Road, Annajaf, Iraq

Abstract: ***This paper presents an experimental study on the influence of real fire flame on the Load Capacity of Steel-Reinforced Concrete (SRC) Columns. A ten reduced scale SRC column specimens have the same dimensions and the same reinforcement were tested. But with different temperature levels (25,350, 550 and 750 °C), a compressive strength of concrete (30.29MPa and 40.41MPa) named series C1 and C2 correspondingly, and eccentricity (0, and 40mm). After curing and at age more than 28 days seven specimens were exposed to fire flame from 4 sides for a one-hour time period, then cool down to ambient temperature naturally, after that they have been tested with three unburned columns (control specimens) to failure under loading. The results illustrated a significant reduction in the ultimate load for all column specimens after fire flame exposure. The residual ultimate load at a temperature levels of (350,550, and 750 °C) for concentric loading was (91.6%,78.5%, and 57.4%) for series C1 and (85.3%,73.4%, and 53.5%) for series C2 respectively, whereas residual ultimate load at a temperature of (550 °C) and eccentrically loaded at (e = 40mm) was (74.1%) for series C1.***

Keywords: SRC column, exposed to fire, load capacity

1. Introduction

Nowadays various structural systems are used to get functional requirements or performance in structures, one of these systems is the composite construction, it is commonly used to attain lower story heights, long spans, and provide lateral stiffness. The structural and constructional advantages of both steel and concrete are used in Composite construction. Steel has a high strength to weight and stiffness to weight ratios and high ductility. Concrete has low costs of material, good resistance to fire, and is easy to place. [1]–[3]. Members of composite steel-concrete can be made by a different cross section, but concrete-encased steel of I-shape is the most commonly used (also known as Steel-Reinforced Concrete column, SRC column) and concrete-filled tubes of steel [4]. Columns are considered one of the most important structural elements, any damage or collapse for them endangers the safety of the structure to risk. [5].Temperature propagates in concrete sections at approximately 1/20 the rate in steel. This explanation for the long fire resistance times of SRC columns. Because of the decrease of stiffness and strength degradation in the concrete part at temperatures more than 300 °C, the stresses increased in the steel part and, therefore, collapse happens before the steel part is heated up to 500 °C, which is the critical temperature normally [6]. There are many experimental and theoretical research conducted on the exposure of SRC column to fire [7]–[13].

2. Experimental Work

2.1 Materials

The used materials in this research are:

2.1.1 Concrete

Locally available materials were used to produce concrete. The mix of concrete was designed based on ACI 211-2002 [14]. The concrete mix proportions are summarized in table 1.

Table 1: proportion of concrete mixes

Type of Constituent	Mix Proportion	
	C1	C2
Cement (Kg/m3)	394	429
Fine aggregate (Kg/m3)	717	733
Coarse aggregate (Kg/m3)	1024	1024
Water (L/m3)	205	193

2.1.2 Steel Bars

Two types of deformed reinforcement were used in the study with a diameter of Ø8mm for longitudinal and Ø6mm for ties. The test was accomplished in the laboratory of Consulting Engineering Bureau -University of Kufa. Table 2 shows results of tensile test for all these bars used in study. See table 2.

Table 2: Steel Bars Test Results

Diameter of Bar mm	Bar Yield Strength Mpa	Bar Ultimate Strength Mpa
8	513.74	639.2
6	560	602

2.1.3 Steel I-section

A steel I-section shape was used in this research. Two tension coupons from the web were tested according to the ASTM A370 [15]. The test was accomplished in the laboratory of the University of Kufa. See Table 3 and figure 1.

Table 3: Sectional Properties of I-Steel and test results

Area of Section	mm2	757
H	mm	80
B	mm	42
s=r1	mm	3.9
T	mm	5.9
C	mm	10.5
h-2c	mm	59
Yield Strength	Mpa	365
Ultimate strength	Mpa	500

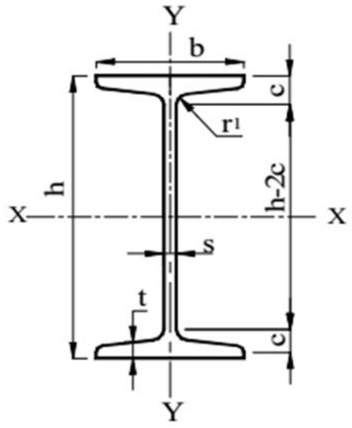

Figure 1: Sectional Properties of I-Section

2.2 Steel Reinforced Concrete (SRC) Column Specimens

All column specimens have the same dimensions of a square cross-section (170mm x 170mm) and 1000 mm total length, each column reinforced with embedded structural steel of I-shape, 4Ø8mm were used as longitudinal reinforcements and Ø6mm bars were used for ties with 100mm spacing as shown in Figure 2. The specimens of columns were divided into 2 series C1 and series C2 with compressive strength of concrete (30.29 and 40.41 Mpa) respectively, and 2 groups the first group concentrically loaded and the second group eccentrically loaded by the eccentricity of (40mm). Column specimens details are summarized in Table 4. The columns that with concentric loading is identified by 2 symbols, while the columns that with eccentric loading is identified by 3 symbols. The symbol (C1) and (C2) refer to compressive strength of concrete (30.29 and 40.41 Mpa) correspondingly, the symbol (25, 350, 550, and 750) °C refers to the temperature levels, and the symbol (E) refers to the eccentricity of loading.

Table 4: the tested column specimens details

No.	Series	Group	Stage of Temperature (°C)	Symbol of Column	Compressive Strength of Concrete (Mpa)	Applied Load Eccentricity (mm)
1	C1	1	25	C1-25	30.29	0
2	C1	1	350	C1-350	30.29	0
3	C1	1	550	C1-550	30.29	0
4	C1	1	750	C1-750	30.29	0
5	C2	1	25	C2-25	40.41	0
6	C2	1	350	C2-350	40.41	0
7	C2	1	550	C2-550	40.41	0
8	C2	1	750	C2-750	40.41	0
9	C1	2	25	C1-E-25	30.29	40
10	C1	2	550	C1-E-550	30.29	40

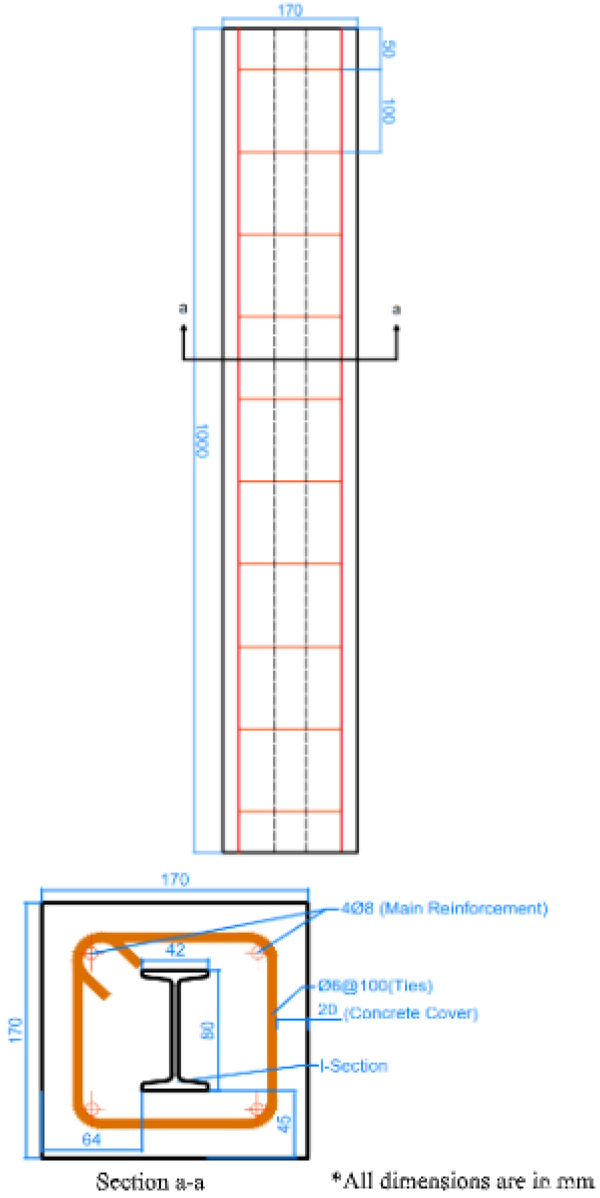

Figure 2: Details of SRC Column Specimens

2.3 Process of the burning

At age more than 28 days seven columns were exposed to direct flame of fire from four sides with temperature levels of (350, 550, and 750 °C) for one hour exposure duration then, the fire was put out and the specimens were left to cool down naturally in the stove. The burning Process adopted by the researchers [16], [17] is employed. See figure 3.

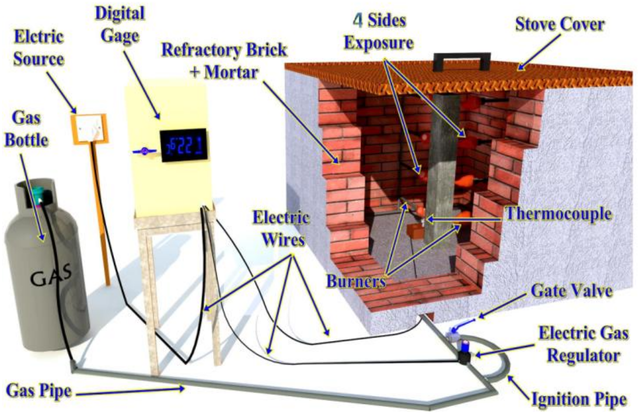

Figure 3: burning process and stove details

2.4 Testing Procedure of SRC Columns

The specimens of the column were tested after burning and cooling under increasing load up to failure by using a calibrated electrohydraulic testing machine with 2000 kN capacity in structure laboratory of Kufa University. The column specimen was placed vertically in its position for testing and then, the dial gauge was adjusted in its position. The dial gauge having an accuracy of 0.01mm per deviation and a capacity of 25mm was used to measure displacement. The test began by applying 5kN and considered zero loading. At zero loading, dial gauges were reset and mechanical strain gauge was read. The testing continued until the specimen of the column indicated a rapid drop in load capacity with raising the axial deformation by applies the load in small increments. The displacement versus load reading was recorded at the same time for each load increment by linking multiple HD video Cameras to a computer to record the testing parameters until failure occurred. See figure 4.

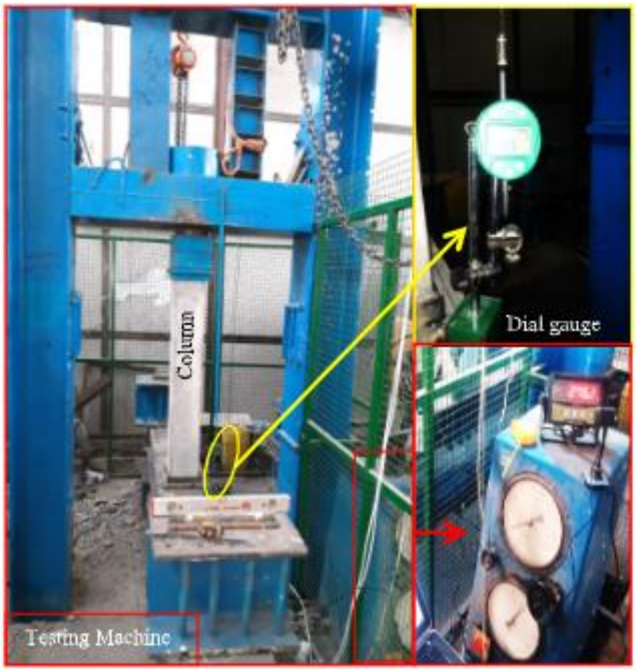

Figure 4: testing process

3. Results and Discussion

3.1 Load carrying capacity and load displacement relationships of SRC columns

The load-carrying capacity represents the ultimate applied load that can be applied on the tested column specimens. The failure occurs after a drop appeared in a reading of a testing machine with a rapid deformation in a column. In order to estimate the residual loading capacity of columns after burning, the behaviors of columns tested at room temperature consider as reference specimens for comparison. In order to estimate the load-caring capacity of the tested column specimens the main structural characteristics observed and recorded during the test of each column specimens and at each stage of loading. The observed characteristics are the axial displacement and the ultimate failure load. In general, the ascending portion of the curves for all the specimens was usually linear.

3.1.1 The behaviour of SRC Columns at Normal Temperature

In Figure 5 and Figure 6, they are illustrating the following:
The ultimate load was increased by (22.45%) for zero eccentricity when increasing concrete compressive strength from 30.29 MPa to 40.41MPa, while the ultimate load was decreased by (21.21%) for compressive strength 30.29 MPa when increasing eccentricity from zero to 40mm. At the same load, the displacement was decreased for an increase of compressive strength.

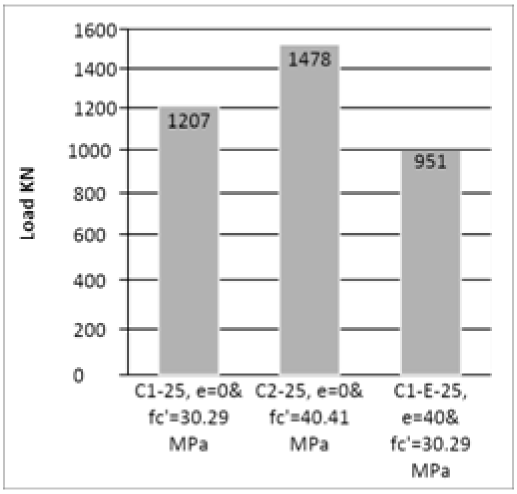

Figure 5: Ultimate Axial Load of SRC Columns at Room Temperature

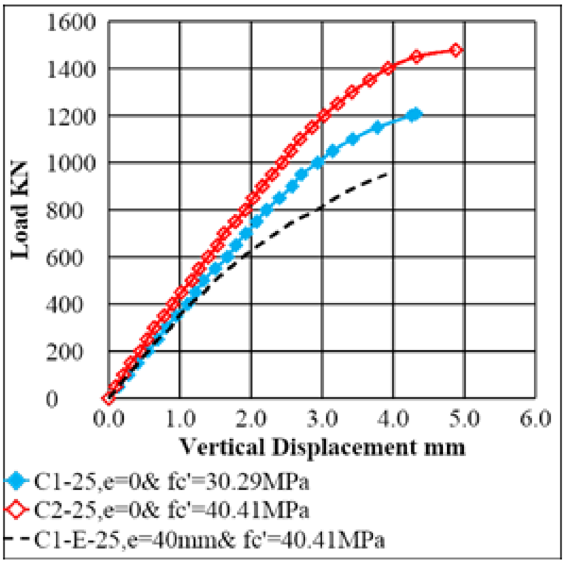

Figure 6: the load-vertical displacement curve for SRC columns at room temperature

3.1.2 Behaviour of SRC Columns at Elevated Temperature

The influence of burning by real flame of fire on the characteristic of axial deformation and load carrying capacity of the SRC column specimens for series C1 and C2 are presented in Figures 7,….., and 12.

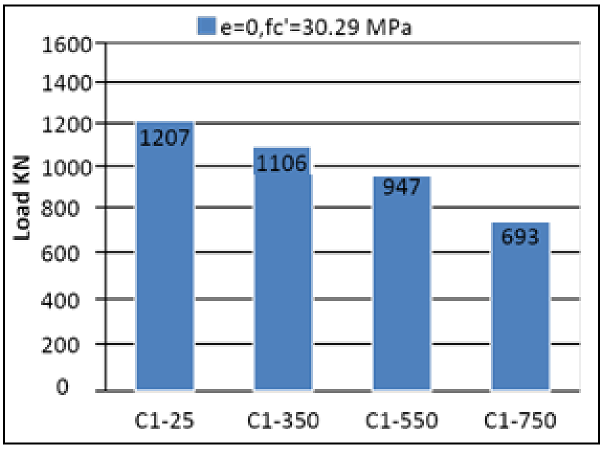

Figure 7: Ultimate Axial Load of For Group one series C1

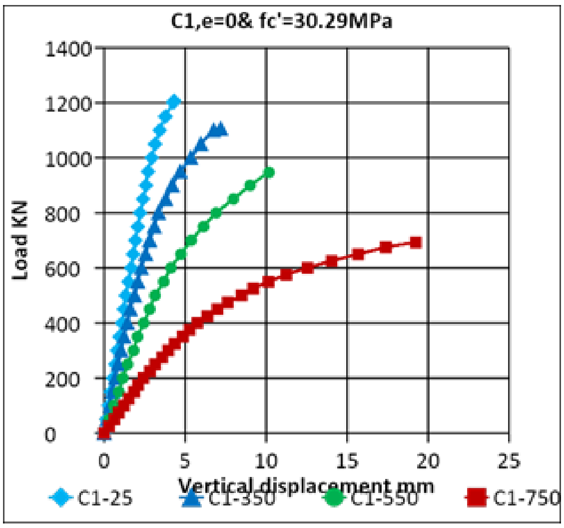

Figure 8: The Load-Vertical Displacement Curve for column Specimens of Group one series C1

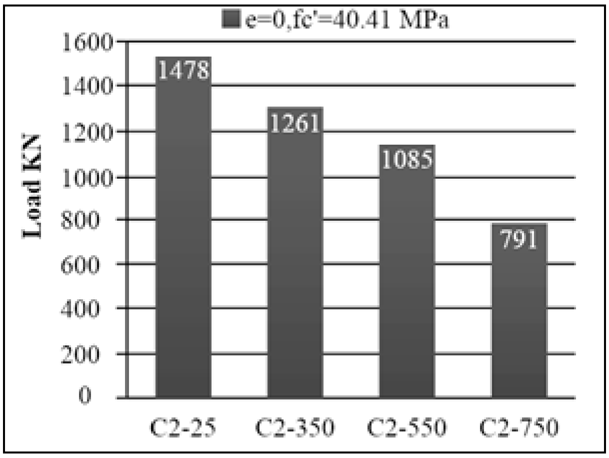

Figure 9: Ultimate Axial Load of SRC Columns For Group one series C2

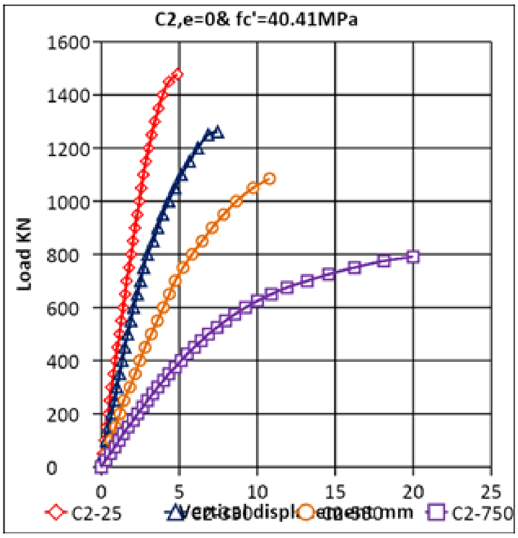

Figure 10: The Load-Vertical Displacement Curve for Column Specimens of Group one series C2

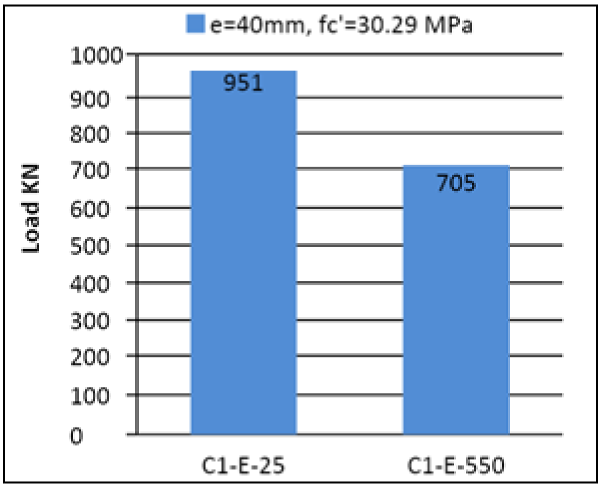

Figure 11: Ultimate Axial Load of SRC Columns For Group two series C1

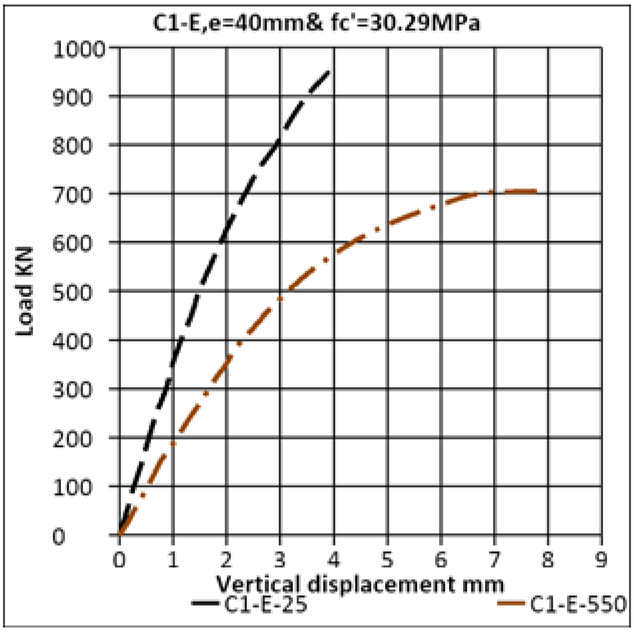

Figure 12: the Load Vertical-Displacement Curve for Column Specimens of

3.2 Effect of Burning on the Load Carrying Capacity of Columns

The test results of the control and burned column specimens are summarized in Table 5 for both series C1 and C2. It is obvious that the values of the ultimate load, decreased for all specimens when exposed to fire flame.

- The deformation of burned SRC column specimens is significantly greater than that of unburned SRC columns for the same compressive strength of concrete and the fire temperature has a noteworthy influence on the axial displacement of columns for series C1 and C2.
- The ultimate load was decreased by (8.4%) for (C1-350) and (14.7%) for (C2-350) with respect to (C1-25) and (C2-25) when increasing temperature to 350°C. This can be explained by the low decrease in the resistance of concrete and steel at this relatively low temperature.
- The tested specimens show a further loss in ultimate load at a temperature of 550 °C where the (C1-550) and (C2-550) loss (21.5%) and (26.6%) from the ultimate load in compare with (C1-25) and (C2-25).
- At temperature around 750°C, the specimens exhibit a further loss of ultimate load. Ultimate load was decreased by (42.6%) for (C1-750) and (46.5%) for (C2-750) in compare with (C1-25) and (C2-25).
- In group two the lost in ultimate load was (25.9%) for (C1-E-550) in comparison with (C1-E-25).
- For the same concrete compressive strength of (30.29 MPa) and temperature level of (550 °C), but for the eccentrically loaded column at 40mm, the decrease in the ultimate load was (25.55%) in compare with the concentrically loaded column.
- Increase of compressive strength of concrete for the same temperature level decrease the residual ultimate load. But this effect decreases with increasing temperature.
- It can be concluded that the rise in the fire temperature reduced the load capacity of column specimens and the vertical displacement increase.

It is clear from the test results that the percentage of residual ultimate load decreases for series C1 and C2 and for all exposure temperatures of (350, 550, 750 °C). The reduction in the ultimate load-carrying capacity of the column specimens can be attributed to the fact that the fire flame subjected to the SRC columns causes loss of free water in the concrete by evaporation. With the continued exposure of the column to the flame of the fire, the concrete compressive strength and yield strength of steel resistance will be decreased and the pressure resulting from the evaporation of free water in the concrete in some cases may cause fragmentation and damage of the surface layer of the concrete causing decrease in concrete section and its strength. This decrease in the concrete compressive strength and yield strength of steel is causing a decrease in the load-carrying capacity of the column specimens.

It can also be observed that the rise in the temperature of the fire reduces the carrying capacity of the load and raises the axial displacement of the SRC columns. This can be attributed to the fact that heating causes a decrease in stiffness of the column, which is mainly due to the decrease in the modulus of elasticity of concrete and steel and the low effective partition due to the cracking of concrete.

Table 5: The summary of results

Number	Column Symbol	Load Carrying Capacity Pu (KN)	Change in Pu (%)	Percentage Residual Load Carrying Capacity (%)	Axial Displacement at Ultimate Load (mm)
1	C1-25	1207	0.0	100.0	4.32
2	C1-350	1106	-8.4	91.6	7.20
3	C1-550	947	-21.5	78.5	10.18
4	C1-750	693	-42.6	57.4	19.24
5	C2-25	1478	0.0	100.0	4.88
6	C2-350	1261	-14.7	85.3	7.45
7	C2-550	1085	-26.6	73.4	10.79
8	C2-750	791	-46.5	53.5	20.00
9	C1-E-25	951	0.0	100.0	3.91
10	C1-E-550	705	-25.9	74.1	7.89

3.3 Failure Modes

3.3.1 Failure Modes at normal temperature:

For the columns with zero eccentricity, the failure of (C1-25) and (C2-25) was sudden failure and occurred at end of column length by crushing of concrete and local bucking for steel. See figure 13 and 14. For the column with 40mm eccentricity the failure of (C1-E-25) occurred at end of column length by spalling out of concrete cover. See figure 15.

Figure 13: failure mode of (Specimen C1-25) crushing of concrete and local buckling of steel

Figure 14: failure mode of (Specimen C2-25)) crushing of concrete and local buckling of steel

Figure 15: failure mode of (Specimen C1-E-25) spalling out of concrete cover

3.3.2 Failure Modes at Elevated Temperature:

For the columns with zero eccentricity, the failure of (C1-350), (C1-550), (C1-750), (C2-350), (C2-550), and (C2-750) occurred at middle of column length by crushing of concrete with gradually concrete spalling and local buckling for steel. See figures 16, ……, and 21. For the column with 40mm eccentricity the failure of (C1-E-550) occurred at end of column length by spalling out of concrete cover. See figure 22. The pattern of failure appears more fragile with increased temperature.

Figure 16: failure mode of (Specimen C1-350) crushing of concrete and local bucking for steel

Figure 17: failure mode of (Specimen C1-550) crushing of concrete and local buckling for steel

Figure 18: failure mode of (Specimen C1-750) crushing of concrete and local buckling for steel

Figure 19: failure mode of (Specimen C2-350) crushing of concrete and local buckling for steel

Figure 20: failure mode of (Specimen C2-550) crushing of concrete and local buckling for steel

Figure 21: Failure mode of (Specimen C2-750)) crushing of concrete and local buckling for steel

Figure 22: failure mode of (Specimen C1-E-550) spalling out of concrete cover

4. Conclusions

1) It is clear from the test results that the percentage of remaining ultimate load decreases for series C1 and C2 and for all exposure temperatures of (350, 550, 750 °C).
2) Rise in the fire temperature reductions the load-carrying capacity and rises axial displacement in column specimens
3) The rise in concrete compressive strength for the same temperature level increases the lost in ultimate load.
4) The residual ultimate load at a temperature of (350,550, and 750 °C) and concentric loading was (91.6%,78.5%, and 57.4%) for series C1 and (85.3%,73.4%, and 53.5%) for series C2 respectively. whereas ultimate load at a temperature of (550 °C) and eccentrically loaded at (e = 40mm) was (74.1%)for series C1
5) For the same concrete compressive strength of (30.29 MPa) and temperature level of (550 °C), but for the eccentrically loaded column at 40mm, the decrease in the ultimate load was (25.55%) in compare with the concentrically loaded column.
6) The failure pattern becomes fragile for burnt columns and appears more fragile with increasing temperature.

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Author Profile

Amjad H. Al-Modhafer received the B.Sc. and M.Sc. degrees in Civil Engineering from University of Al-Nahrain in 1998 and 2001. He received degree (Ph.D.) in Civil Engineering / Structural Engineering from University of Baghdad in 2010. He received Post Doctor in Earthquake Engineering from University Tehran in 2016. Member in the academic staff (Assistant professor) at Civil Eng. Dept. Faculty of Engineering/ Univ. of Kufa / Since 2001. Member of the Iraqi Engineers Union / Affiliation since 2001. Member of the Iraqi Teachers Union / Affiliation since 2005. Now he the Iraqi Cultural Attaché in Iran.

Ahmed H. Ali received the B.Sc. degree in Civil Engineering from Kufa University in 2013. Member of Iraqi Engineers Union since 2014.