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Review on Fire Resistance of Reinforced Concrete Column

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Abstract - *The fire resistance of the columns is traditionally derived from the experimental method throughout the world. For a long time, the design of columns is done based on the tabular values derived from experimental method. Now many people have come up with new approach which takes different fundamental characteristics of column during fire into consideration, they have developed different equations to predict the fire resistance of column. In this paper we are going to review the recent development of equations and their comparison with experimental results and discuss the shortcomings and advantages.*

Key Words: Fire Resistance, Column, Fundamental Characteristics, Equations, Comparison

1. INTRODUCTION

In the wake of rapid industrialisation and urbanisation the reinforcement concrete was the need of the hour. However, with increasing number of the fire incidents the fire resisting capability of reinforced cement concrete came under the question. The earlier studies had more focus on improving fire resisting property of concrete. Fire Resistance (FR) is defined as the period for which the structural element demonstrates resistance to fire maintaining its structural stability, integrity and temperature conveyance [1]. With the help of experiments different countries came up with their own codes like Australian code (AS 3600 – 2001), European countries have Euro code (EN 1992-1-2-2004), British standard code (BS 476 parts 20-23), Indian standard code (IS 3809-1979) are all based on the International Standard ISO 834 except United states, Canada and some other countries follow ASTM E119. One thing common between all the codes is that they mainly concentrate on fire temperatures to be maintained during the test. Serval experimental studies has been done and with the data collected the star rating system and tabular model has been created to give design idea for fire resistance. Since this star ratings and tabular model are limited by the particular dimension of column and the cover provided and does not take factors like load ratio, slenderness ratio, strength of construction material, direction of fire exposure etc. in to account. Where as some codes like Eurocode and Australian codes have given some simple equations to calculate the fire resistance. Though they have covered most of the parameter earlier still an important factor like confinement effect is missing from the equations.

The experimental method does provide the results for fire resistance of the column but comes with following drawbacks and advantages:

Table 1

Relative merits for experimental method of fire test

Methods for Fire resistance calculation	Drawbacks	Advantages
1. Experimental method	1. Method largely focuses on the dimensions of the column and clear cover provided neglecting important factors like load ratio, steel ratio, material strength etc.	1. Experimental method is very important for validation of any new equation for predicting and confirming the fire resistance values provided.
	2. Star rating system and tabulated fire resistance ratings only provides general idea for design of column rather than the detailed design.	2. Experimental method gives first hand report which actively demonstrate that without human error the most reliable fire resistance value can be obtained
	3. The experimental method for fire resistance does cost a fortune and require a lot of space.	
	4. Proper expertise and extensive safety precautions are necessary for execution of experiments.	

For the exact purpose of removing this drawbacks people have come up with new analytical equations which provides much more effective way to predict the fire resistance. These equations are derived using the data gathered in the experimental method and then using set of computer tools and mathematical concepts. These new equations take many of the essential parameters like slenderness ratio, load ratio, longitudinal and transverse reinforcement ratio, effective cover thickness, aggregate type, load eccentricity, concrete strength etc. in account.

2. RESEARCH SIGNIFICANCE

The variations in analytical methods can give a very key differences and similarities which can be very beneficial in extending the study further for fire resistance in column. These can be done by comparing the Formulas for each method and understanding the factors included for each of the equations. In this paper various paper are reviewed to get the good understanding of factors included in the equations for determining the fire resistance of column.

3. FACTORS AFFECTING FIRE RESISTANCE

3.1 Load Ratio

Results from past fire tests clearly illustrate that load intensity has a significant influence on fire resistance of RC columns. The fire resistance decreases with the increase in load ratio [10]. The increase in eccentricity of load decreases the fire resistance of column [7].

3.2 Longitudinal steel ratio

The ratio of longitudinal reinforcement also influences the fire resistance of the RC columns. An increase in the reinforcement ratio leads to lower fire resistance in RC columns. This can be attributed to the fact that for the same cross-sectional area of column there is more steel present, the properties of which deteriorate quickly with temperature. Steel loses its strength with the rise in its temperature at a faster rate than concrete. This leads to reduction in fire resistance of the RC columns [9].

3.3 Effect of Confinement

The layout of ties and confinement of columns has a marked influence on the fire performance of both the NSC and HSC columns, which is not being considered in design codes. The confinement of core of concrete has both positive and negative impact on the fire resistance of column depending upon the design. The effect of confinement is more pronounced in NSC columns than in HSC. Increasing the confinement by 50% increased the fire resistance by 12 and 3.5% respectively in NSC and HSC columns respectively [5].

3.4 Type of Concrete (Based on strength)

The strength of concrete has significant influence on the fire performance of concrete structures. Results indicate that the HSC columns exhibit lower fire resistance than the NSC columns due to explosive spalling [10].

3.5 Shape of Column

From the experiments it was found that the rectangular or circular shape does not differ in case of spalling though the rectangular shape can provide a little edge over the circular column [7].

3.6 Transverse Reinforcement

The effect of transverse reinforcement in column varies according to the spacing of lateral ties. The closer the spacing the greater the fire resistance up to a certain limit since increase in steel content can decrease the fire resistance.

3.7 Admixtures

Admixtures can greatly increase or decrease the fire resistance of RC column. One of the Admixture is polypropylene fibres, it is determined from the experiment that the Under relatively low temperatures (early stage of the fire) the polypropylene fibres melt leaving randomly oriented net of channels inside the concrete which help the high-pressure vapour to escape and relieve the pressure inside the concrete by avoiding explosions [12].

4. FORMULATION OF EQUATIONS

The equation given for fire resistance of reinforced concrete column is derived by the observed values during the experiments and then performing the mathematical analysis of the same. The generally accepted sequence of order is given in the following flow chart.

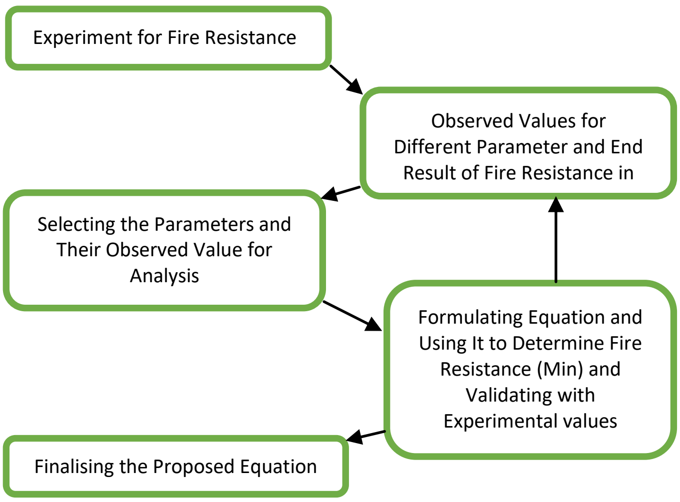

Fig. 1 Sequential flow chart of formulation of equation

Table 2

Summary of all the authors and their equation [52];[3];[15];[9];[5]

Authors	Description	Formulation
Australian code method (2001)	The equation comes with limitations like the column should be constructed with f_c in the range of 20 MPa to 50 MPa and L_e not less than 5 D_c. K = a coefficient dependent on steel ratio (1.5 when A_s/A_g < 0.025; or 1.7 when A_s/A_g ≥ 0.025), f_c = characteristic compressive strength, D_c = smaller dimension of rectangular column, D_g = greater dimension of rectangular column, N^* = the design axial force for the fire limit state, L_e = the effective length of column.	$FRP = \left(\frac{K \times F_C^{1.3} \times D_C^{3.3} \times D_g^{1.8}}{10^5 \times N^{*1.5} \times L_e^{0.9}}\right)$
Eurocode EN-1992-1-2 (2004)	Here, $R_{\eta fi}$, R_a, R_l, R_b, R_n are fire rating values determined empirically from experience and regression models based on experimental results corresponding to amount of longitudinal reinforcement, load ratio, compressive strength of concrete, cover of concrete, area of core, effective length, restraint conditions and load eccentricity respectively. This equation is based on an empirical and theoretical works of Franssen et al (2003)	$R_f = 120\left(\frac{R_{\eta fi} + R_a + R_l + R_b + R_n}{120}\right)^{1.8}$
Venkatesh Kodur and Nikhil Raut (2012)	A simplistic equation for determining fire resistance where, ksh = factor that depends on permeability of concrete, total eccentricity due to fire and load and slenderness of the RC Column; kcp = factor depends on the concrete cover and percentage of longitudinal steel; SR = Slenderness ratio; and LR = Load ratio.	$R = C_t\,[\,8 \times k_{cp} \times k_{ec} \times (30 - (S_R + 5) \times (L_R - 0.2))\,]^{0.94}$
Venkatesh Kodur and Nikhil Raut (2012)	Since above equation does not take bi-eccentric condition a new coefficient k_{sh} was added to account for fire induced biaxial bending effects. k_{sh} comprises of two sub coefficients namely k_{ec} and k_{sp} to account for eccentricity and spalling respectively.	$R = C_t\,[\,8 \times k_{sh} \times k_{cp} \times (30 - (S_R + 5) \times (L_R - 0.2))\,]^{0.94}$
Asif Shah & U.K. Sharma (2017)	In this equation the effect of confinement is taken in to consideration besides other parameter, where, FR is the fire resistance in minutes, Spl accounts for the longitudinal reinforcement percentage and is ratio of area of steel to the total gross area of the cross section. Sr is the slenderness ratio of the column and Lr is the load ratio of the column i.e., the ratio of the applied load to the design carrying capacity of the column.	$FR = \frac{K_{cf}^{0.218} S_{pl}^{1.67} S_r^{4.09} L_r^{-0.87}}{831.76}$

3. COMPARISON OF RESULTS

In paper published by Asif Shah & U.K. Sharma the primary focus was the effect of confinement besides the parameters like slenderness ratio, longitudinal reinforcement, load ratio. The experiment was performed at IIT Roorkee India, with specially designed furnace in which eight columns were tested. The detailed specifications are given in [5]. The columns were considered to have failed when the hydraulic jack could no longer resist the load. The effect of confinement (Kcf) is the product of confinement spacing (Ks) and confinement efficiency given as:

$$K_{cf} = K_s \times K_e \ldots\ldots\ldots\ldots\ldots \; (1)$$

Where, the confinement spacing is calculated by:

$$K_s = \frac{\rho_s \times fyh}{f'c} \ldots\ldots\ldots\ldots\ldots \; (2)$$

$$\rho_s = \frac{Astv \times Lstv}{Acore \times S^*} \ldots\ldots\ldots\ldots\ldots \; (3)$$

where A_{stv} is the area of transverse steel, L_{stv} is the length of the transverse tie at any cross section, s* = clear spacing between the ties or spirals, A_{core} = b_c d_c, b_c and d_c = core dimensions to the center line of the ties across the width and depth of the section, respectively.

confinement efficiency of lateral steel arrangement (K_e) is calculated by following equation:

$$K_e = \left(\left(1 - \frac{1}{\alpha A_{core}} \sum_{i=1}^{n} W_i^2\right) \times \left(1 - \frac{s^*}{2b_c}\right)\right) \times \left(1 - \frac{s^*}{2d_c}\right) \ldots\ldots \; (4)$$

where, K_e = confinement effectiveness coefficient ($K_e \leq 1$); n = number of spaces between tied longitudinal bars; and α = constant.

After doing the experiments on all eight columns the observed values were tabulated and then the Non- linear regression analysis by least square method after logarithmic transformation of variables was carried out. Then the following design equation was derived:

$$Fr = \frac{K_{cf}^{0.218} S_{PL}^{1.67} S_R^{4.09} L_R^{-0.87}}{831.76} \ldots\ldots\ldots\ldots \; (5)$$

Then the fire resistance values were determined by it. Some of the values from Kodur et al. were also taken and a comparative graph has been plotted which is shown below:

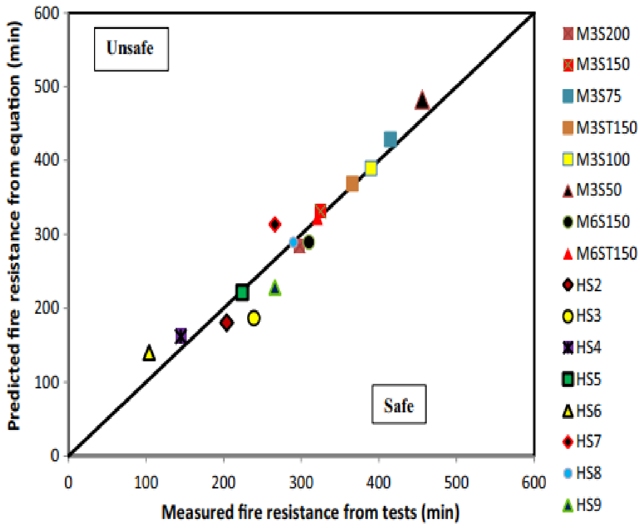

Fig. 2 Comparison of predicted and measured values of fire resistance. (Asif Shah (2017**))**

In the paper published by Venkatesh Kodur and Nikhil Raut the equation proposed takes in to consideration the variables like effective cover thickness, aggregate type, load eccentricity, concrete strength, along with slenderness ratio, load ratio, longitudinal and transverse reinforcement ratio. To derive to the equation data from the previous fire resistance test were gathered. The equation was developed by curve fitting technique in which the polynomial curve was fitted with to the data gathered which include all the important parameter. Statistical software was used to find a polynomial that accurately fits the data. That polynomial was then simplified and reduced to derive the following equation:

$$R = C_t \, [\, 8 \times k_{cp} \times k_{ec} \times (30 - (S_R + 5) \times (L_R - 0.2))\,]^{0.94} \ldots \; (6)$$

where R is fire resistance (min), SR is the slenderness ratio of the column, LR is load ratio of the column and Ct is a constant based on the aggregate type used in concrete (1.0 and 1.1 for siliceous and carbonate aggregate respectively), kcp is a constant based on the cover thickness and the percentage steel and is given by:

$$k_{cp} = \frac{[(C_e - 82) \times (S_p + 10.5) + 870]}{390} \ldots\ldots \; (7)$$

where Ce is the effective concrete cover thickness (mm), Sp is the percentage of steel in the column, kec is a constant based on the load eccentricity, load ratio and slenderness ratio and is given by:

$$k_{cp} = \frac{[(S_R - 243) \times (E_C - 768) - 83250]}{99880} \ldots\ldots \; (8)$$

where Ec is eccentricity of the applied load.

The equation was then used to determine the fire resistance value to compare with the experimented results, ACI, Eurocode and Australian code (equation for which are given in table 2) which are given in the table below:

Table 3

Fire resistance comparison from proposed equation with code provisions [15]

Column	Fire Resistance (min)				
	Test	Proposed eqn.	ACI	Eurocode	Australian code
21BC	107	71	30	70	98
31BC	63	63	60	59	118
31CC	123	82	60	84	227
33AC	69	57	60	87	177
22BC	97	94	30	87	83
III3	181	183	180	230	258
CS27	48	42	90	78	84
CS13	85	58	90	92	135
CS4	63	55	90	91	119
CS36	35	26	30	72	445
CS19	53	26	30	102	262
CS33	50	41	60	102	283

4. DISCUSSIONS

1. The equations stated here all gives conservative results as compared to experimental results for fire resistance of column as shown in fig. 3.

2. A new variable/parameter can be added i.e., the seismic vibrations. Since the large fire are produced due to an explosion or earthquake this parameter can help to achieve safe design for such cases.

3. The equations proposed by Asif H. Shah and V.R. Kodur have given better results than Eurocode and Australian code. Moreover V.R. Kodur give better result since the equation includes eccentric load and concrete strength.

5. CONCLUSIONS

In the conclusion we can say that the analytical method for predicting the fire resistance provide much more leniency and simplification. The analytical method also includes much of parameters which were left in the experimental method. The analytical equations produced conservative and simplified results.

Though there is still scope for improvement i.e., inclusion of seismic vibrations.

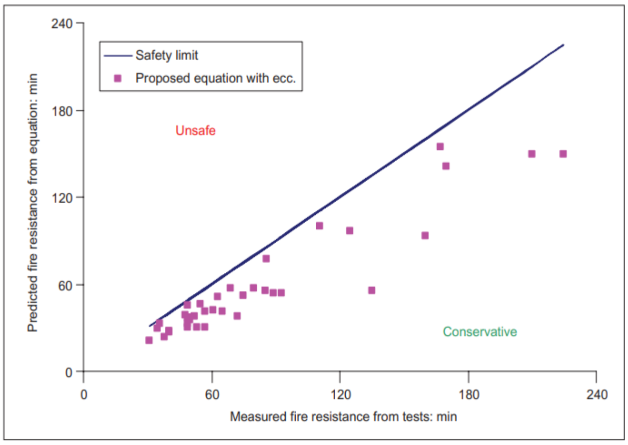

Fig. 3 Comparison of predicted fire resistance with the measured fire resistance for columns with eccentric load (Venkatesh Kodur and Nikhil Raut (2012))

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