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Finite Element Modelling of Fire Resistance of Reinforced Concrete Columns

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Abstract

Finite element modelling is performed in this study for reinforced concrete columns which is subjected to thermal load (fire). Previous experimental studies observed the fire behavior of reinforced concrete columns but no studies observed the fire behavior of such columns having different cross sections and reinforcement ratios numerically. Fire is applied to the surface of the columns in the form of thermal load. Convection and Radiation has been applied accordingly to the column surfaces. Temperature dependent material properties has been given as input. In this research, numerical analysis is done in ABAQUS software and results are analyzed in terms of fire resistance, maximum temperature developed, temperature contour etc. The fire resistance found using the finite element model demonstrates excellent consistency with standard furnace test outcomes of former research verifying the dependability of the model. Then a parametric study comprised of forty models was performed keeping the principles of verified model same, with varieties of cross sections of column and steel percentages which has produced significant information about the resistance of these types of columns against fire. It is found that bigger column sizes offer more fire resistance in most of the cases whereas higher steel percentages result in less resistance to fire. Results of the parametric study have been compared with existing previous researches. Relationship is established through linear regression analysis between these parameters which is useful while predicting the fire resistance of same type of columns.

1. Introduction

Fire is one of the humanity's oldest inventions that is often beyond our control. When a fire breaks out in a structure, it can cause extensive damage and make it unsuitable for reuse. (Rashidi, 2013). Structural fire engineering aims to evaluate the safety of

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buildings and structures during fires. Engineers employ numerical analysis also as a key tool of fire engineering discipline (Gernay & Dimia, 2011). Over the years, there has been a considerable amount of research carried out in the area of structural fire protection. The design of structural members should not only meet load-bearing requirements but also meet the necessary fire resistance standards to be used in buildings (Kodur *et al.*, 2004). Structures with frames are frequently built using Reinforced Concrete (RC) columns because of their exceptional resistance to compression loads. As one of the main requirements for building design is fire safety, these columns must also have the necessary fire resistance. This requirement derives from the fact that structural integrity is the final barrier of defence in the event that fire suppression and control systems malfunction (Kodur & Rout, 2009). Because of their lower heat conductivity, concrete members of a building structure are typically thought to perform better in fire situations than bared steel members (Zhaodong & Jie, 2018). Concrete buildings seldom collapse as a result of fire or extreme heat shock, according to a survey done by the Concrete Industry in 2008 (Qiu *et al.*, 2021). Nonetheless, there is a great deal of fire-induced damage to concrete structural components, which can be brought on by the material's deterioration at high temperatures, the constraint effect from thermal expansion and contraction, or the transfer of structural loads during a fire (Qiu *et al.*, 2021).

The current process for evaluating reinforced concrete columns fire resistance relies on prescriptive approaches and often depends on the concrete cover thickness, component size, and the kind of aggregate (ACI, 2014) and many of the crucial factors, including load level, fire situation, concrete strength, and slenderness are not taken into consideration (Kodur & Rout, 2009) although researches have proved that parameters for example level of load, reinforcement percentage, effective length of the column, strength of concrete, size and form of the cross section and kind of aggregate have substantial impact on fire resistance (Guo & Shi, 2011; Kodur & Rout, 2009; Kodur & Rout, 2012; Han *et al.*, 2013; Rodrigues *et al.*, 2014). In the United States, concrete structures must be designed in compliance with the American Concrete Institute's (ACI 318) standards (ACI, 2005). Although ACI 318 standard does not include any fire provision, it refers to ACI 216.1 standard (ACI, 2014), which provides guidelines for assessing the fire resistance ratings of structural elements made of concrete and masonry. Specific aggregate types, column sizes, concrete cover thickness to main reinforcement and the number of column sides exposed to fire are all included in the calculated fire ratings. To ensure the integrity of the column in the event of a fire, additional guidelines for tie design are supplied. For assessing the fire resistance of RC columns, Eurocode 2 (Eurocode, 2004) offers a selection of tabular, simple or sophisticated approaches. The tabular method is the most efficient way to determine the lowest possible dimensions and cover thickness in an RC column for the necessary fire resistance rating. In recent study, (Pham *et al.*, 2024) mentioned, parameters that affect the lowering of post fire strength are load ratio, concrete cover thickness and reinforcement ratio. Therefore, research needs to take place regarding fire behavior of RC columns having different cross sections and reinforcement ratio. Several columns need to be examined under fire load to observe the behavior of these columns while subjecting to thermal load.

Many experimental studies have been conducted over the years to observe the fire behavior of reinforced concrete columns subjected to "standard fire" (Franssen & Dotreppe; 2003; Aldea *et al.*, 1997; Dotreppe *et al.*, 1997). These studies reveal that, when an RC column is exposed to high temperatures, the material characteristics significantly change and the strength of the concrete and reinforcement is reduced. In addition, the structure's internal temperature propagation is irregular, which leads to an inconsistent loss of strength and ultimately, the collapse of the structure (Buchanan & Abu, 2017; Zhang & Usmani, 2015). While analyzing the behavior of RC columns, realistic fire model including both heating and cooling phase where temperature is getting down to ambient temperature is preferable (Gernay & Dimia, 2013). Various experimental and numerical studies have examined the behaviour of RC columns in fire including cooling phase (Gernay *et al.*, 2022; Molkens, 2022; Gernay, 2019; Gernay & Dimia, 2013).

The conventional method of assessing the performance of load bearing structural elements under the action of fire is through the application of the standard furnace test. The major research organizations have collaborated through the International Organization of Standardization (ISO) to introduce an international specification for conducting fire resistance tests, namely ISO 834. The standard time-temperature curve which is called ISO 834 curve follows the equation:

$$T = 345 \times \log10(8t + 1) + 20 \quad (1)$$

Here, t = time of test (min)

In this research, ISO 834 fire curve has been developed by using the above-mentioned formula for four hours (240 mins) which is presented in Figure 1. The graphs show that temperature rises up to 1152.8° C at 240 mins. Subsequently, this fire curve has been given as thermal load in numerical modelling.

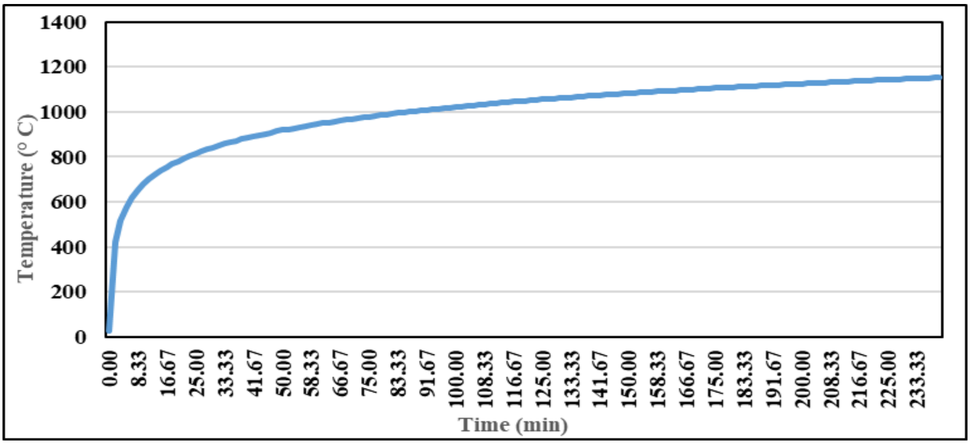

Figure 1: ISO 834 Fire curve

Three steps are typically involved in the numerical analysis of a structure that has been exposed to fire: first, the progression of the gas temperature in the chamber gets established; second, the distribution of temperature in the structural member sections is determined through thermal analysis; and third, the behaviour of the structure under elevated temperatures is evaluated through mechanical analysis (Gernay & Dimia, 2011).

A numerical technique for addressing engineering and computational physics problems is the Finite Element Method (FEM). Finite Element Analysis (FEA) is another name for it. The method of finite elements, an algebraic system of equations is produced by the problem formulation. The approach provides approximations of the unknown values at a specific number of locations throughout the domain. It breaks down a big problem into smaller, easier components known as finite elements in order to solve it. A bigger system of equations that describes the entire problem is then put together from the basic equations that model these finite elements. Then, by minimizing a related error function, FEM approximates a solution using variation techniques from the calculus of variations. Some commercially-available 'Finite Element Analysis' packages are able to describe the thermal behaviors of reinforced concrete. (Terro & Sullivan, 1992) developed a model for the structural behavior of reinforced concrete under transient temperature conditions. ABAQUS, a general-purpose FEM software tool, was used for the numerical modelling and analysis of the RC column.

Over the course of time, some researchers have examined the behaviour of RC columns in fire numerically but not many existing researches have examined the fire behaviour of RC columns having different cross sections and reinforcement ratios. The goal of this study has been set to assess the fire resistance of reinforced concrete columns having different steel ratios and cross sections by performing parametric study using a validated finite element model. At first, a numerical model of reinforced concrete column subjected to thermal load and axial compression will be developed in ABAQUS 6.13-1 (ABAQUS, 2014). Suitable standard furnace test results have been collected (Kodur & Rout, 2009; Balaji *et al.*, 2015, Gernay & Dimia, 2013). Developed model will be verified against collected experimental results. The numerical results obtained from the model will be compared with the results found by previous researchers using same type of model. A parametric study will be performed to investigate the fire endurance of RC columns having different cross-sectional area and steel ratio. Results of parametric study will be compared with similar results found by previous researches (Balaji *et al.*, 2015; Mohammed & Said, 2022). After parametric study, relationship between cross section of the column, different steel ratios and fire endurance will be developed by performing linear regression analysis.

2. Finite Element Modelling

2.1 Introduction

The process used to create the finite element models for this study will be explained in this section. A finite element model of RC column sections was developed using ABAQUS 6.13-1 (ABAQUS, 2014). The entire simulation process of this software can be divided into three parts: pre-processing, processing and post-processing. The developed numerical model was verified against the standard furnace test outcomes found by (Kodur & Rout, 2009). Analysis was performed using two types of steps. For thermal analysis, coupled temperature displacement step was used whereas for axial capacity, static general step available in ABAQUS library was used. All the material property used in this analysis were temperature dependent. From the analysis, the axial capacity, fire resistance are determined. The following sections focus on particular modelling methodologies.

2.2 Material Properties

In this section, material properties used for the modelling in ABAQUS have been discussed. Reinforced concrete columns are made of two main materials, those are concrete and steel. In this research two types of material properties have been assigned for both concrete and steel. Thermal properties and mechanical properties. Thermal properties include specific heat and thermal conductivity. Mechanical properties mainly include Poisson’s ratio and modulus of elasticity. The following subsections explain the details of material properties.

2.2.1 Thermal Properties of Concrete

To evaluate the thermal response of a concrete element, it is necessary to have data on the variation of thermal conductivity, specific heat and density. In this research, the density of plain normal weight concrete was taken as 2400 kg/m^3 as per Eurocode 1992-1-1 (Eurocode, 2004). Whereas according to the equation given in Eurocode 1992-1-1 (Eurocode, 2004), following Table 1 was used in this simulation for specific heat and thermal conductivity.

Table 1: Material properties of concrete

Specific Heat (J/KgK)	Thermal Conductivity (W/mK)	Modulus of Elasticity (N/m^2)	Temperature (°C)
900	1.94	1.70×10^{10}	25
900	1.77	1.70×10^{10}	100
950	1.66	1.66×10^{10}	150
1000	1.55	1.62×10^{10}	200
1025	1.45	1.49×10^{10}	250
1050	1.36	1.36×10^{10}	300
1100	1.18	1.19×10^{10}	400
1100	1.03	1.02×10^{10}	500
1100	0.89	8.50×10^{9}	600
1100	0.78	6.80×10^{9}	700

1100	0.69	5.95 x10^9	800
1100	0.61	5.10 x10^9	900
1100	0.56	4.25 x10^9	1000

2.2.2 Mechanical Properties of Concrete

Mechanical properties of concrete include Poisson's ratio and Modulus of elasticity. The value of Poisson's ratio of concrete was chosen as 0.18 for this simulation. According to Eurocode 1992-1-1 (Eurocode, 2004), modulus of elasticity of concrete was used as per Table 1.

2.2.3 Thermal Properties of Steel

Like concrete, thermal conductivity, specific heat and density was given as input to describe the thermal properties of steel. In this research, the density of steel was taken as 7800 kg/m^3 as per Eurocode 1992-1-1 (Eurocode, 2004). Whereas according to the equation given in Eurocode 1992-1-1 (Eurocode, 2004), following Table 2 was used in this simulation for specific heat and thermal conductivity.

Table 2: Material properties of steel

Specific Heat (J/KgK)	Thermal Conductivity (W/mK)	Modulus of Elasticity (N/m^2)	Temperature (°C)
488	53.17	2.00x10^{11}	25
511	50.67	2.00x10^{11}	100
530	49.01	1.90x10^{11}	150
548	47.34	1.80x10^{11}	200
565	45.68	1.70 x10^{11}	250
606	44.01	1.60 x10^{11}	300
667	40.68	1.40 x10^{11}	400
760	37.35	1.20 x10^{11}	500
1009	34.02	6.20 x10^{10}	600
804	30.69	2.60 x10^{10}	700
650	27.36	1.80 x10^{10}	800
650	27.36	1.35 x10^{10}	900
1100	27.36	9.00 x10^{09}	1000

2.2.4 Mechanical Properties of Steel

Mechanical properties of steel include Poisson's ratio and Modulus of elasticity. The value of Poisson's ratio of steel was chosen as 0.3 for this simulation. According to Eurocode 1992-1-1 (Eurocode, 2004), modulus of elasticity of steel was used as per Table 2.

2.3 Element type and Mesh Optimization

An 8-node thermally coupled brick, trilinear displacement and temperature (C3D8T) element was used to model the concrete section. Whereas a 2-node 3-D thermally coupled truss (T3D2T) was used for steel section. A uniform square mesh size of 50 mm by 50 mm (length X width) was used for concrete. For steel section a global seed size of 100 mm was selected. Figure 2 shows a typical finite element mesh (50 mm X 50 mm).

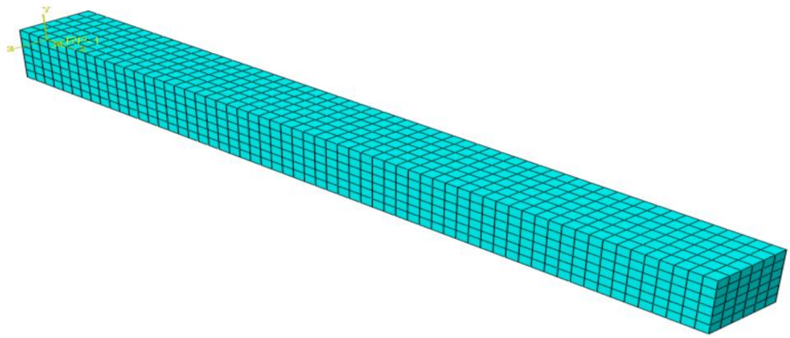

Figure 2: Finite Element Mesh

2.4 Boundary Conditions, Constraints and Load Application

For all the columns, a reference point was created at centroid to apply concentric axial load. Axial load was applied at that reference point. Then, that reference point was coupled with respect to loading end. Fixed ended boundary condition was applied at the other end of the column as shown in Figure 3. Boundary condition and reinforcement detailing of the columns used in both experiment and FEA are shown in Figure 4.

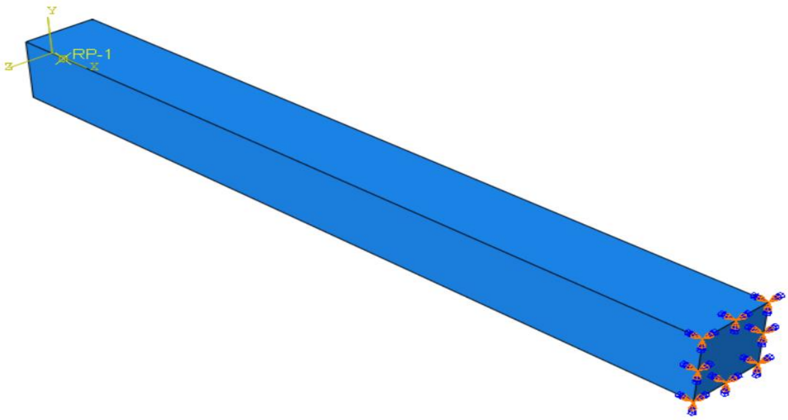

Figure 3: Representation of boundary condition and load

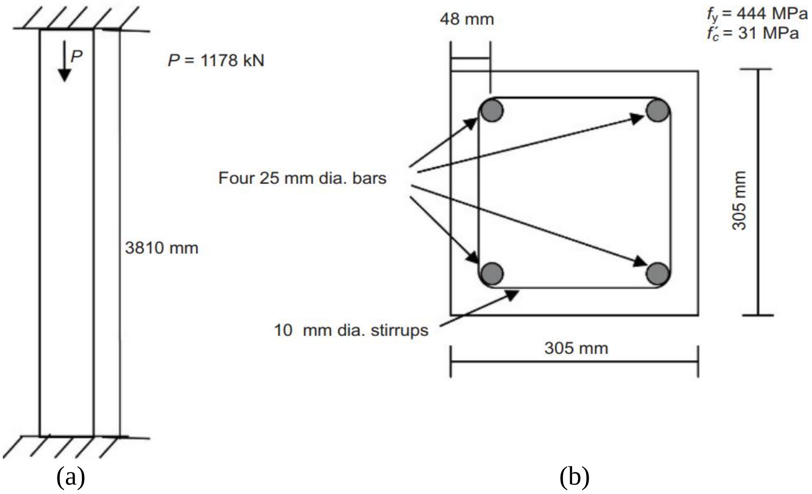

Figure. 4: (a) Elevation (b) Cross sectional details of the column

Embedded region type constraint was used to connect the reinforcement with concrete. Where concrete worked as host region and reinforcement worked as embedded region.

2.5 Defining Steps and Amplitude

Using step module, two steps were defined. One is "heating" for application of thermal fire load and another is "loading" for applying axial concentrated load. Coupled temperature-displacement procedure was used for both the steps. For heating step, the primary arc length was increased by 10, the lowest and ultimate arc length increments were $1x10^{-6}$ and 3600 correspondingly, with an estimated total arc length of 36000 sec (1 hr.). Maximum allowable temperature change per increment was 25°. For loading step, the preliminary arc length was increased by 0.001, the lowest and highest arc length increments were $1x10^{-10}$ and 1 correspondingly, where expected full arc length was 1 sec. A predefined field of 25°C was applied in the initial step to replicate room temperature in the entire zone.

As per Table 3, an amplitude was defined after deriving values from ISO-834 fire curve to apply fire load.

Table 3: Amplitude used in the model

Time (s)	Temperature (°C)
0	25
100	419
200	518
300	577
400	619
500	652
600	679

700	702
800	722
900	739
1000	755
1100	769
1200	782
1300	794
1400	805
1500	815
1600	825
1700	834
1800	842
1900	850
2000	858
2100	865
2200	872
2300	879
2400	885
2500	891
2600	897
2700	903
2800	908
2900	914
3000	919
3100	923
3200	928
3300	933
3400	937
3500	942
3600	946

2.6 Defining Interactions

Fire was applied to the RC column by using interaction module. Fire was applied through three methods of heat transfer. Heat transfer refers to the exchange of thermal energy between two separate systems through the loss of heat. Heat transfer mostly relies on temperature and heat movement. The temperature decides the quantity of thermal energy accessible, while heat flow indicates the movement of that energy.

The three methods of heat transfer are conduction, convection and radiation as shown in Figure 5. As conduction transfers heat through direct molecular collision, it was not needed in current study.

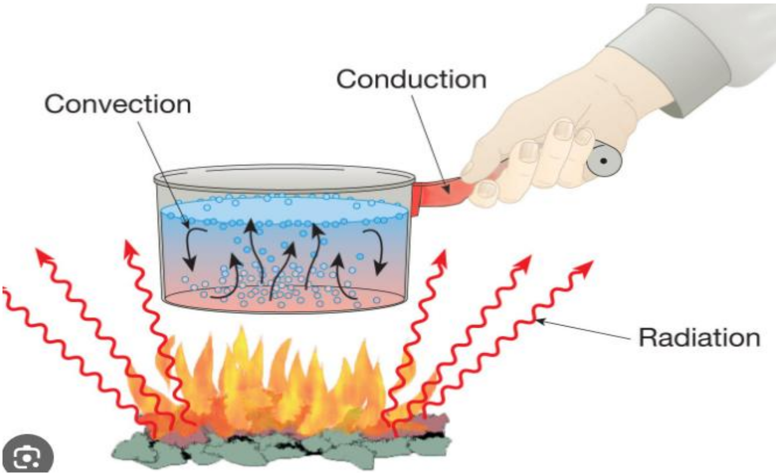

Figure 5: Three methods of heat transfer (Simscale)

A fluid, like air or a liquid, transfers thermal energy when it is heated and moves away from the source. Convection is the term for this kind of heat transmission. Above a hot surface, the fluid rises, expands, and loses density. The convection property for the column was defined using surface film condition option of the interaction module. For four side fire application, this interaction was applied to all four surfaces of the model. Embedded coefficient definition was used where film coefficient was 25. Both the film coefficient amplitude and sink amplitude were used as per ISO-834 fire curve. Sink definition was uniform and sink temperature was as usual 1.

When electromagnetic waves are released, thermal radiation is produced. The energy is carried away from the generating item by these waves. A vacuum or a particular transparent material, whether solid or liquid, can emit radiation. Molecules and atomic particles in matter move randomly, which directly results in thermal radiation. Electromagnetic radiation is released when the charged protons and electrons move. The radiation property for the column was given using surface radiation option. For four side fire application, radiation was applied to all four surfaces of the model. Emissivity distribution was uniform having emissivity of 0.7. Ambient temperature was as usual 1. Ambient temperature amplitude was used as per ISO-834 fire curve. Figure 6 shows the interaction surfaces.

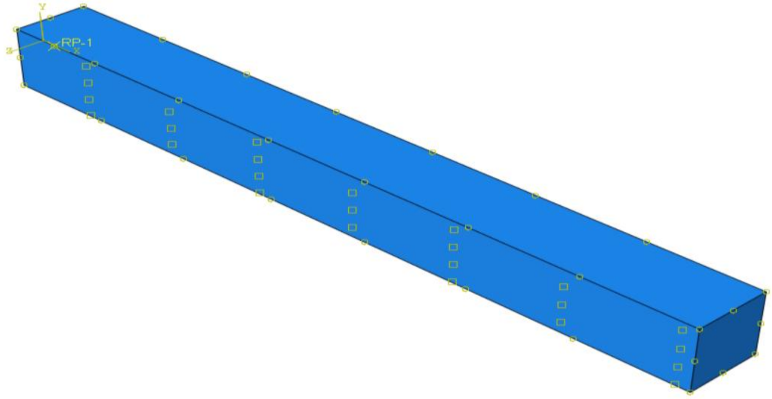

Figure 6: Interactions applied in the model

3. Results and Discussions

3.1 Validation of FEM with Experimental Results

The numerical models that have been built up in this research for RC columns are validated against the standard furnace test outcomes got by (Kodur & Rout, 2009). Validation results are presented in Table 4. Total twenty-two columns have been compared in terms of fire resistance in minute. All the columns were square cross section. Different sizes of the column were considered starting from 203 mm X 203 mm to 407 mm X 407 mm. Reinforcement ratios were different for the columns ranging from 2.19 to 4.38. Slenderness ratios for the columns were also different starting from 16 to maximum 33. It is found that FEA results are close to experimental results in most of the cases which is proving the reliability of the model. The ratio of fire resistance from test to FEA is close to one in all cases. The best ratio 0.99 is found for the column l4 having steel ratio 2.19 and slenderness ratio 22.

Table 4: Comparison of fire resistance predicted by presented model and experimental results

Column	Size: mm	A_s/A_C %	Slenderness Ratio	Fire Resistance: min		Test/FEA
				Test	FEA	
l1	305	2.19	22	240	267	0.9
l2	305	2.19	22	170	193	0.88
l3	305	2.19	22	218	237	0.92
l4	305	2.19	22	220	222	0.99
l7	305	2.19	22	208	219	0.95
l8	305	2.19	22	146	172	0.85
l9	305	2.19	22	187	228	0.82
l12	305	2.19	22	201	226	0.89
l13	305	2.19	22	210	233	0.9
l14	305	2.19	22	227	241	0.94
l15	305	2.19	22	234	244	0.96

lll14	305	2.19	22	183	226	0.81
lll1	305	2.19	31	242	247	0.98
lll2	305	2.19	31	220	227	0.97
l5	407	2.47	16	300	261	1.15
ll10	407	2.47	16	262	254	1.03
l6	203	2.75	33	180	207	0.87
ll11	407	3.97	16	285	274	1.04
l18	305	4.38	22	252	240	1.05
l19	305	4.38	22	225	232	0.97
l12	305	2.19	22	216	235	0.92
ll14	305	2.19	22	328	273	1.2

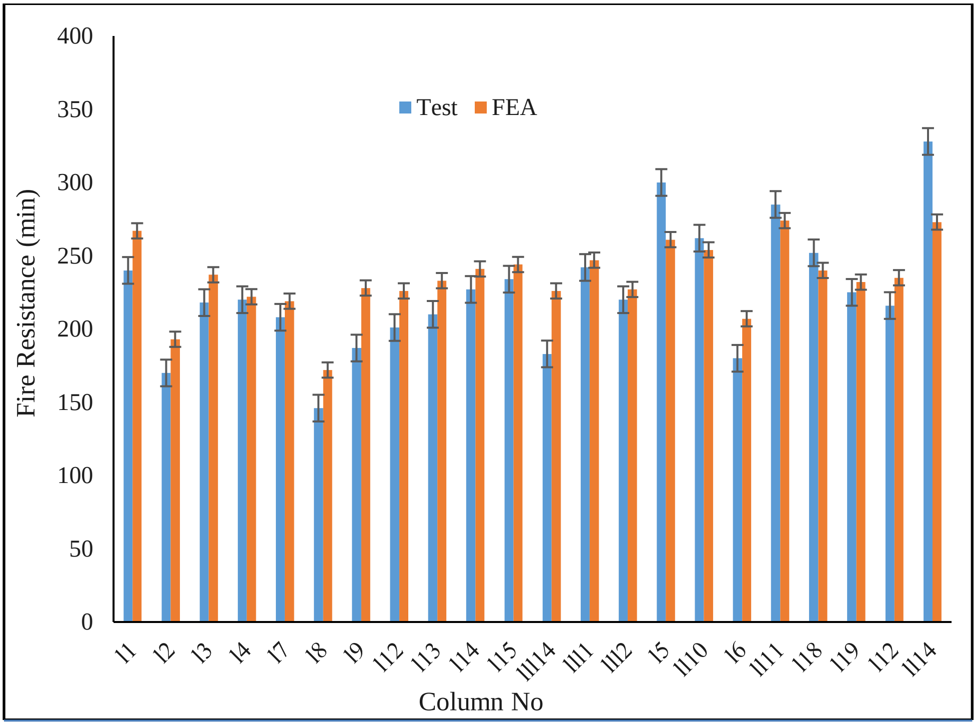

Figure 7: Comparison of fire resistance between experimental and FEA results

Figure 7 shows the comparison of fire resistance between experimental results and FEA results for all twenty-two columns labeled l1 to ll14. The error bar shows the gap between experimental and FEA results.

3.2 Parametric Study for RC Columns

Parametric study is done in this research by using the verified numerical model. Key parameter varied was the cross-sectional size of the square column and reinforcement ratio A_s/A_C for the RC column. To examine the effect of size of the column and reinforcement ratio on fire resistance of the RC column, a total of 40 different finite element models were considered. Figure 8 shows a typical reinforcement detailing used in FEM.

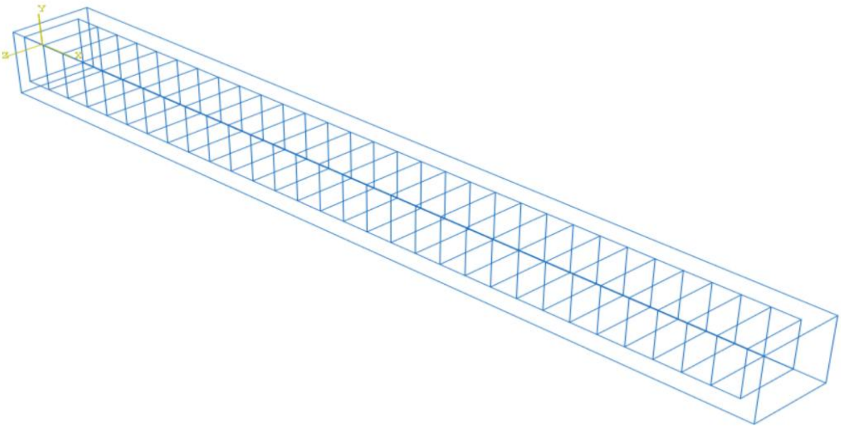

Figure. 8: Reinforcement detailing of the numerical modelling (Column-12)

Table 5: Comparison of parametric study results with previous researches.

Column	Size: mm	Size: mm (Balaji *et al.*, 2015)	A_s/A_C %	A_s/A_C % (Mohammed and Said, 2022)	Fire Resistance: min	Fire Resistance: min (Balaji *et al.*, 2015)	Fire Resistance: min (Mohammed and Said, 2022)
1	200		3.87		174		
2	210		3.51		180		
3	220		3.20		165		
4	230		2.93	3.00	155		175
5	240		2.69		175		
6	250		2.48		203		
7	260		2.29		195		
8	270		2.12		185		
9	280		1.97		210		
10	290		2.42		190		
11	300	300	2.26		230	260	
12	310		2.12		220		
13	320		1.99	2.00	210		200
14	330		1.87		180		
15	340		1.76		200		
16	350		1.66		203		
17	360		1.99		232		
18	370		1.88		190		
19	380		1.79		230		
20	390		1.70		220		
21	400	400	1.61		260	280	
22	410		1.53	1.50	300		280

23	420		1.46		303		
24	430		1.40		320		
25	440		1.69		315		
26	450		1.62		330		
27	460		1.55		340		
28	470		1.48		330		
29	480		1.42		300		
30	490		1.36		340		
31	500	500	1.31		325	300	
32	510		1.26		300		
33	520		1.49		310		
34	530		1.43		290		
35	540		1.38		280		
36	550		1.33		290		
37	560		1.28		300		
38	570		1.24		320		
39	580		1.20		340		
40	590		1.16	1.00	360		345

Table 5 represents the results of parametric study. Size of the square column was varied from 200 mm to 590 mm. Reinforcement ratio A_s/A_C was varied from 1.16 to 3.51. For column 1-9, 4-22 mm Ø bar is used with A_s= 1548 mm^2. For column 10-16, 4-25 mm Ø bar is used with A_s= 2037 mm^2. For column 17-24, 4-29 mm Ø bar is used with A_s= 2580 mm^2. For column 25-32, 4-32 mm Ø bar is used with A_s= 3276 mm^2. For column 33-40, 4-36 mm Ø bar is used with A_s= 4024 mm^2. Fire endurance have been calculated for all fourty columns. It is observed that bigger size columns offered more fire resistance compared with smaller size. The reason is bigger columns have more material between the surface exposed to fire and core of the column so it takes longer for heat to spread to the center and the core stays cooler for longer period of time. Another reason is larger columns absorb more heat before their temperature rises expressively, this delays the temperature increase in the inner parts. Furthermore, higher steel percentages offered lower fire endurance compared with lower percentages. As steel loses strength quickly in heat, higher steel percentages result in having more material that degrades faster in fire. Another reason is higher steel percentages mean that more heat gets transmitted deeper into the column faster as steel is a very good thermal conductor.

Results of parametric study have been compared with similar results found by previous researches. (Balaji *et al.*, 2015) used three square column sizes: 300 mm, 400 mm and 500 mm. They received fire resistance as 260 min, 280 min and 300 min. Whereas by using same cross section, fire resistance received in this study are 230 min, 260 min and 325 min which shows the fire resistances are close. (Mohammed & Said, 2022) used four reinforcement ratios A_s/A_C: 1.00, 1.50, 2.00 and 3.00. The fire endurance of that study is 175 min, 200 min, 280 min and 345 min. Whereas by using same reinforcement ratio, fire resistance received in this study are 155 min, 210 min, 300 min and 360 min which shows the outcomes are similar.

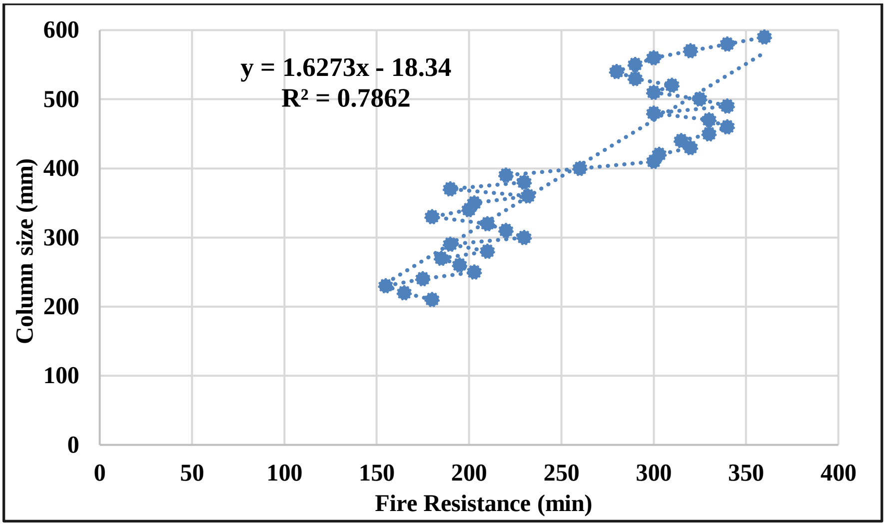

Figure 9: Graph of column size vs fire resistance

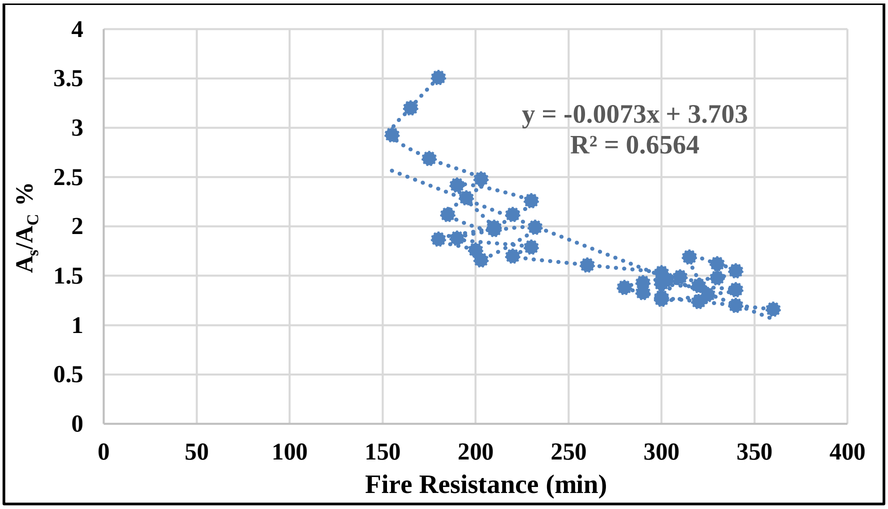

Figure 10: Graph of steel ratio vs fire resistance

Figure 9 represents the relationship between various column sizes and corresponding fire endurance. It is observed that maximum fire resistance of 360 minute is achieved for the biggest column size of 590 mm X 590 mm. Whereas lowest fire endurance of 155 minute is received for the column size of 230 mm X 230 mm. A linear regression analysis is performed between column size and fire resistance. Coefficient of regression is found as 0.7862. For a given column size, corresponding fire resistance can be found from this relationship.

Figure 10 represents the relationship between various reinforcement ratios A_s/A_C and corresponding fire endurance. It is observed that maximum fire resistance of 360 minute is achieved for the lowest reinforcement ratio of 1.16. Whereas lowest fire endurance of 155 minute is received for reinforcement ratio of 2.93. A linear regression analysis is performed between reinforcement ratio and fire resistance. Coefficient of regression is found as 0.6564. For a given reinforcement ratio, corresponding fire resistance can be found from this relationship.

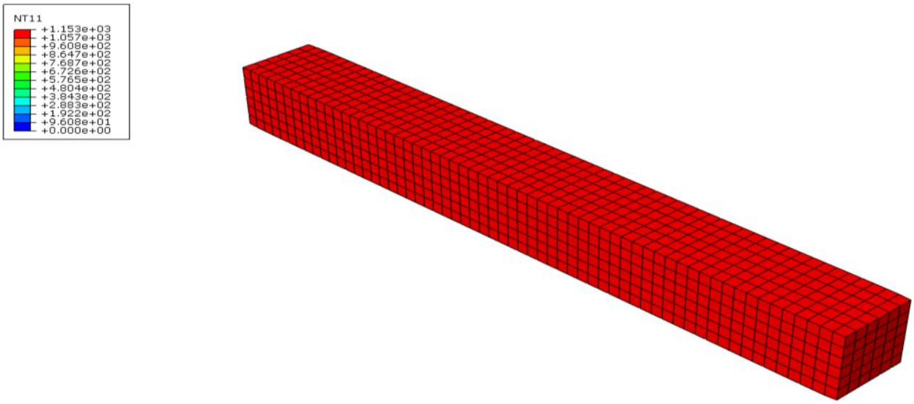

Figure 11: Nodal temperature distribution in the section

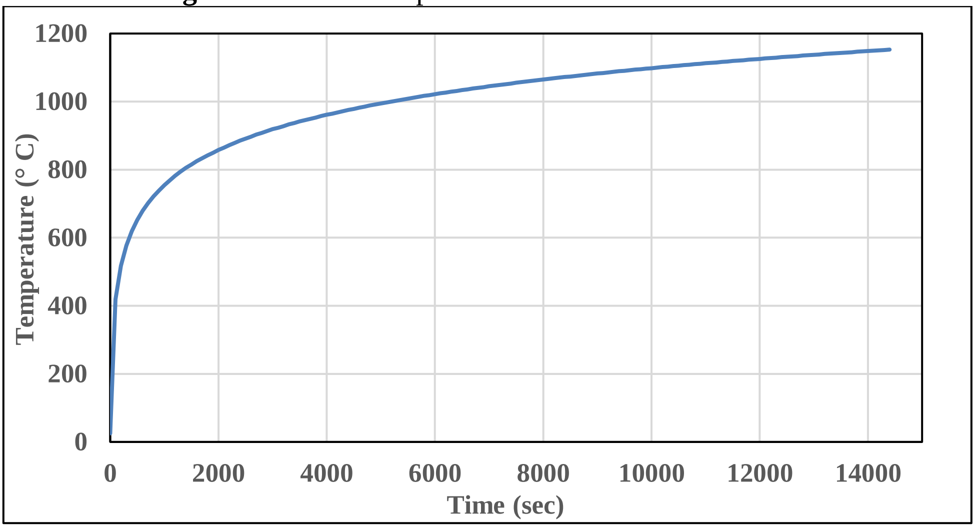

Figure 12: Time vs Temperature graph developed in FEM

Figure 11 shows the nodal temperature (NT11) distribution in the column section. It is observed that maximum temperature is 1153°C whereas minimum temperature is 96°C. Figure 12 shows the graphical representation of this nodal temperature distribution against time.

4. Conclusion

In this study, RC columns subjected to fire load were analyzed numerically. Finite element modelling results were validated against the standard furnace test outcomes. Total twenty-two columns were validated by keeping column size, reinforcement ratio and slenderness ratio same.

By using validated numerical model, a parametric study comprised of 40 numerical models was performed which established the relationship between different size of square column, reinforcement ratio and fire resistance of those columns. Results of parametric study have been compared with similar results found by previous researches.

It is observed that bigger size columns offered more fire resistance compared with smaller size in most of the cases. Furthermore, higher steel percentages offered lower fire endurance compared with lower percentages.

Therefore, it can be said that larger square column size is preferable for getting long duration fire resistance keeping the reinforcement ratio minimum.

In future research, more columns should be analyzed numerically having different types of cross sections to achieve better understanding of the fire resistance of RC columns. Different reinforcement ratios can be used also for a same cross section of column. That will provide more information about the relationship between reinforcement ratio and fire endurance.

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Conflict of interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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