FIRE RESISTANT ANALYSIS OF T-BEAM AND L-BEAM

Feeba George, Mrs. Aneesha Balaji, Mr. Anand Raj

Department of Civil Engineering, SCMS School of Engineering and Technology, M.G University, Kerala, India

Email: feebageorge@gmail.com, Contact no: 8594097829

Abstract— Fire is one of the greatest threats to buildings. Concrete has a good behavior under fire due to the low thermal conductivity and non-combustibility. Concrete can act as a protective cover to steel reinforcement and thus reinforced cement concrete shows good behavior under fire. A finite element method in ANSYS software, for investigating the behavior of T- beam and L- beam under fire is carried out. Thermal analysis is done for beam models. The number of sides exposed to fire, influences the extend of fire resistance of the structural member. As a result the time taken for failure varies rapidly which can be found out using thermal analysis. Temperature is assigned on different sides of the beams as per ISO 834 Standard fire curve. The element type used for concrete in thermal analysis is Solid 70. Link 33 is element type used for steel. The cover provided to steel holds a very important role in the fire resistance of flexural members.

Keywords— T- Beam, L-Beam, Failure criteria, Thermal analysis, ANSYS, Finite element analysis, ISO 834 fire curve

INTRODUCTION

Sustainability of structures is a major concern in the construction industry. Exposure to high temperature is an extreme condition that leads to change in materials properties which can result in change in entire behavior of structural element. Concrete under high temperature has a complex behavior due to differences found in coefficient of thermal expansion. Mechanical properties of high strength concrete at high temperature are different from the conventional concrete in two main areas: first, loss of strength in the intermediate temperature range 100°C to 400°C and second the occurrence of spalling of the HSC. Strength loss is considered by in-corpora ting the code and design specifications during the design stage.

Spalling of concrete happens during the initial stages of the fire due to the formation of water pressure in the matrix of concrete or the effect of various thermal expansions in matrix. Fire resistance of concrete is affected by presence of free moisture or exposure to different levels of humidity (RH). Presence of free moisture depends on the nature of coarse aggregate and exposure to humidity. During fire, rate of transmission of the high temperature to the core of concrete is high which leads to rapid loss of concrete surface layers (spalling). Fire resistance is a characteristic property of a building assembly referring to the ability to withstand the effects of fire. Restricting fire spread is includes limiting heat transmission to the unexposed side and preventing crack development, which can permit the passage of flame. Engineering analysis of response of fire-exposed structural assemblies involves consideration of:

1. Fire exposure conditions
2. Material properties at high temperatures
3. Thermal response of structure
4. Structural response of heated assembly

LITERATURE SURVEY

Bruce Eillingwood et al.(1991)[2] presented a study on the behavior of reinforced concrete beams exposed to fires. Data are presented from fire tests of six full- scale beams continuous over one support. All six beams developed significant shear cracks near continuous support. Mathematical models for predicting thermal and structural response of concrete beams exposed to fires were developed. These models predicted the experimental behavior with accuracy for purposes of limit state design. All beams tested developed shear cracks at 90 minutes after the start of fire. Flexural cracks were found in the positive moment region after 30 minutes, and extended rapidly. The behavior of reinforced concrete structures exposed to fires depends upon the thermal properties of steel and concrete, strength and stiffness properties of concrete and steel at high temperatures and the ability of the structure to redistribute the internal forces during the course of fire.

Dietmar Hosser et al. (1994)[5] carried out a study on simply supported composite beams connected to reinforced concrete slabs. A theoretical study for finding the effective slab width of composite concrete beams exposed to fire has been prepared using a finite element analysis. The effect of top transverse reinforcement in the concrete slab on fire resistance and crack propagation are investigated. By doing the finite element analysis, the internal temperature field for any cross section can be established. Four composite beams connected to concrete slabs are tested. For theoretical model, ANSYS software was used. The study was done to extend the experimental work on fire resistance of composite beams into a theoretical study using finite element method.
Xudong Shi et al. (2004)[15] studied six specimens with different concrete cover thickness tested to study the influence of the concrete cover on the properties of concrete members exposed to fire. The specimens were heated on the two lateral sides and bottom surfaces. From the test results, it is shown that the bottom concrete cover has significant influence on the ultimate loading capacity. The lateral concrete cover has a less effect on the fire resistance compared to bottom concrete cover thickness. All specimens are 1300mm long. 10mm diameter bars were used for longitudinal bars and 3.5 mm diameter bars were used for stirrups. The stirrups were spaced at 80 mm c/c. The specimens were tested after 60 days. By increasing the bottom cover thickness, the fire resistance of flexural members can be improved. For flexural members with larger spans and loads, it is not possible to strengthen their fire resistance only by increasing the concrete cover thickness.
L. Dahmani et al. (2008)[6] illustrated the aspects connected with the numerical evaluation of thermal stress induced by high temperature. In order to study the thermal induced tensile stresses, a numerical model for the evaluation of thermo-mechanical response of concrete beam to high temperature is presented. A heat conduction model by finite element method to obtain temperature distribution data of a reinforced concrete beam at high temperatures is carried out. A transient thermal analysis is carried out. A temperature of 600^0C was applied at the bottom of the concrete beam, and 25^0C was applied at the upper surface. The concrete initial temperature is set to 20^0C. The study deals with aspects connected to the numerical modeling of thermal induced stresses in the reinforced concrete beam. The ANSYS finite element code has been utilized for performing a non- linear, transient, thermal-structural analysis, by considering the thermal dependent properties of concrete as thermal conductivity and specific heat. The results provide sufficient data for the further studies that will be carried out to study the degree of damage and the safety aspects connected with thermal induced stresses in the reinforced concrete beam to high gradient temperature.
R. Srinivasan et al. (2010)[10] presented a finite element analysis of a beam of size 100×150mm with 3 bars of 12mm diameter and stirrups of 2 legged 6mm diameter at 100mm c/c. There are three techniques to model reinforcement in finite element models: discrete model, embedded model, and smeared model. The most preferred one among these is discrete model. Finite element analysis represents a numerical method. The numerical analysis was performed with ANSYS. The element types used in ANSYS for concrete are solid 65 and for reinforcements is link 8. The aim of this study is to compare the results from elastic analysis of a reinforced beam under transverse loading to that obtained from theoretical analysis. Validation of ANSYS software is also carried out by comparing the results.
David N Bilow et al. (2008**)** presented a summary of the behavior of structures under fire and techniques which have been used successfully to design concrete structures to reduce the effects of severe fires. A new method for determining fire exposure used by engineers is to calculate the fire load density. Then, based on ventilation conditions and source of combustion, determine the temperature at different times. Another thing considered in the analysis is the usage of active fire protection systems e.g. sprinklers or fire brigades on growth of the fire. Once the temperature time relationship is determined using a standard curve, the effect of the rise in temperature on the structure can be easily found out. The rise in temperature results in the free water in concrete to change from a liquid state to gaseous state. This change causes variations in the rate with which heat is transmitted from the surface into the interior of the concrete.
S.M. Huang et al. (2008)[12] studied the fire resistance of concrete members with SMPM (high-strength steel wire mesh and polymer mortar) which is a new technique of structural strengthening. Experiments were carried out to investigate the flexural behavior of 3 RC beams:1) beam which is not on fire, 2) fire- exposed, 3) strengthened specimen after fire. The experimental results showed that the flexural load-carrying capacity and stiffness of the fire-exposed RC beam were decreased. The temperature distribution of the beam is calculated by thermal analysis with ANSYS. The flexural load-carrying capacity and stiffness of the strengthened beam were also increased. The effect of this rehabilitation can reach the level of RC beams before fire on load-carrying capacity. Three RC specimens were produced. The design strength of concrete is M_{20}. Compared to the fire-exposed beam without reinforcement, working condition improvement of the strengthened fire-exposed beam was quite visible.

THERMAL ANALYSIS OF L-BEAM

When there is a reinforced concrete slab over a reinforced concrete beam, the slab and beam can be designed and constructed in such a way that they act together. The concrete in slabs, which is on the compression side of the beam, can be made to resist the compression forces, and tension can be carried by the steel in the tension side of the beam. This combined beam and slab units are called flanged beams. They may be T or L Beams, depending on whether the slab is on both is on both or only on one side of the beam.

The element type used for thermal analysis of L-Beam is SOLID 70 AND LINK 33 elements. The important dimensions required for modeling L beam are obtained from IS 456:2000.

$$\text{Effective width, } b_f = \frac{l_0}{12} + b_w + 3D_f = \frac{5}{12} + 0.2 + (3\times 0.1) = 1m \quad (1)$$

b_w = 200mm, D_f =100mm, l_0 = 5m

b_f = effective width of flange, l_o = span

b_w = Breadth of the web, D_f = Thickness of flange

Table:1 Details of L- beam

L Beam	Properties
Span, l_o	5m
Reinforcement	20mm diameter bars
Width of flange(b_f)	1m
Thickness of flange(D_f)	0.1m
Breadth of web (b_w)	0.2m
Concrete cover	20mm
Thickness	350mm

The modeling of L beam is carried out by generating the key points in active coordinate system. The cross section of the beam is created by joining the line elements with the obtained key points. To obtain the volume, extrude the area created by the previous line elements. Then the model is meshed as per requirements.

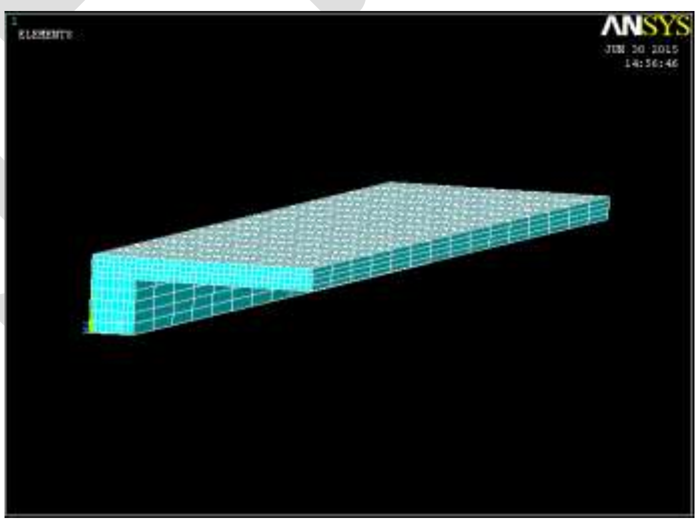

Figure:1 Meshed model of L beam

Load is assigned as per ISO 834 Standard fire curve and exposed to fire for 4 hours with different types of exposures:

- 2 sides exposed from inner bottom sides
- 3 sides exposed

- 4 sides exposed

FAILURE CRITERIA

The model generates nodal temperature at various fire exposure times. This parameter is used to check the predefined failure criteria. At every time step, each segment of the structural member is checked against the thermal failure criteria as per the codes. The temperature in the longitudinal bar can exceed the critical temperature of 593^{0}C for reinforcing steel. So, the time of failure is considered as the critical temperature of steel.

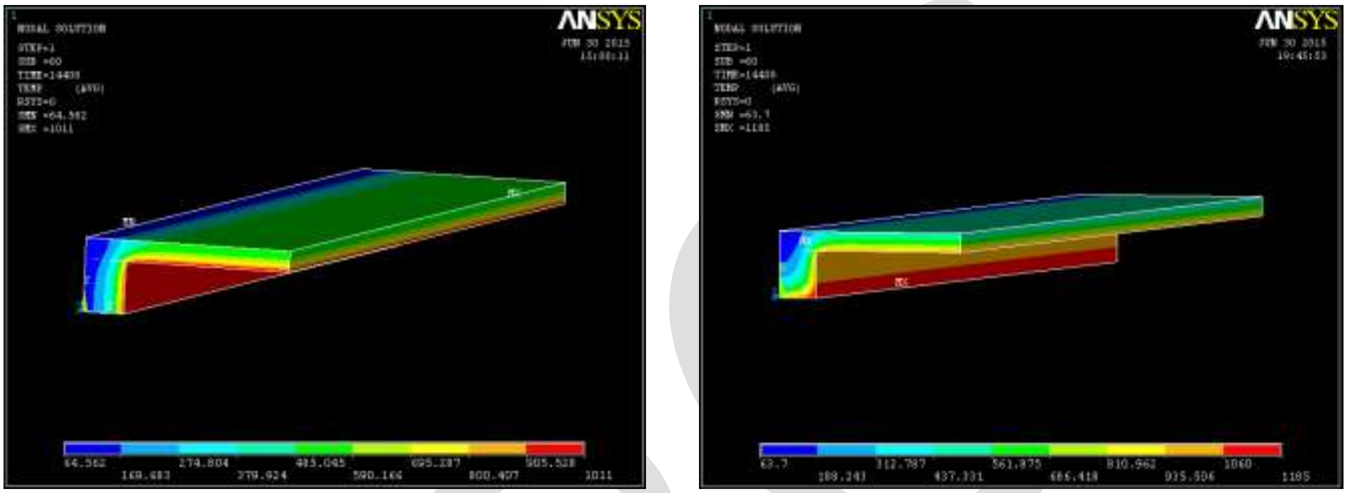

Figure: 2 Nodal temperature of L beam when exposed from (i) 2 bottom inner sides (ii) 3 bottom inner sides

The maximum temperature of 1011 ^{0}C is found at the bottom phase of the beam when exposed from the bottom two sides of the beam and a temperature of 1183 ^{0}C is obtained as nodal temperature when 3 bottom sides are exposed to high temperature.

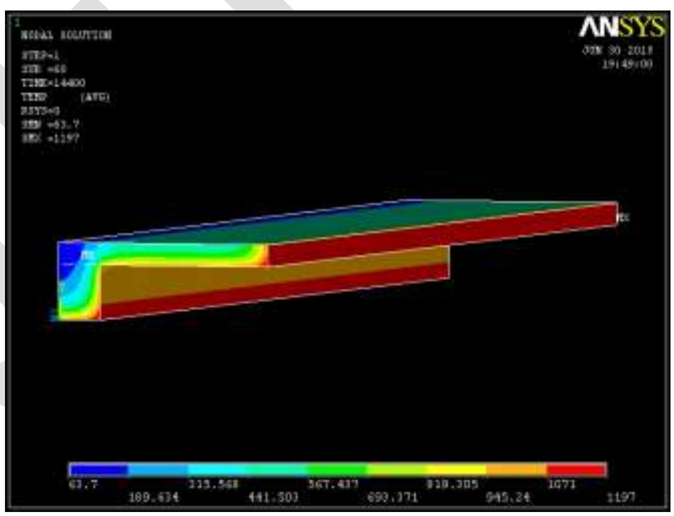

Figure:3 Nodal temperature when 4 inner bottom sides are exposed to fire

The critical temperature of reinforcement is 593^{0}C, beyond which failure of reinforcement begins. The L beam is subjected to fire for 4 hours. The time at which the temperature of the reinforcement reaches 593^{0}C is found out through thermal analysis. When two inner sides of the beam are exposed to fire for 4 hours, the failure of reinforcement takes place at 149 minutes (2.48 hours). When three inner sides of the beam are exposed to fire for 4 hours, the failure of reinforcement takes place at 83.5 minutes (1.39 hours). When two inner sides of the beam are exposed to fire for 4 hours, the failure of reinforcement takes place at 54 minutes.

Table 2: Time taken for failure

Type of beam	**Failure criteria of reinforcement**	**Type of fire exposure(4 hours)**	**Time of failure (Minutes)**
L beam	593^0C	2 sides exposed	149.33
		3 sides exposed	83.5
		4 sides exposed	54

THERMAL ANALYSIS OF T-BEAM

The element type used for thermal analysis of T-Beam is SOLID 70 AND LINK 33 elements. The important dimensions required for modeling T beam are obtained from IS 456:2000.

$$\text{Effective width, } b_f = \frac{l_0}{6} + b_w + 6D_f \qquad (2)$$

$$= \frac{5}{6} + 0.2 + (6 \times 0.1) = 2\text{m}$$

b_w = 200mm, D_f =100mm, l_0 = 5m

Where, b_f = effective width of flange

l_o = span

b_w = Breadth of the web

D_f = Thickness of flange

Table: 3 Details of T beam

T Beam	**Properties**
Span, l_o	5m
Reinforcement	20mm dia bars
Width of flange(b_f)	1.7m
Thickness of flange(D_f)	0.1m
Breadth of web (b_w)	0.2m
Thickness	350mm

The modeling of L beam is carried out by creating the key points in active coordinate system. The cross section of the beam is created by joining the line elements with the obtained key points. To obtain the volume, extrude the area created by the previous line elements. Then the model is meshed as per requirements.

FAILURE CRITERIA

The model generates temperature at various fire exposure times. This parameter is used to check the failure criteria. At every time step, each segment of the structural member is checked against the failure criteria of thermal analysis as per the codal provisions. The temperature in the longitudinal steel bar can exceed the critical temperature of 593^{0}C for reinforcing steel. So, the time of failure is considered as the critical temperature of steel.

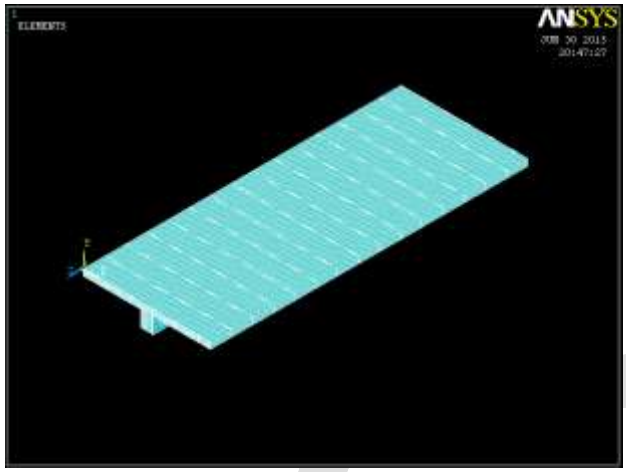

Figure: 4 Meshed model of the beam

Load is assigned as per ISO 834 Standard fire curve and exposed to fire for 4 hours with different types of exposures:

- All sides exposed from inner bottom side.
- 4 sides exposed
- 3 sides exposed

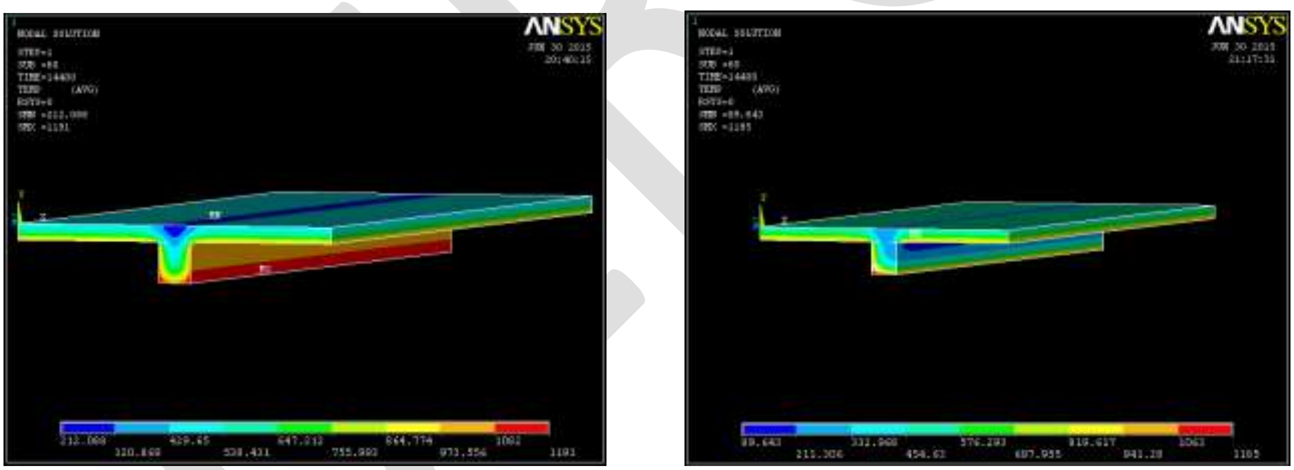

Figure: 5 Nodal temperature of T beam when exposed from (i) all bottom sides (ii) bottom 4 sides

The critical temperature of reinforcement is 593^{0}C, beyond which failure of reinforcement begins. The T beam is subjected to fire for 4 hours. The time at which the temperature of the reinforcement reaches 593^{0}C is found out through thermal analysis. When all inner sides of the beam are exposed to fire for 4 hours, the failure of reinforcement takes place at 77.25 minutes (1.28 hours). When four inner sides of the beam are exposed to fire for 4 hours, the failure of reinforcement takes place at 83.26 minutes (1.387 hours). When three inner sides of the beam are exposed to fire for 4 hours, the failure of reinforcement takes place at 134.33 minutes (2.23 hours).

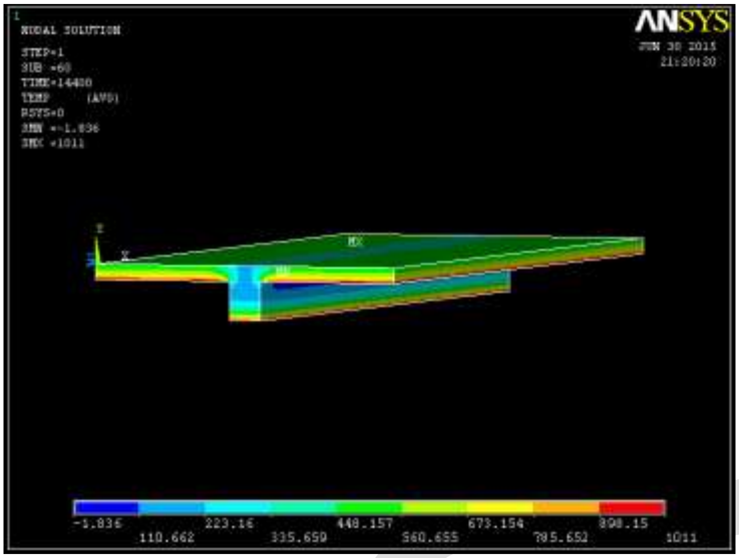

Figure: 6 Nodal temperature of T beam when exposed from bottom 3 sides

Table: 4 Time taken for failure

Type of beam	**Failure criteria of reinforcement**	**Type of fire exposure(4 hours)**	**Time of failure (min)**
T beam	593 ^{0}C	5 sides exposed	77.25
		4 sides exposed	83.26
		3 sides exposed	134.33

CONCLUSIONS

General Conclusions obtained from fire resistant analysis of T-beam and L-Beam includes:
The type of exposure and the number of sides exposed to fire is having a great effect in the fire resistance of both beams and slabs. Cross section of beams like T beam and L beam are having a good fire resisting capacity. For T beam and L beam, the failure of reinforcement takes place at an earlier stage of fire exposure i.e., the time taken for failure decreases when it is exposed to fire from more number of sides. When more number of sides exposed to fire, failure takes place at a faster rate. So, the time taken for failure decreases when the beam is exposed to fire from more number of its sides. The time taken for failure for different types of exposure conditions is accurately obtained and is compared. A thermal failure criterion is more critical compared to deflection criteria and rate of deflection criteria during the fire exposure.

ACKNOWLEDGEMENTS

First of all, I am thankful to God Almighty, for showering His blessings upon me for making me capable of doing this work on time. I express my sincere gratitude to Mrs. Aneesha Balaji, Assistant Engineer, KSEB for her valuable guidance and support in completing this work. I am grateful to Mr. Anand Raj, Assistant Professor, Department of Civil Engineering, SCMS School of Engineering and Technology, for his valuable suggestions and guidance.

REFERENCES:

[1] Ahmed M. Hassan, "Behavior of Continuous Flat Slab Exposed to Fire", *World Applied Sciences Journal, pg:*788-794, 2013

[2] Bruce Ellingwood, T.D Lin "Flexural And Shear Behavior of concrete beams during fire", *Journal of Structural Engineering*, pg:440-458, 1991

[3] C Sangluaia, M K Haridharan, C Natarajan, A. Rajaraman "Behavior of Reinforced Concrete Slab Subjected To Fire", *International Journal Of Computational Engineering Research,* Vol. 3, pg*:* 195-203, 2010.

[4] C E Zhou, "Non linear finite element analysis of reinforced concrete structures subjected to transient thermal loads" Computers and concrete, Vol.2, pg:455-479, 2005

[5] Dietmar Hosser, Thomas Dorn, Osama EI-Nesr "Experimental and numerical analysis Composite Beams exposed to fire", *Journal of Structural Engineering,* pg:2871-2892, 1994

[6] Dahmani. L, "Thermal cracking response of reinforced concrete beam to gradient temperature", 2008.

[7] Faris Ali, Ali Nadjai, "Experimental and numerical study on performance of concrete slabs subjected to severe fire", *Fire safety science,* pg:1255-1266, 2008

[8] Howard R.Baum, "Simulating fire effects on complex building structures", *Fire safety sciences,*pg:3-18, 2005

[9] James A. Milke," Analytical methods of to evaluate fire resistance of structural members", *Journal of Structural Engineering*, pg:1170-1181,1999

[10] R. Srinivasan, K. Santhiya "Flexural behavior of reinforced concrete beams using finite element analysis", 2010.

[11] Rene D Borst, "Analysis of concrete structures under thermal loading", *Elsivier science publishers*, pg: 293-310, 1989.

[12] S.M. Huang, Q.L. Yao , B. Song, "Study on flexural behavior of fire exposed RC Beams strengthened with SMPM", 2008

[13] Sherif Yehia ,**"**Performance of Structures Exposed to Extreme High Temperature- An Overview", *Open Journal of Civil Engineering*, pg:154-161, 2013

[14] Shubhangi Chafale, K.R.C. Reddy,"Analysis of deep beam-A parametric study using Finite Element Method", *IOSR Journal of Mechanical and Civil Engineering, pg: 34-39, 2014*

[15] Xudong Shi, "Influence of Concrete Cover on Fire Resistance of Reinforced Concrete Flexural Members", *Journal of Structural Engineering,* pg:1225-1232, 2004

[16] BS 476-20: 1987 , *Fire tests on building materials and structures*

[17] *Eurocode 2: Design of concrete structures - Part 1-2: General rules - Structural fire design*, 1992

[18] IS: 1641-1988 Indian Standard- "*Code of practice for fire safety of building,* Bureau of Indian Standards, New Delhi,1988 .

[19] IS:1642- 1989 Indian Standard- "*Fire safety of buildings : Details of construction, code of practice*" Bureau of Indian Standards, New Delhi,1990

[20] IS:3809- 1999 Indian standard – *"Fire resistance test of structures*" Bureau of Indian Standards, New Delhi,1979