Behaviour of Reinforced Concrete Slab Subjected To Fire

Mr. C Sangluaia [1], Mr. M K Haridharan[2], Dr. C Natarajan[3], Dr. A. Rajaraman[4]

[1] M Tech Scholar, National Institute of Technology, Thiruchirappalli, India ,
[2]PhD Scholar, National Institute of Technology, Thiruchirappalli, India,
[3]Professor, National Institute of Technology, Thiruchirappalli, India
[4]Former Visiting Professor, Indian Institute of Technology, Madras, India

Abstract

The behavior of reinforced concrete slab exposed to fire is presented. Two stages of analysis is carried out using Finite Element package ABAQUS to find thermal response of structural members namely thermal analysis and structural analysis. In the first step, the distribution of the temperature over the depth during fire is determined. In the next step, the mechanical analysis is made in which these distributions are used as the temperature loads. The responses of structure depend on the type of concrete and the interactions of structural members. The RCC slab were modeled to show the role of slab thickness, percentage of reinforcement, width of slab and different boundary condition when expose to fire loading. Effects for both materials in RCC slab at elevated temperatures are also evaluated.

Keywords: ABAQUS, Concrete, Fire, Floor slabs, Modeling, Structural response, Thermal response.

1. Introduction

Fire is considered one of the most serious potential risks for buildings and structures. But concrete is generally considered to have an acceptable resistance to fire in comparison with other construction materials such as wood or steel. When concrete remains exposed for long time to high temperatures, mechanical losses of its properties take place. Laboratory experiences show that in case of concrete not protected the mechanical properties decrease drastically for temperatures above 300ºC. They are attributed to the microstructure transformations occurring in cement paste and aggregates, and the volume changes induced by thermal stresses. After fire the assessment of deterioration of the structure is needed in order to identify the level of damage induced by the chemical transformation and the cracking, both contributing to losses in mechanical strength.The behaviour of structures exposed to fire is usually described in terms of the concept of fire resistance, which is the period of time under exposure to a standard fire time-temperature curve at which some prescribed form of limiting behaviour occurs. In real buildings structural elements form part of a continuous assembly, and building fires often remain localized, with the fire-affected region of the structure receiving significant restraint from cooler areas surrounding it. The real behaviour of these structural elements can therefore be very different from that indicated by standard furnace tests.

When concrete is under fire, it usually causes a build-up of pressure within the concrete after exceeding 100^0C.When the temperature reaches about 400 °C, the calcium hydroxide in the cement will begin to dehydrate, generating more water vapour and also bringing about a significant reduction in the physical strength of the material [1]. The material behavior during heating is nonlinear itself according to its deterioration with temperature [2]. Most real fires heat the floor and beams from below, leading to a regime in which temperature differentials develop between the upper and lower surfaces. These differentials lead to thermally induced bending or thermal bowing, which can increase deflections. High temperatures will result in loss of strength (both yield and ultimate strengths) and stiffness (moduli of elasticity) [3]. Whilst material degradation is the key phenomenon in determinate structures under fire, for highly redundant structures the single most important factor is the effect of thermal expansion [3].

2. Mechanical Behaviour of The Constituent Materials

2.1 General

Constitutive laws are used to define the stress–strain characteristics of a material. The accuracy of the analysis is dependent on the constitutive laws used to define the mechanical behaviour. In materials such as concrete, structural steel and reinforcing steel, profiled steel sheeting and shear connectors, the constitutive laws are represented by the stress–strain relationships of the materials. In this paper, the mechanical behaviour at ambient and elevated temperatures is considered. When elevated temperature is involved, the main properties required to carry out an accurate calculation of the temperature distribution in a composite cross-section are the specific heat, thermal expansion and thermal conductivity.

2.2 Thermal properties of concrete: An important design consideration for concrete includes the effects of fire. The behaviour of concrete slabs subjected to fire conditions is complex. In a fully developed fire, to prevent fire spread to the upper floors, the slab has to carry and withstand the applied loads and prevent collapse during and after the fire. The effect of fire, which is not generally considered in typical structural design practice, involves the thermal conductivity, specific heat and high thermal expansion of the concrete. This will cause the surrounding structure to respond against these effects and generate compressive forces in the heated concrete slab.

2.2.1 Thermal conductivity. Thermal conductivity is the capability of a material to conduct heat, and is defined as the ratio of heat flux to the temperature gradient. It represents the uniform flow of heat through concrete of unit thickness over a unit area subjected to a unit temperature difference between the two opposite faces [6]. The thermal conductivity of siliceous aggregate concrete as represented in Eurocode 2, British Standards Institution in section 3.3.3 is shown in Fig 1.

2.2.2 Specific heat. The specific heat of a material is the amount of heat per unit mass which is required to change the temperature of the material by a degree. The specific heat of concrete with siliceous aggregates as a function of temperature according to Eurocode2, British Standards Institution in section 3.3.2 is shown in Fig. 2.

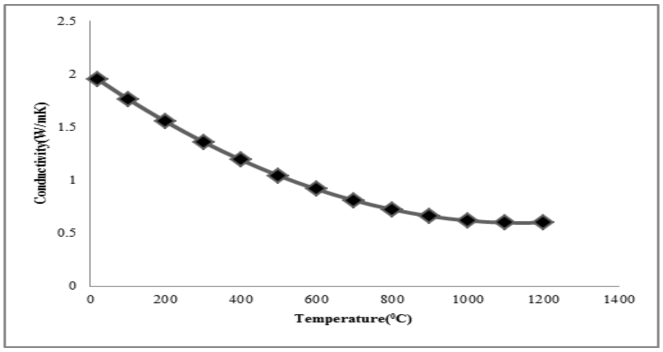

Fig. 1 Thermal conductivity of concrete, EC2 [4]

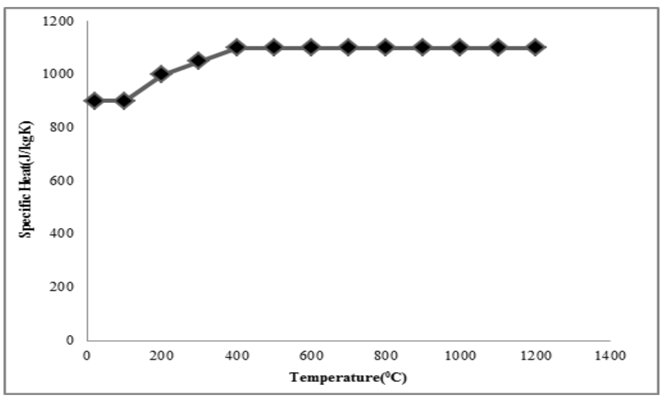

Fig. 2 Specific heat of concrete, EC2 [4]

2.2.3 Thermal expansion. Due to its isotropic nature, concrete exhibits thermal expansion when it is subjected to a temperature change. Cracking occurs when stresses develop in concrete structures due to non-uniform thermal expansion. The thermal expansion of concrete with siliceous aggregates expressed as a function of temperature according to Eurocode 2, British Standards Institution in section 3.3.1 is shown in Fig. 3

2.2.4 Stress–strain relationship of concrete at elevated temperatures. The most substantial consequence of fire on a concrete slab is the stiffness and strength degradation which may lead to eventually collapse. It is important to study the concrete property changes according to temperature. The stress–strain relationship of concrete with siliceous aggregates expressed as a function of temperature according to Eurocode 2, British Standards Institution and the distributions given in Figs. 5 and 6 represent the compressive and tensile stress–strain behaviour of the concrete, respectively. Fig. 4 illustrates that the compressive strength of the concrete decreases when temperature increases but the ultimate strain of the concrete increases with temperature. The tensile strength of the concrete also decreases with an increase in temperature, as depicted in Fig. 5. A tensile stress can also be obtained for temperatures up to 500^0C. The modulus of elasticity of the concrete in Fig. 6 decreases with an increment in temperature. The reduction of the modulus of elasticity is due to the rupture of bonds in the microstructure of the cement paste when the temperature increases and is the result of the onset of rapid short-term creep.

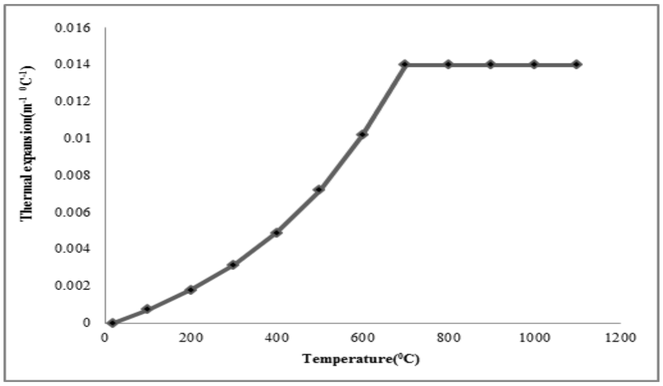

Fig. 3 Concrete thermal expansion, EC2 [4]

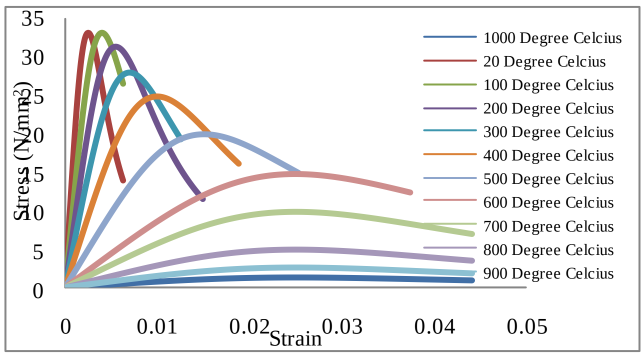

Fig. 4 Compressive stress–strain relationship at elevated temperature for concrete, EC2

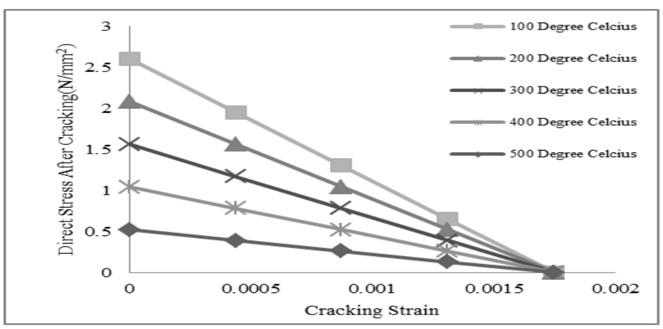

Fig. 5 Tensile stress–strain relationship at elevated temperature for concrete, EC2

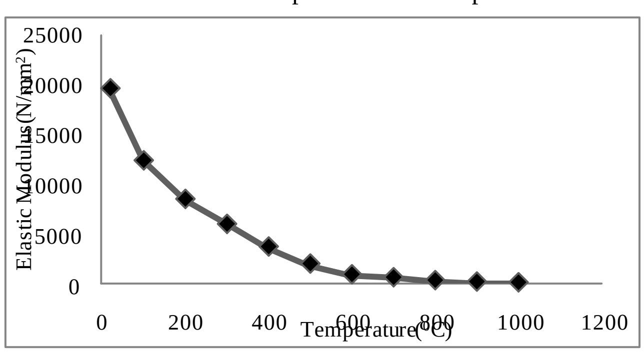

Fig. 6 Modulus of elasticity of structural concrete at elevated temperatures, EC2.

2.3 Thermal properties of steel

The stress–strain characteristics of reinforcing steel are essentially similar to structural steel. Their behaviour is initially elastic after which yielding and strain hardening develops. A piecewise linear approach was found to be sufficiently accurate to represent the stress–strain relationship. Moreover, these curves are utilized in the model when the stress–strain data is not available. The stress–strain relationship for structural steel is represented as a simple elastic–plastic model with strain hardening. The mechanical behaviour for both compression and tension is assumed to be similar. Fig. 10 represents the stress–strain relationship for steel. The effects of thermal conductivity, specific heat and high thermal expansion of the reinforcing steel are considered when the temperature changes.

2.3.1 Thermal conductivity. The thermal conductivity of steel depends mainly on the amount of alloying elements and on the heat treatment. The thermal conductivity of steel according to Eurocode 3, British Standards Institution in section 3.4.1 .3 is presented in Fig. 7

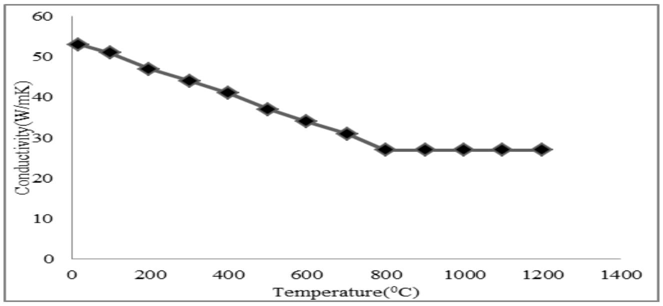

Fig. 7 Thermal conductivity for structural steel, EC3.

2.3.2 Specific heat. The specific heat of the steel is expressed in Eurocode 3, British Standards Institution in section 3.4.1.2 and is shown in Fig. 8

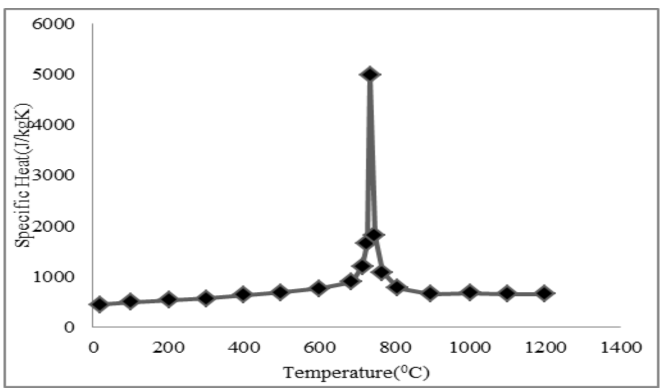

Fig. 8 Specific heat of structural steel, EC3.

2.3.3 Thermal expansion. The thermal expansion of steels depends mainly on the heat treatment used. The coefficient of thermal expansion of steel at room temperatures is expected to be 11:4x10^{-6} m^{-1} C^{-1}. Furthermore, the thermal elongation of structural and reinforcing steel according to Eurocode 3, British Standards Institution is evaluated in section 3.4.1.1 and is illustrated in Fig. 9

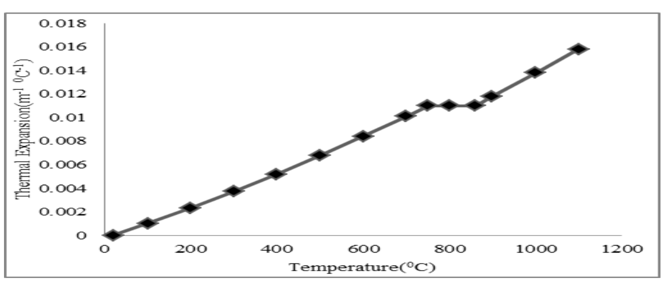

Fig. 9 Specific heat of structural steel, EC3.

2.3.4 Stress–strain relationship of reinforcing steel at elevated temperatures. Most normal constructional steels have well-defined yield strengths at normal temperatures. Upon further temperature increase, the ultimate strength of the steel declines steadily. The stress–strain relationships may be applied to steel in both tension and compression. The effects of high temperature on creep have also been taken into account. The stress–strain relationships of structural steel as a function of temperature according to Eurocode 3, British Standards Institution are shown in Fig. 10.The ultimate strength of the structural steel decreases when the temperature increases, as illustrated. Furthermore, the modulus of elasticity decreases with an increase in temperature. The relationship of the modulus of elasticity of the structural steel according to temperatures is illustrated in Fig. 11.

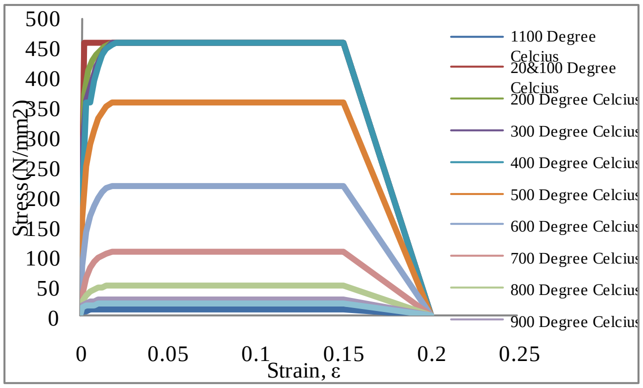

Fig. 10 Stress–strain relationship at elevated temperature for structural steel, EC3.

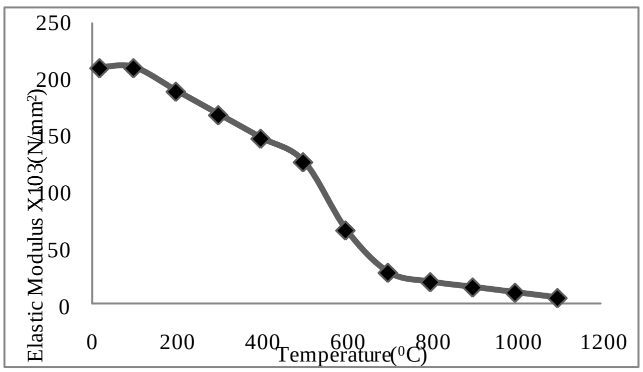

Fig. 11 Modulus of elasticity of structural steel at elevated temperatures, EC3.

3. Finite Element Analysis at Elevated Temperatures

Finite element package ABAQUS was used to model and analyze the RCC slabs. Dynamic temperature displacement explicit analysis was performed to input the temperature distribution obtained from thermal analysis to the structure analysis so as to obtain the required stress, strain and displacement.

3.1 Experimental Tests

Experimental results were taken from the test conducted by BRE (Building Research Establishment) slab test on RCC in Cardington, Bedford. The tests were made in the fire resistance floor furnace at the Warrington Fire Research Centre [6] heated under ISO-834 curve shown in Fig 1. The slab is design to resist up to 90 minutes. The ends of each slab were simply supported

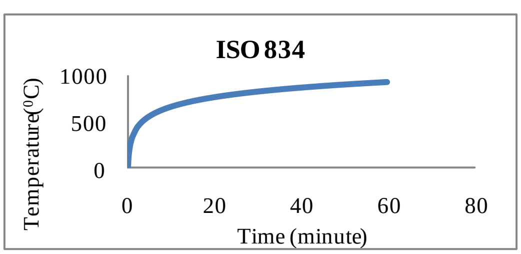

Fig. 12 ISO-834 Fire standard curve (BS 456 part 20) [6]

3.2 Finite Element Type and Mesh

Three-dimensional solid element and surface element were used to model the test specimen in order to achieve an accurate result from the finite element analysis. For concrete, C3D8RT- An 8-node thermally coupled brick, tri-linear displacement and temperature was used and for steel, SFM3D4R- A 4-node quadrilateral surface element, reduced integration was used.

3.3 Model Validation

For validating the existing experimental test result by using ABAQUS, the modeling of slab is shown Fig. 12. RCC slab are heated from below by ISO-834 fire. In ABAQUS, the RCC slab model is heated up to 90 minutes as the slab is design to resist up to 90 minutes .Two stage analysis is carried out that is thermal and structural analysis. The analysis results are compared with experimental results.

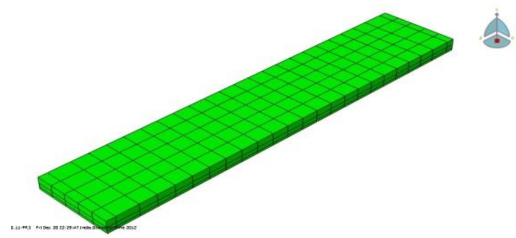

Fig 13 Slab Modeling of RCC by ABAQUS

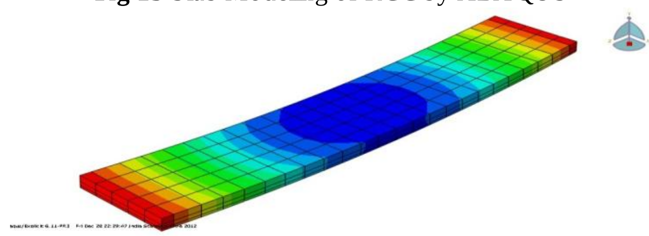

Fig 14 RCC slab model showing displacement contour by ABAQUS after temperature loading.

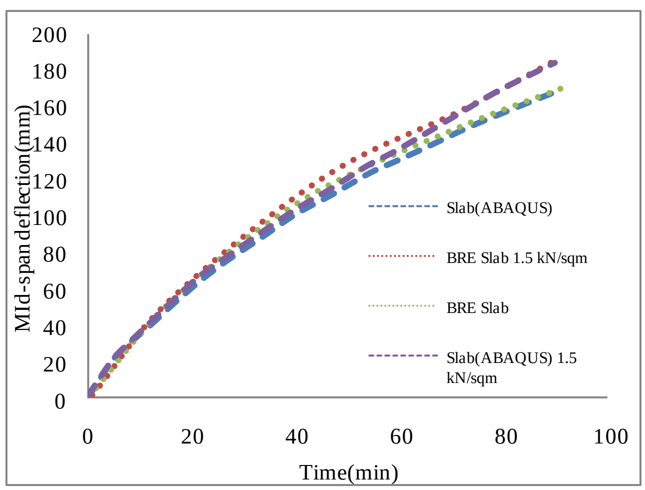

Fig. 15 Comparison of 150mm BRE slab with ABAQUS model, Mid-span deflection with Time

4. Result and Discussion

4.1 General

RCC models are taken to study the thermal response of building subjected to fire. Non-linear analysis is carried out with full temperature on different boundary condition. Similarly non-linear analysis is carried out on different bars and different thickness. It is modeled in three dimensional for temperature-time curve ISO-834. ABAQUS/CAE 6.11 has been used for the analysis of thermal and structural behaviour of concrete structures for different temperature. Thermal analysis is done based on steady state condition in three dimensional members.

4.2 Temperature Analysis

Table 1 Specification of slab for studying temperature distribution

Span	4.5 m
Width × Depth	925 mm × 150 mm
Temperature	ISO-834 Curve
Concrete grade	M30

The temperature analysis is performed independently of the structural analysis. To perform the temperature analysis, the geometry of the cross-section is similar to the structural analysis specimen. Conversely, its material properties are defined in chapter 3 for concrete and structural steel, respectively. The materials in the section can vary from element to element, and their properties are temperature dependent. The mechanical behaviour is much more complicated when the temperature changes because there are two materials involved, which are mainly concrete and steel. The test specimen model is similar to the structural analysis model in order to compare the results. Fire is usually represented by a temperature–time curve ISO-834 fire (BS 456 part 20) [8] in Fig 12. This gives the average temperature reached during a fire in a small sized compartment or in the furnaces used for fire resistance tests

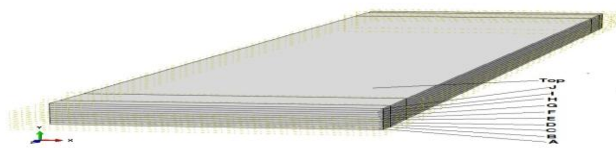

Fig. 16 Different layers of the slab

The resulting temperature distributions have been adopted here for the application of the finite element ABAQUS analysis. Fig. 16 show that the concrete & reinforcing steel are divided into layers which is necessary to differentiate the temperature distributions according to time. Fig 17 provides the temperature distribution of the layers with respect to time

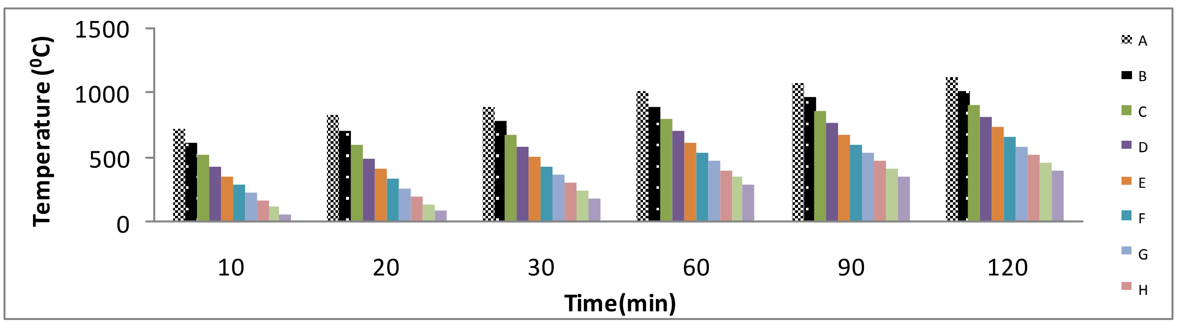

Fig. 17 Temperature changes according to time

4.3 Analysis

ABAQUS/CAE 6.11 has been used for the analysis of thermal and structural behaviour of concrete structures for different temperature. Thermal analysis is done based on steady state condition in three dimensional members. Temperature distribution is found in thermal analysis and by using the thermal result in structural static analysis.

4.3.1 Role of width of slab

For studying the role of width in slab two thickness of slab are studied (i.e. 150mm and 180mm

Table 2 Specification of slabs for studying role of width of slab

Span	4.5 m
Live Load	1.5 kN/m^2
Width	9m, 4.5m, 3m & 2.25m
Slab thickness	150 mm & 180 mm
Rebar	8mm dia
Temperature	ISO-834 fire
Support condition	Simply supported on two side Free on the other two side

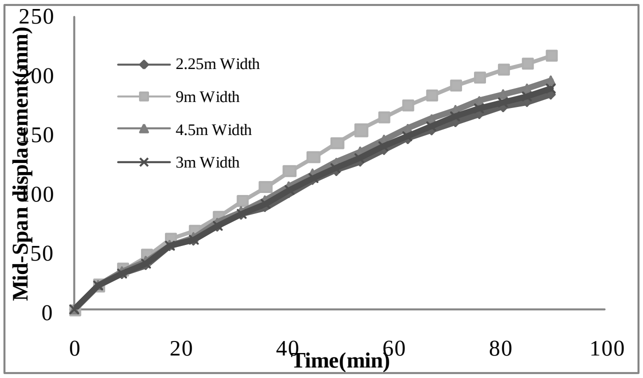

Fig. 18 Effect of 150mm thick slab, 4.5m span c/c with LL

For studying the role of width of slab, RCC slab model are analyzed by using thickness as 150mm thick slab with load of 1.5kN/m^2 with different width i.e. 9m, 4.5m, 3m, 2.25m. The mid-span deflection vs. time are given in Fig. 18 in which after 90minutes of fire exposure, slab with 9m, 4.5m, 3m, 2.25m thickness have mid-span deflection of 217mm,196mm,188mm & 183mm. The allowable temperature is then calculated from the allowable deflection as 518^0C, 520^0C, 523^0C & 527^0Cfor 9m, 4.5m, 3m, 2.25m width slab.Another RCC slab model are analyzed by using thickness as 180mm thick slab with load of 1.5kN/m^2 with different width i.e. 9m, 4.5m, 3m, 2.25m. The mid-span deflection vs. time are given in Fig. 19 in which after 90minutes of fire exposure, slab with 9m, 4.5m, 3m, 2.25m thickness have mid-span deflection of 173mm,163mm, 158mm & 153mm. The allowable temperature is then calculated as 550^0C, 560^0C, 580^0C & 614^0C for 9m, 4.5m, 3m, 2.25m width slab

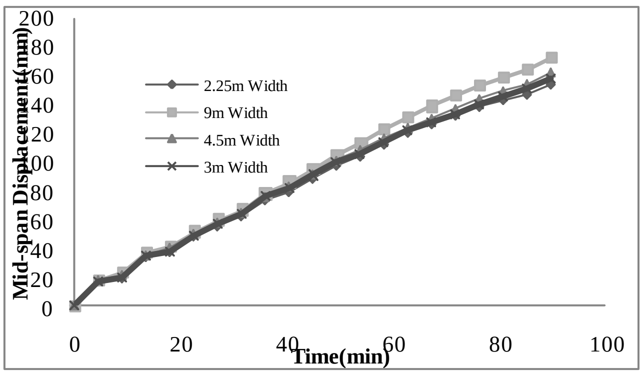

Fig. 19 Effect of 180mm thick slab, 4.5m span c/c with LL

Fig. 18 & Fig 19 shows the effect of 150mm and 180mm slabs with different width 9m, 4.5m, 3m, 2.25m for normal weight concrete slabs, when exposed to ISO 834.the deflection is highest in 9m width and followed by 4.5m & 3m and lowest in 2.25m width. This shows that the larger width of the slab deflects less, which shows that thermal bowing is inversely proportional to the width for simply supported slab.

4.3.2 Role of rebar in slab

Table 3 Specification of slabs for studying role of rebar in slab

Span	4.5 m
Live Load	1.5 kN/m^2
Width	4.5m
Slab thickness	150 mm
Rebar	6mm, 8mm, 10mm dia
Temperature	ISO-834 fire
Support condition	Simply supported on two side Free on the other two side

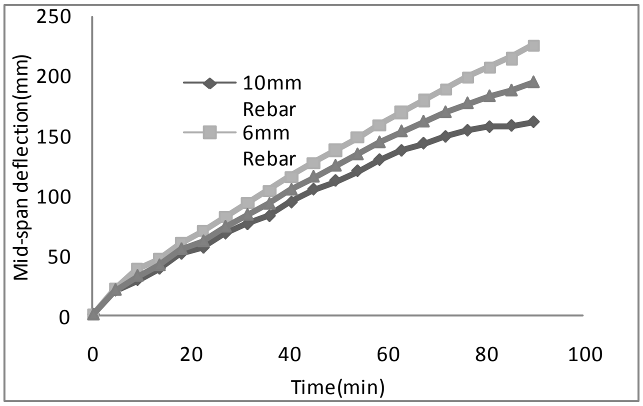

Fig. 20 Effect of 150mm thick slab, 4.5m span c/c, 4.5m width with LL

For studying the role of rebar, first 3 RCC slab model are analyzed by giving load 1.5 kN/m^2 with different rebar i.e. 6mm, 8mm & 10mm rebar. The mid-span deflection vs. time are given in Fig. 20 in which after 90minutes of fire exposure, slab with 10mm,8mm & 6mm rebar have mid-span deflection of 162mm,195mm &225mm. The allowable temperature is then calculated from the allowable deflection as 524^{0}C, 520^{0}C, 516^{0}C for 10mm, 8mm, 6mm rebar.

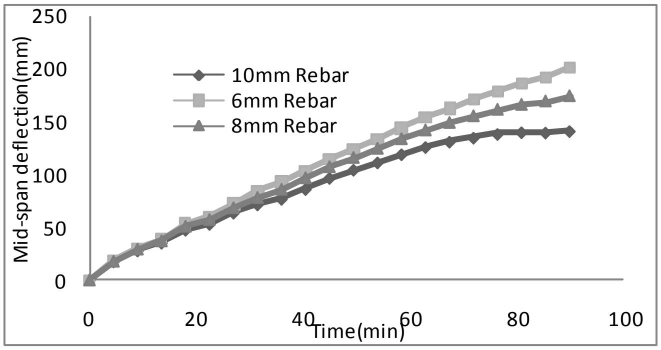

Fig. 21 Effect of 150mm thick slab, 4.5m span c/c, 4.5m width without LL

For studying the role of rebar, another 3 RCC slab model are analyzed without giving load (.i.e. with only self-weight load) with different rebar i.e. 6mm, 8mm & 10mm rebar. The mid-span deflection vs. time are given in Fig. 20 in which after 90minutes of fire exposure, slab with 10mm,8mm & 6mm rebar have mid-span deflection of 141mm,174mm &202mm. The allowable temperature is then calculated from the allowable deflection as 546.7^{0}C, 540^{0}C, 536^{0}C for 10mm, 8mm, 6mm rebar. Fig. 20 & Fig 21 shows the effect of 6mm, 8mm and 10mm rebar 150mm slabs with live load and without live load with 4.5m width for normal weight concrete slabs, when exposed to ISO 834.The deflection is highest in 6mm diameter bar and followed by 8mm & 10mm diameter bar. Therefore, Fig. 19 & Fig. 20 clearly shows that increase in percentage of steel in RCC slab decreases the deflection when subjected under fire.

4.3.3 Role of slab thickness

Table 4 Specification of slabs for studying role of slab thickness

Span	4.5 m
Live Load	1.5 kN/m^2
Width	4.5m
Slab thickness	150mm, 180mm & 250mm
Rebar	8mm dia
Temperature	ISO-834 fire
Support condition	Simply supported on two side Free on the other two side

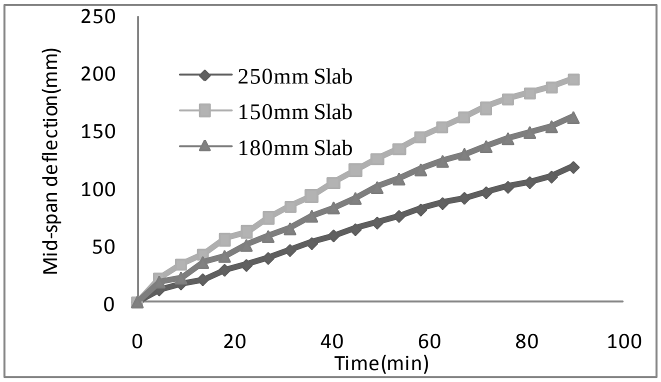

Fig. 22 Effect of slab, 4.5m span c/c, 4.5m width with rebar & LL

For studying the role of slab thickness by ABAQUS, RCC slab model are analyzed by giving load 1.5kN/m^2 with different thickness i.e. 150mm, 180mm & 250mm. The mid-span deflection vs. time are given in Fig. 22 in which after 90minutes of fire exposure, slab with 150mm, 180mm & 250mm thickness have mid-span deflection of 196mm,163mm &119mm. The allowable temperature is then calculated as 520^{0}C, 560^{0}C, 660^{0}C for 150mm, 180mm & 250mm thick slab.

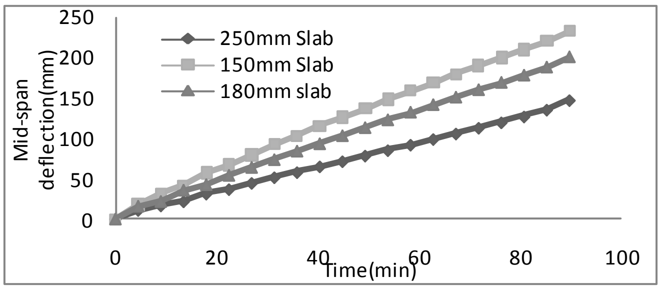

Fig. 23 Effect of slab, 4.5m span c/c, 4.5m width without rebar & LL

Here, RCC slab model are analyzed without giving load and without rebar in slab and with different thickness i.e. 150mm, 180mm & 250mm. The mid-span deflection vs. time are given in Fig. 22 in which after 90minutes of fire exposure, slab with 150mm, 180mm & 250mm thickness have mid-span deflection of 234mm,201mm &147mm. The allowable temperature is then calculated as 541^{0}C, 585^{0}C, 664^{0}C for 150mm, 180mm & 250mm thick slab without rebar.Fig. 22 & Fig. 23 show the effect of slab thickness with rebar and live load & without rebar and live load, when exposed to ISO 834. The thicker slab deflects less which is what one might expect intuitively and agrees with the theory of thermal bowing which shows that thermal bowing is inversely proportional to the slab thickness. The defection curve for the non-loaded 180mm thick slab suggests that the relative magnitudes of deflection agree with the theory of thermal bowing up to 90 min the curve for 180mm thickness lies between those for 150 and 250 mm.

4.3.4 Role of boundary condition

Table 5 Specification of slabs for studying role of boundary condition

Span	4.5 m
Live Load	1.5 kN/m^2
Width	4.5m
Slab thickness	150 mm
Rebar	8mm dia
Temperature	ISO-834 fire
Support condition	Pinned-pinned, Pinned-roller, fixed-fixed, fixed roller on two side & Free on the other two side

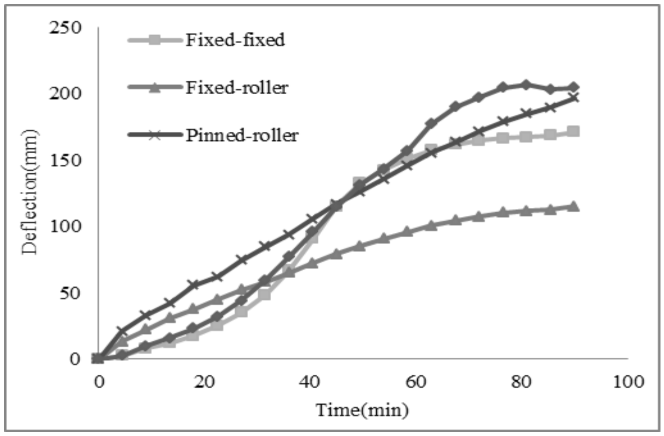

Fig. 24 Effect of slab on different boundary condition, 4.5m span c/c, 4.5m width with LL

Fig. 24 shows the effect of slab on different boundary condition with 1.5 kN/m^2 live load when exposed to ISO 834. Fixed-fixed and pinned-pinned have less deflection till 20 minutes and then suddenly increases. After exposure for 90 minutes, fixed-fixed, fixed-roller, pinned-roller, pinned-pinned have deflection of 171mm, 115mm, 196mm, 204mm. The safe temperatures are calculated from allowable deflection. Safe temperature for fixed-fixed, fixed-roller, pinned-roller, pinned-pinned are 748 ^{0}C, 604 ^{0}C, 541 ^{0}C, 717 ^{0}C.

5. Conclusions

- ❖ An accurate finite element model has been developed by using ABAQUS to study the behavior of reinforced concrete slab when subjected to fire. Based on the comparisons between the results obtained from the finite element models and available BRE slab experimental results, it was observed that they are in good agreement. The mid-span deflection with duration of heating is accurately predicted by the finite element model and a maximum discrepancy of 6% was observed when comparing the finite element model with experimental studies.
- ❖ Temperature distribution was studied for different layers of the slab along the depth of the slab when temperature changes according to time and it was found that temperature decreases along the depth of the slab
- ❖ Role of width of slab, role of rebar and role of slab thickness were also observed in this paper and it was found that
- ➢ For simply supported slab , displacement increases when width of slab increases
- ➢ Displacement decreases when percentage of steel in RCC slab increases
- ➢ Displacement decreases when thickness increases
- ❖ Role of boundary condition were also observed and it was found that fixed-fixed have the highest safe temperature and followed by pinned-pinned, fixed-roller, pinned-roller.

References

[1]. Ian A. Fletcher, Stephen Welch, José L. Torero. Behaviour of Concrete Structures in Fire. BIBLID, 112: 37-52, 2007

[2]. Khoury, G. A. . Effect of Fire on Concrete and Concrete Structures. *Progress in Structural Engineering and Materials*, 2, 4: 429-447.2000

[3]. Rotter J.M, Sanad A.M.,Usmani A.S. and Gillie .M. Structural Performance Of Redundant Structures Under Local Fires In Proceedings of Interflam. Edinburgh, Scotland, 1999.

[4]. British Standards Institution. Design of concrete structures, Part 1.1 General rules and rules for buildings. London: British Standard Institute 2004. ENV 1992-1-1.

[5]. British Standards Institution. Design of the steel structures, Part 1.1 General rules and rules for buildings. London: British Standard Institute 2002. ENV 1993-1-1.

[6]. ISO Fire Resistance Tests. Elements of Building Construction, ISO 834, International Organization for Standardization. Geneva, 1975

[7]. ASTM Standards. Standard Test Methods for Fire Tests of Building Construction and Materials, in Annual Book of ASTM Standards. Vol. 04, Designation: E 119-88, ASTM, 922–942, 1988

[8]. Bailey C.. Holistic Behaviour of Concrete Buildings in Fire. Structures & Buildings, 152 : 199-212, 2002

[9]. Dhaval Vora, Umesh Kumar Sharma , Pradeep Bhargava. Finite Element Analysis Of Composite Columns Subjected To Fire. Journal of Structural Engineering, 37: 322 – 328, 2010.

[10]. Gordon M.E. Cooke. Behaviour of precast concrete floor slabs exposed to standardized fires. Fire Safety Journal, 36: 459-475. 2001.

[11]. Kang S.W. and Hong, S.G.. Material Model and Thermal Response Analysis of Concrete at Elevated Temperatures. Journal of the Korea Concrete Institute, 13: 268–276, 2001.
[12]. Kang, Suk Won, Hong, Sung-Gul . Behavior of Concrete Members at Elevated Temperatures Considering Inelastic Deformation. Fire Technology, 39:9–22, 2003
[13]. Kuldeep Prasad, Howard R. Baum . Coupled Thermal-Elastic Response of Structures to Fires Building and Fire Research Laboratory. National Institute of Standards and Technology Gaithersburg, MD 20899, 2006.
[14]. Li L, Purkiss J. Stress-Strain Constitutive Equations of Concrete Material at Elevated Temperatures. Fire Safety Journal, 40: 669-686, 2005.
[15]. Mirza O, B. Uy . Behaviour of headed stud shear connectors for composite steel–concrete beams at elevated temperatures. Journal of Constructional Steel Research, 65: 662–674, 2009.
[16]. Schneider U. Concrete at High Temperatures – A General Review. Fire Safety Journal, 13: 55-68, 1988.
[17]. Sebastjan Bratina, Bojan Cas, Miran Saje, Igor Planinc. Numerical modelling of behaviour of reinforced concrete columns in fire and comparison with Euro code 2. International Journal of Solids and Structures, 42: 5715–5733, 2005.
[18]. Terro, M. J. . Numerical Mod el ling of the Behaviour of Concrete Structures. ACI Struct Journal, 95: 183-93, 1998.
[19]. Usmani, A. S., Rotter, J. M., Lamont, S., Sanad, A. M., Gillie M. Fundamental Principles of Structural Behaviour under Thermal Effects. Fire Safety Journal, 36: 721-744, 2001.