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RESEARCH ARTICLE

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A STUDY ON FIRE PERFORMANCE OF REINFORCED CONCRETE SLABS USING FINITE ELEMENT METHOD

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ABSTRACT
Building codes detail the types of construction materials, assemblies, and fire suppression systems that are required for various building types. This prescriptive method has prevented structural engineers from exposure to performance based design approaches for fire safety. The motivation for this thesis was to increase the awareness of the structural engineering field to the concepts behind structural design for fire safety. Extensive research has been published on the performance of structural steel in fire conditions, and simplified design tools already exist to describe its behaviour. Such tools do not exist for reinforced concrete structures. Research on concrete has been more focused on material properties rather than structural performance.

INTRODUCTION

1.1 GENERAL

The objective of fire safety is to protect life and property. Fires can occur at any time in buildings, and the safety of occupants and maintaining the integrity of the structure are of major importance. Building codes prescribe detailed measures for the fire safety of structural members because when other means for containing a fire fail, such as a fire suppression system ,structural integrity is the last line of defence. Code-based structural fire safety requirements refer to fire resistance which is defined as the ability of a structural element to maintain its load-bearing functions under standard fire conditions. The fire resistance rating of a structural member is the elapsed time it exhibits resistance with respect to structural integrity, stability, and temperature transmission while exposed to standard fire conditions. The measured fire resistance of a structural member or assembly is dependent on the geometry of elements, materials used in construction, load intensity, fire exposure, and the characteristics of a given furnace. Testing for the fire resistance of materials is done in laboratories by exposing elements to fire conditions and monitoring their performance. Numerical and analytical methods were developed based on these fire tests as an economical alternative to laboratory testing. Over the past two decades there has been a widespread use of finite element programs to determine structural performance in both standard and natural fire conditions.

The above methods for predicting fire resistance do not increase the awareness of structural engineers to the concepts of design for fire conditions. They are either prescriptive in their application to design or being performed by the materials and fire communities whose interests are geared towards properties of materials in fire conditions and complicated performance-based analyses of structural elements. The motivation for this thesis was to increase the awareness of the structural engineering field to the concepts behind structural design for fire safety. The development of simplified design tools that predict the fire performance of structural elements is of utmost importance to practicing structural engineers. These tools address structural fire performance from an applied design approach similar to those which exist for the effects of wind and earthquake loads. Extensive research has been published on the performance of structural steel in fire conditions, and simplified design tools already exist to describe its behaviour. However, such tools do not exist for reinforced concrete structures where research has been focused on the material properties of concrete in fire conditions rather than structural performance. This thesis describes the computer modelling of a one-way reinforced concrete slab under fire conditions. This exercise was carried out in two stages, namely transient thermal analysis and thermo-structural analysis using the standard time-temperature curve specified by IS: 3809-1979.

The structural engineering community worldwide is witnessing a renewed interest in the fire resistance of buildings following the September 11 attacks in New York City. The Mumbai incident of November 26 has also added to the interest especially among our own structural engineers. In Mumbai, terrorists used explosives to spread fire to cause maximum damage to human life and one of the heritage structures of India, Hotel Taj. Unfortunately, in the few decades, reports of India's human and property losses because fire breakouts are on the rise.

The fire resistance rating of building-elements in India is determined by the standard fire test provisions of IS 3809:1979.However, such test setups are expensive to build. As a result, only a few organisations conduct research in the field. However the disadvantage in studying the performance of a structure under fire conditions can be overcome by using an approach based on finite element modelling. The idea of using computer modelling to access fire rating of buildings is encouraged by the recent advances in fire science and technology that have fostered a movement in the US and European countries emphasising the adoption of performance based design standards and building codes. The transition towards performance-based codes, which is already being practiced in several countries, relies on computer modelling as the predominant tool for design and analysis.

1.2 NEED FOR THE SYUDY

The structural engineering community worldwide is witnessing a renewed interest in the fire resistance of buildings following the September 11 attacks in New York city. The Mumbai incident of November 26 has also added to the interest especially among our own structural engineers.

The fire resistance rating of building elements in India are determined by the standard fire test provisions of IS 3809:1997.

However such test setups are expensive and to overcome this finite element modeling approach is used

1.3 OBJECTIVE OF THE STUDY

The objectives of this thesis are to categorize the research and to explore a simplified design tool that can be used by practicing structural engineers to assess the performance of concrete elements during fire conditions. Also, through the application of the design tool the user will gain an understanding of concretes thermal properties and basic principles of heat transfer.

1.4 SCOPE OF THE STUDY

The following is a list of activities that define the scope of this work:

- Investigate literature covering the performance of reinforced concrete elements exposed to fire conditions and create an annotated bibliography of works relevant to the topic.
- Investigate concepts of heat transfer in concrete and their application to one-dimensional thermal analyses.
- Develop a spreadsheet tool that calculates cross-section temperature distributions in concrete slabs.

- Perform studies of the fire performance of concrete slabs with varying aggregates and thicknesses against different fire exposures.

LITERATURE REVIEW

2.1 GENERAL

Several researchers have carried out investigations to understand the behaviour of Circular Hollow Section .The latest study carried out in the last decade has been presented in this chapter after an elaborate and detailed literature review

2.2 LITERATURE SURVEY

Bushev et al. (1972) text presents methods for testing and calculating the fire resistance of various structural elements. The fire resistance of concrete structures is examined using a numerical method based on the ISO 834 time-temperature curve. Time-dependent material properties for concrete established during testing in the late 1960s are presented for different aggregates. When examining the literature it was found the time-dependent properties were not accurate when compared with more recently established data (Malhotra 1982).

CRSI (1980) The Concrete Reinforcing Steel Institute published this text in 1980 to summarize the available technical information covering the fire resistance of reinforced concrete elements. Building code requirements for fire resistance are detailed as well as analytical and rational methods for calculating fire endurance based on ASTM E119 testing. Example problems are presented that illustrate the structural behaviour of concrete elements and systems in fire conditions along with design procedures. The empirical design procedures utilizing isotherms from ASTM E119 fire testing provide a more realistic prediction of the performance of a real structure in an actual fire by detailing the effects fire has on the capacity of concrete elements as opposed to following prescriptive fire resistance ratings.

Malhotra (1982) provides background on fire resistance needs and requirements, methods for determining fire severity, and the material properties of concrete at elevated temperatures. Design methods for the fire performance of reinforced concrete elements are introduced. The proposed design procedure utilizes empirical temperature distribution charts derived from concrete specimens tested according to ISO 834 specifications and data for the strength of concrete and reinforcing steel at elevated temperatures.

Lie et al. (1985) book published in 1985.It discusses the concept of fire development and severity as well as economic losses due to fire. The behaviour of concrete materials in fire conditions is detailed as well as an analytical method for predicting the fire resistance of concrete elements using the ISO 834 fire curve. The concept of applying one-dimensional analysis to predict the behaviour of three-dimensional elements is implemented in the analytical procedure.

Munukutla (1989) details numerical simulations of the fire performance of concrete walls. He developed a finite element program to compute temperature profiles within concrete walls for various types of fire conditions. The program performs a one-dimensional heat transfer analysis for a wall exposed to fire on one side. Temperature distributions through the thickness of the wall are calculated using the finite difference method with a correction factor for the unexposed surface. The material properties of concrete are input to the formulation as temperature- dependent values

Wade (1993) presented design methods that assess the fire performance of reinforced concrete elements. There are some differences between the works of Wade and Malhotra. Wade's procedure makes use of updated empirical temperature distribution charts and data for the strength of concrete and reinforcing steel at elevated temperatures. It also includes alternate design equations for fire conditions that consider building type.

He describes a series of fire tests that were conducted on reinforced concrete slabs composed of different aggregates. Slabs of either 60mm (Alluvial Quartz, Quarried Greywacke, Limestone, and Pumice) or 175mm (Alluvial Quartz and Quarried Greywacke) were prepared, and their mix design and aggregate properties are detailed. Two slabs, each of area 1m by 1m, were cast with reinforcing steel for each aggregate type and thickness. Thermocouples were placed at the following predetermined depths: 60mm slabs (exposed face, 20mm, 40mm, and unexposed face) and 175mm slabs (exposed face, 35mm, 70mm, 105mm, 140mm, and exposed face). The slabs were cured for 28 days in ambient conditions. A diesel-fired pilot furnace was used to test the concrete slabs at BRANZ laboratories in accordance with the ISO 834 specifications. The specimens were tested unloaded in a vertical orientation and fastened to a frame using two bolts on each side resulting in partial restraint against thermal expansion, but not to an extent that would significantly affect their fire performance. The fire resistance of each slab was recorded following the failure criteria set forth by the ISO 834 standard fire test.

Lie (1992) text explains fire resistance needs and requirements according to the prescriptive methods proposed in building codes in addition to the basic principles of

Fire protection. The thermal and mechanical properties of concrete are detailed. Lie describes the application of multiple numerical techniques for calculating temperatures and fire resistance for concrete elements. Numerical methods for a wide variety for concrete structural members are detailed including columns with rectangular, square, or circular cross-sections, floor and roof slabs, and concrete-filled tubular steel columns.

Cooper and Franssen (1999) report identifies partition designs for which the use of one-dimensional thermal analysis in fire modelling would lead to a successful evaluation of their thermal fire performance. It was determined that gypsum-panel/steel-stud or wood-stud wall systems, concrete block wall, and poured concrete

slabs supported by steel beams have three-dimensional elements that have negligible heat transfer effects so a one-dimensional thermal analysis will produce successful results when applied correctly. The authors conclude that reinforced concrete beam/slab systems require a two-dimensional analysis because of heat transfer in the beams.

Performance of Concrete Elements in Fire Conditions

The measures used to assess the fire performance of concrete elements remain the traditional practice of fire testing along with numerical and analytical methods and finite element software. All of which have been developed to simulate fire testing results. Sensory and optical techniques have been developed to determine the post-fire material properties of concrete. However, these methods are used in the evaluation of fire damage and cannot be applied to the assessment of concrete performance during fire conditions.

METHODOLOGY

3.1 THERMAL ANALYSIS PROCESS

Modelling of slab includes the following steps.

- Literature collection.
- Slab design.
- Determination of design fires.
- Finite element modelling.

Thermal analysis of slab is done by the following procedure using the ANSYS software.

- Selection of relevant design fire scenarios.
- Determination of the corresponding design fires.
- Calculation of the temperature rise of the structural members.
- Calculation of the mechanical response.

3.2 FIRE TESTS

Fire tests represent the oldest method to evaluate the fire endurance of structural elements. As early as 1918, fire tests were being performed on building columns at the Underwriters' Laboratories (1918). Fire tests expose structural elements to different fire severities and are either performed within a furnace or on full-scale buildings. Many countries use full-scale fire resistance tests to evaluate the fire performance of structural elements. Full-scale tests are preferred for the study of structural elements and assemblies of a relatively small extent because they give a more accurate representation of the various phenomena that occur during fire conditions such as the effects of thermal expansion and deformation under load.

3.2.1 Furnace testing

Test furnaces are the most common method used to evaluate the fire resistance of structural elements. The furnaces' chamber is heated either electronically or by burning liquid fuel. The temperature history in the furnace is controlled by a designated fire curve, typically those of "standard fires". Usually, furnaces are equipped with devices to measure temperatures, and deformations, and to load test specimens. Furnaces follow different testing specifications depending on the laboratory and are specially constructed for their purpose. There are vertical furnaces that are constructed for testing vertical partitions such as walls and doors; horizontal furnaces are used for testing horizontal partitions such as floors and roofs. Also, there are special beam and columns furnaces, although they are often tested in horizontal furnaces. Some furnaces are even designed so that all types of building elements can be tested. Fire tests in furnaces are carried out by exposing certain surfaces of a test specimen to heating in a manner that simulates its exposure to heating in a fire (Wade 1993). Generally, test specimens are construction elements for which a fire resistance classification is desired. Specimens are tested under conditions that are similar to those in service such as loading and restraint.

Thermocouples are placed in the furnace and within specimens to measure temperatures. A specimen is considered fire resistant during a test up until the point it does not satisfy certain testing criteria with respect to stability, integrity, and thermal insulation.

3.2.2 Full scale fire tests

Occasionally full-scale fire tests are performed on structural systems. These tests give a more realistic representation of fire performance because they simulate the performance of a system as opposed to the study of discrete elements or small-scale assemblies. The major drawback of full-scale testing is that it is extremely expensive in comparison with furnace testing. The most comprehensive full-scale testing completed took place in 1995 in Cardington, England. A series of fire tests were carried out on an eight-storey, steel-concrete composite structure. As an outgrowth of the Cardington tests, numerous numerical and theoretical models have been developed to simulate the performance of the structure. The test results and the subsequent models have deepened understanding of the mechanical behaviour of highly redundant structures in extreme fires.

3.2.3 Standard fires

Most fire resistance tests follow time-temperature curves that serve as "standard fires" which are idealized simulations of room fires. Since the tests follow established time-temperature curves, the heat load imposed on a test specimen is calculable at any point during testing. Standard fire test time-temperature curves for various countries can be seen in Literature. (Lie et al.1985). The most widely used standard test conditions are the ASTM E119 and ISO 834.

Temperature values, *T* (ºC), for the ISO 834 fire follow the equation.

$$T=345\log_{10}(8t+1)+T_0$$

Where *t* (minutes) is the time and *To* (ºC) is the ambient temperature. Failure criteria for the ISO 834 fire are (Malhotra 1982):

- Collapse or the downward deformation of flexural members exceeding L/30 where L is the span
- Ignition of a cotton pad held close to an opening for 10 seconds
- Temperature of the unexposed face rising more than 140ºC as an average or by more than 180ºC at any point.

The ASTM E119 curve is defined by discrete points which can be seen along with the corresponding ISO 834 temperatures. A simplified equation that approximates the ASTM E119 curve is given by (Lie et al. 1985):

$$T=750(1-e^{-3.79533\sqrt{t_h}})+170.41\sqrt{t_h}+T_0$$

Where t_h (hours) is the time. The conditions for failure for reinforced concrete components exposed to the ASTM E119 protocol Collapse of the component or failure to inhibit passage of flame or hot gases

- Attainment of the limiting average temperature of 593ºC in reinforcement

- Rise of 139ºC in the average temperature of the unexposed surface of the test component.

Table 3.1 ISO 834 and ASTM E119 Time-Temperature Curves at Various times

Time (minutes)	ASTM E119 Temperature (ºC)	ISO 834 Temperature (ºC)
0	20	20
5	538	576
10	704	678
30	843	842
60	927	945
120	1010	1049
240	1093	1153
480	1260	1257

3.2.4 Natural fires

Standard fires are suitable for comparison purposes but do not provide a true indication of how structural components and assemblies will behave in an actual fire. Other than collapse the failure criteria for both the ISO 834 and ASTM E199 tests are not related to any physical limit state performance. Their increasing temperatures do not reflect the fact that natural fires, also known as compartment fires, decrease in intensity once the fuel in the compartment has been burned. Furthermore, the standard fire curves do not account for material composition within the compartment, the boundary construction of the compartment, or ventilation effects. Compartment fires have been utilized to better represent the conditions of natural fires within furnace testing. Fire curves that portray compartment fires characterize the fuel and dimensions in typical room compartments. The two significant factors affecting fire curves are the fire load, q (MJ/m2), and the ventilation or opening factor, ϕ($m^{1/2}$), described as:

$$\phi = A\sqrt{h}/At$$

Where *Ao* (m2) is the total area of window and door openings, *h* (m) is the weighted average of height openings, and A_t (m2) is the total area of compartment bounding surfaces. In 1976 the National Bureau of Standards completed a survey of fire and live loads in office buildings in the U.S .These fire curves are similar to those experienced in compartment tests and contribute to better understanding the performance of structural elements and assemblies in actual fires.

3.2.5 Numerical and analytical methods

Due to the costs involved in performing fire tests, numerical and analytical methods have been developed as an economic alternative for determining fire resistance. These methods have proven to be successful in predicting the fire resistance of structural elements (Lie et al. 1985), and the application and limitations of each are explained.

The main advantage of analytical methods is that simple graphs and formulae can be used to estimate the fire resistance (Lie et al. 1985; Malhotra 1982; Wade 1993). These techniques eliminate the need for computers and special testing devices, and estimations can be done quickly without much effort by applying simple algebra. However, analytical procedures are less accurate in determining temperatures in structural elements than numerical and testing procedures because their application is limited to specific conditions and assumptions. Numerical methods, albeit more complicated, have several advantages over their analytical counterparts (Lie et al. 1985). For instance, they enable the solution of complex heat transfer problems for which analytical solutions have not yet been developed. Additionally, solving the governing heat transfer equations numerically allows for the implementation and investigation of temperature- dependent material properties. On the other hand, use of numerical methods is more complicated and time consuming than the use of analytical methods. Time is needed to develop and input the model as well as to review and interpret the body of results. Computers have reduced calculation time significantly but the preparation phase before execution is still cumbersome and involves programming equations into software applications as well as determining material properties as a function of time.

Special-Purpose Finite Element Software

Advancements in computer capabilities led to the development of special-purpose finite element software programs such as ANSYS that model the performance of structural elements in fire conditions. These programs adhere to numerical methods and also consider the effects of restraint, loading, and deformation which allow for incredibly realistic simulations. Entire structural systems can be analyzed with these powerful programs. The drawbacks of finite element software packages are that they are expensive, their interface is difficult to learn, and analyses are time consuming.

3.3 CODAL RECOMMENDATIONS

- Fire resistant test on structures is done based on IS 3809-1999.
- This standard specifies the standard heating and pressure conditions, test method for various categories such as walls and partitions, columns, beams, floors, roofs etc.

3.3.1 Standard heating conditions

The temperature-rise within the furnace shall be controlled so as to vary according to the following relationship:

$$T - T_o = 345 \log_{10} (8t + 1)$$

Where, T =furnace temperature at time t, expressed in degrees Celsius.

T_0 = initial furnace temperature, expressed in degrees Celsius.

t = time expressed in minutes.

The curve representing this function is known as the '*Standard time temperature rise curve*'.

3.3.2 Minimum dimensions

The following shall be the minimum dimensions of the parts of a test specimen exposed to fire

a) Walls and partitions

Height = 3 m

Width = 3 m.

b) Floors and roofs: Supported on two sides

Span =4 m

Width =2 m.

c) Floors and roofs: Supported on four sides

Span = 4 m

Width =3 m.

d) Beams Span = 4 m.

e) Columns Height = 3 m.

The following properties and characteristics should be noted during the whole test period:

a) **Deformations** which can facilitate an analysis of the structural behaviour of the element and an application of the test results.

b) Free movements of the element.

c) **Forces and moments** transmitted to the element by restraint.

d) Other phenomena which are of importance for the load-bearing capacity of the element, such as cracking, splitting and structural transformations of materials.

3.3.3 Duration of test

Normally, the test specimen shall be heated in the manner **until failure occurs** under any one of the relevant test requirements, namely:

1. load-bearing capacity.
2. Insulation.
3. Integrity.

3.3.4 Exposure to heat

- ❖ Free-standing columns shall be tested by applying heat on all sides over their whole height.
- ❖ Beams shall be tested by applying heat to three sides of the beam.
- ❖ Separating elements represented by test specimens of elements which have the function of separating spaces shall be heated over the whole or one face only.

3.3.5 Load bearing capacity

For load-bearing elements of structure, the test specimen shall not collapse in such a way that it is no longer performs the load-bearing function for which it was constructed.

3.3.6 Insulation

For elements of structure such as walls and floors which have the function of separating two parts of a building:

a) The average temperature of the unexposed face of the specimen shall not increase above the initial temperature by more than 140°C.

b) The maximum temperature at any point of this face shall not exceed the initial temperature by more than 180°C, and shall not exceed 220°C irrespective of the initial temperature.

3.3.7 Integrity

For elements of structure such as walls and floors, the presence and formation in the test specimen of cracks, holes or other openings through which flames or hot gases can pass so as to cause initial integrity failure, shall not occur.

3.4 MECHANISM OF HEAT TRANSFER

Conduction.

The conduction is defined as the transfer of energy from one point of a medium to another under the influence of temperature differences.

Convection.

Convection is the term used for heat transfer mechanism which takes place in a fluid because of a combination of conduction due to the molecular interactions and energy transport due to the macroscopic (bulk) motion of the fluid itself.

Radiation.

3.5 FINITE ELEMENT ANALYSIS

3.5.1 Ansys

ANSYS is a general purpose finite element analysis (FEA) software package. ANSYS is the most advanced comprehensive and reputable finite element analysis and design software package available for civil engineering projects. The software implements equation that governs the behaviour of these elements and solves them, creates a comprehensive explanation of how the system acts as a whole. These results can be presented in tabulates or graphical forms. This type of analysis is typically used for the design and optimisation of a system far too complex to analyse by hand.

3.5.2 Need for using Ansys

ANSYS provides acts cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping. With virtual prototyping techniques, users can iterate various scenarios to optimise the product long before the manufacturing is started. This enables a reduction in the level of risk and in the cost of risk and in the cost of ineffective designs. The manufactured nature of ANSYS also provides a means to ensure that users are able to see the effect of a design on the whole behaviour of the product, be it electromagnetic, thermal, mechanical etc. ANSYS is a general purpose finite element modelling package for numerically solving a wide variety of mechanical problems. These problems include static/dynamic structural analysis (linear and non-linear), heat transfer and fluid problems, as well as acoustic and electromagnetic problems.

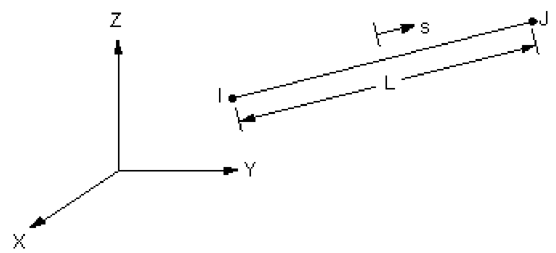
Modeling of slab

3.5.4 Slab design

Short Span (Clear) = 3 m
Long Span (Clear) = 5m
Live Load on the Slab (LL) = 3.5Kpa
Comp.stess of concrete, fck = 25Mpa
Tensile stress of steel, fy = 415Mpa
Unit wt of concrete, γ = 25KN/m^3
Unit wt of floor finish 50 mm = 24KN/m^3
Clear concrete cover = 25 mm
Bearing of slab = 230 mm
Overall depth = 125 mm
Dia of bars for short direction = 8 mm
Dia of bars for long direction = 10 mm
Effective Depth = 100 mm
End condition = one .

Loading on the slab

Dead Load of the slab (DL) = 3.25 KN/m^2
Floor Finish =1.20 KN/m^2
Other Load =0.5 KN/m^2
Live Load on the slab =3.5 KN/m^2
Total Load on the slab (TL) =8.45 KN/m^2
Design Load = (Total Load x Load Factor)
=8.45*1.5
=12.68 KN/m^2
Effective Span, lx = 3.1 m
ly = 5.1 m
Ratio, r =ly/lx= 1.645 m



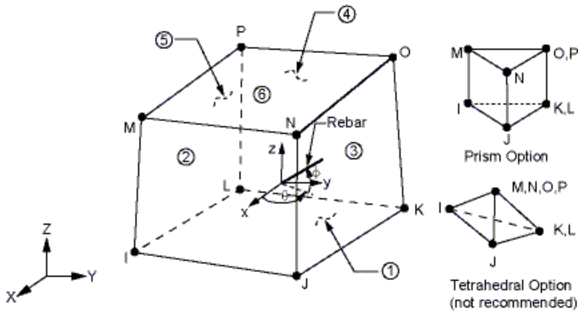


Fig 3.1 concrete element

Table 3.2 Dia and spacing of reinforcement

	Dia of bar (mm)	Spacing for Short Span(mm)	Dia of bar(mm)	Spacing for Long Span(mm)
Top R/F (At support)	8	140	10	270
Bottom R/F (At Mid Span)	8	190	10	270

3.5.5 Concrete Element

SOLID65 is used for the 3-D modelling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modelling reinforcement behaviour. Other cases for which the element is also applicable would be reinforced composites (such as fibreglass), and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Up to three different rebar specifications may be defined. Fig 3.1 shows the solid 65 concrete element.

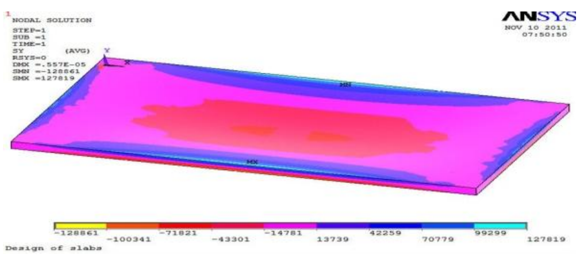


Fig 3.3 Slab model

3.5.6 Reinforcement Element

LINK8 is a spar element which may be used in a variety of engineering applications. This element can be used to model trusses, sagging cables, links, springs, etc. The 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions. Following Fig 3.2 shows the degrees of freedom for LINK 8 element.

3.5.7 Slab Model

The slab is designed using ANSYS 11 Software of dimension 5 X 3 m. the model has been created using solid 65 concrete element and link 8 element for reinforcing steel.Fig 3.3 shows the meshed model of a reinforced concrete slab

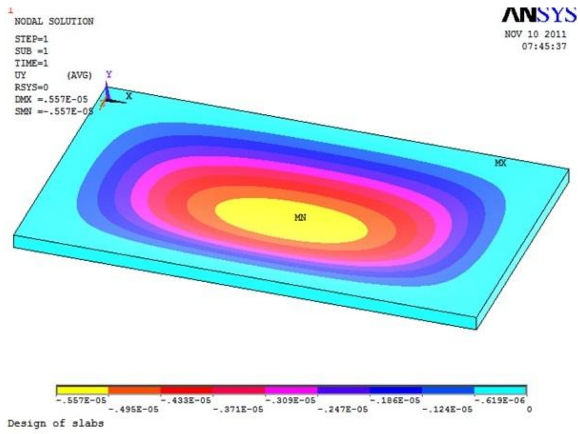


Fig 3.4 Deflection contour

3.5.8 Results

- Live load applied =3.5kpa.
- Slab dimensions =5x 3 m.
- Type of slab = Two way slab.
- Maximum deflection obtained= 5.57 mm.

The deflection in the slab is maximum at the center as shown in Fig 3.4 and minimum at the corners of the slabs.

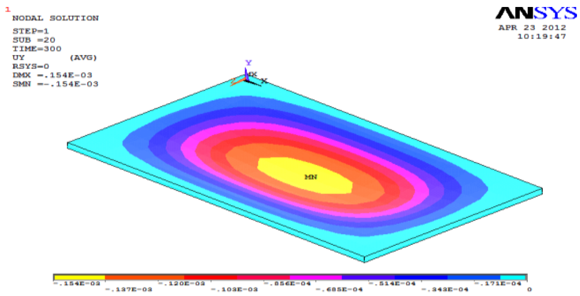


Fig 3.5 Stress contour

From the following Fig 3.5 we may conclude that the stresses are maximum at the corners where the translation and rotation are restrained, at the central portion of the slab.

RESULTS AND DISCUSSION

4.1 THERMAL- STRUCTURAL ANALYSIS

A fixed slab of dimension 3m x 5m is analysed with a pressure of 3500 N/m^2 and compared with an slab of same dimension excited to a temperature of 586°C at the bottom and 30°C (room temperature) at the top surface for a time duration of **5 min**.

Analysis data:

- Slab dimension = 3mx5mx 0.125m.
- Compressive strength of concrete = 25 M pa.
- Yield strength of steel = 415 M pa.
- Element used= SOLID70 (3-D Thermal solid).

= LINK 33 (2-D Thermal element).

= SOLID 65 (8-noded concrete element).

= LINK 8 (Reinforcement bar element).

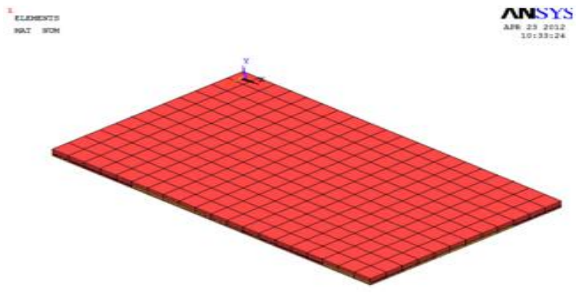


Fig 4.1 Meshed Slab model

The displacement along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.2 and Fig 4.3 respectively.

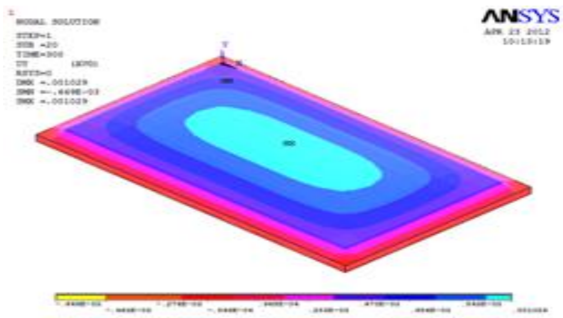


Fig 4.2 Displacement considering applied load

The bending stress along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.4 and Fig 4.5 respectively.

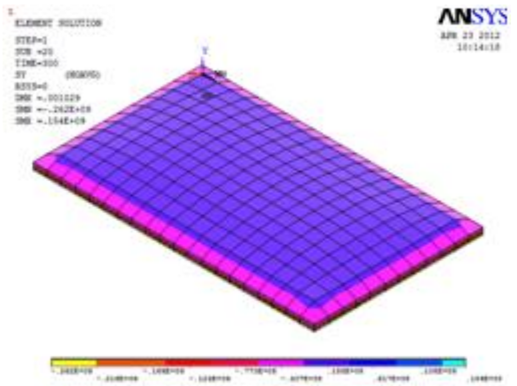


Fig 4.5 Bending stress considering both thermal and applied load

The elevation of temperature of 6 nodes with respect to time along the cross section of the slab at mid span is as given in Fig 4.6 and Fig 4.7.

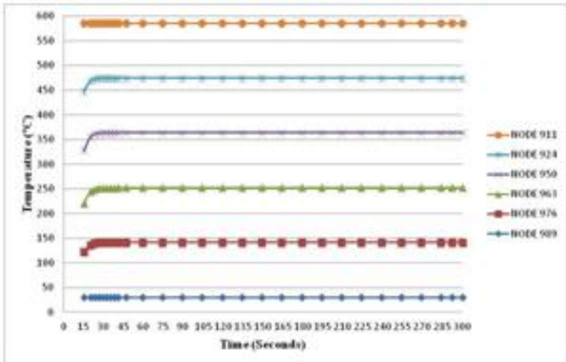


Fig 4.6 Temperature variation with time along the c/s of slab

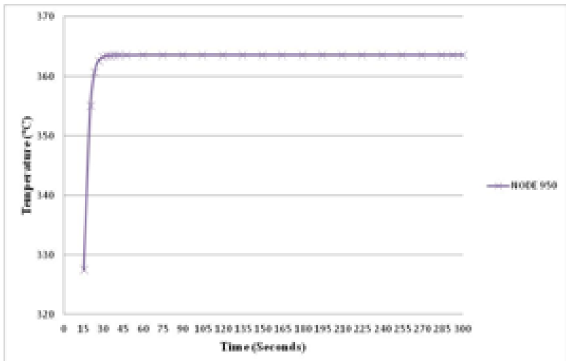


Fig 4.7 Temperature variation of a node with respect to time

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The variation of temperature along the cross section at six different nodes spaced at 25 mm at the mid span of the slab with respect to temperature is given in Table 4.1.

Table 4.1 Time-Temperature variation along cross section of slab

Time (Sec)	Temperature (ºC)					
	Node 911	Node 924	Node 950	Node 963	Node 976	Node 989
15	586	447.783	327.529	221.014	123.108	30
20	586	469.136	355.127	244.403	136.422	30
23	586	472.92	360.707	249.592	139.495	30
26	586	474.157	362.602	251.421	140.601	30
29	586	474.577	363.252	252.058	140.99	30
32	586	474.722	363.478	252.279	141.126	30
35	586	474.772	363.556	252.357	141.173	30
38	586	474.79	363.584	252.384	141.19	30
41	586	474.796	363.594	252.394	141.196	30
47	586	474.799	363.599	252.399	141.199	30
59	586	474.8	363.6	252.4	141.2	30
74	586	474.8	363.6	252.4	141.2	30
89	586	474.8	363.6	252.4	141.2	30
104	586	474.8	363.6	252.4	141.2	30
119	586	474.8	363.6	252.4	141.2	30
134	586	474.8	363.6	252.4	141.2	30
149	586	474.8	363.6	252.4	141.2	30
164	586	474.8	363.6	252.4	141.2	30
179	586	474.8	363.6	252.4	141.2	30
194	586	474.8	363.6	252.4	141.2	30
209	586	474.8	363.6	252.4	141.2	30
224	586	474.8	363.6	252.4	141.2	30
239	586	474.8	363.6	252.4	141.2	30
254	586	474.8	363.6	252.4	141.2	30
269	586	474.8	363.6	252.4	141.2	30
284	586	474.8	363.6	252.4	141.2	30
292	586	474.8	363.6	252.4	141.2	30
300	586	474.8	363.6	252.4	141.2	30

Fig 4.8 shows the variation of temperature along the cross section of the slab for an initial temperature of 586°C at the bottom and 30°C at the top surface of the slab.

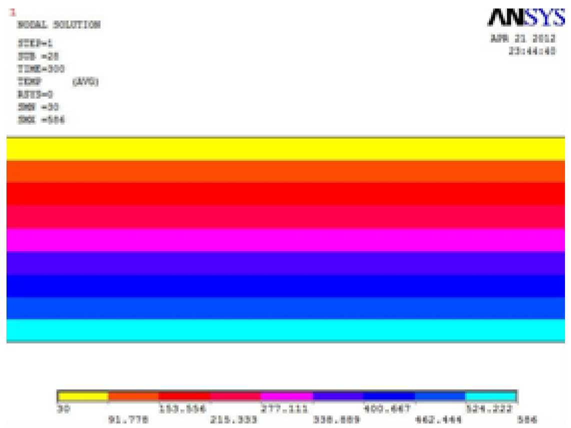

Fig 4.8 Temperature variation along cross section

RESULTS

Maximum bending stress = 145.32 k Pa.

Maximum bending stress including thermal load= 154 M pa.

Maximum displacement = 1.54 mm.

Maximum displacement including thermal load = 2.3 mm.

4.1.1 Thermal structural analysis (case 2)

A fixed slab of dimension 3m x 5m is analysed with a pressure of 3500 N/m^2 and compared with an slab of same dimension excited to a temperature of 689°C at the bottom and 30°C (room temperature) at the top surface for a time duration of **10 min**.

The displacement along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.9 respectively.

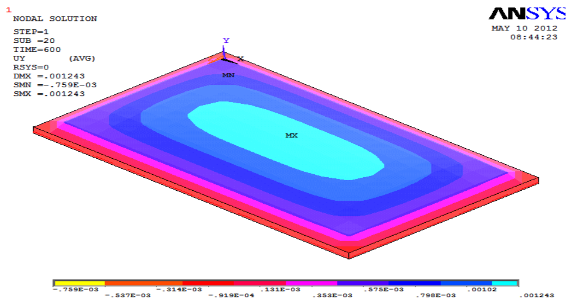

Fig 4.9 Displacement considering both thermal and applied load

The elevation of temperature of 6 nodes with respect to time along the cross section of the slab at mid span is as given in Fig 4.10 and Fig 4.11.

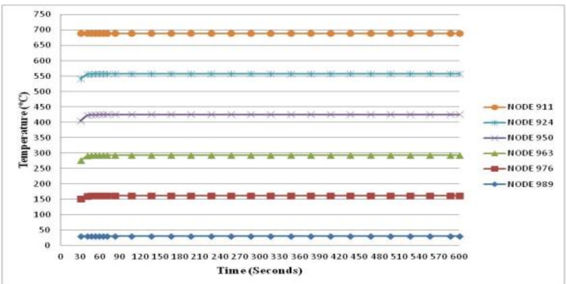

Fig 4.10 Temperature variation with time along the c/s of slab

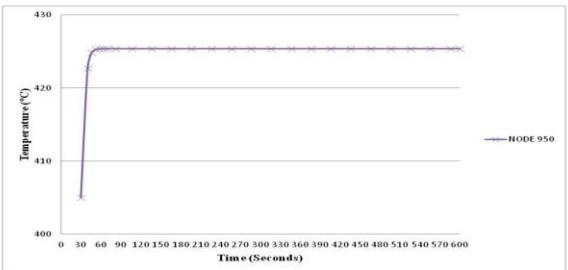

Fig 4.11 Temperature variation of a node with respect to time

The variation of temperature along the cross section at six different nodes spaced at 25 mm at the mid span of the slab with respect to temperature is given in Table 4.2.

Table 4.2 Time-Temperature variation along cross section of slab

Time (Sec)	Temperature (ºC)					
	Node 911	Node 924	Node 950	Node 963	Node 976	Node 989
30	689	541.862	405.003	276.016	151.821	30
40	689	555.39	422.688	291.039	160.271	30
46	689	556.836	424.839	293.054	161.468	30
52	689	557.124	425.282	293.484	161.729	30
58	689	557.184	425.375	293.575	161.785	30
64	689	557.196	425.394	293.595	161.797	30
70	689	557.199	425.399	293.599	161.799	30
82	689	557.2	425.4	293.6	161.8	30
106	689	557.2	425.4	293.6	161.8	30
136	689	557.2	425.4	293.6	161.8	30
166	689	557.2	425.4	293.6	161.8	30
196	689	557.2	425.4	293.6	161.8	30
226	689	557.2	425.4	293.6	161.8	30
256	689	557.2	425.4	293.6	161.8	30
286	689	557.2	425.4	293.6	161.8	30
316	689	557.2	425.4	293.6	161.8	30
346	689	557.2	425.4	293.6	161.8	30
376	689	557.2	425.4	293.6	161.8	30
406	689	557.2	425.4	293.6	161.8	30
436	689	557.2	425.4	293.6	161.8	30
466	689	557.2	425.4	293.6	161.8	30
496	689	557.2	425.4	293.6	161.8	30

526	689	557.2	425.4	293.6	161.8	30
556	689	557.2	425.4	293.6	161.8	30
586	689	557.2	425.4	293.6	161.8	30
600	689	557.2	425.4	293.6	161.8	30

The bending stress along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.12 respectively.

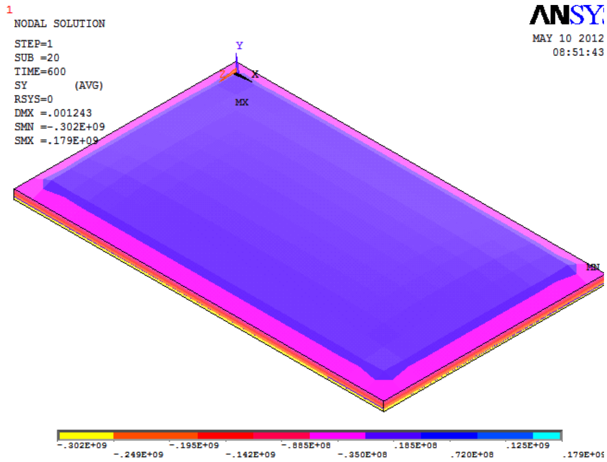

Fig 4.12 Bending stress considering both thermal and applied load

RESULTS

Maximum bending stress = 145.32 kPa.

Maximum bending stress including thermal load= 179 Mpa.

Maximum displacement = 1.54 mm.

Maximum displacement including thermal load= 2.6 mm.

4.1.2 Thermal structural analysis (case 3)

A fixed slab of dimension 3m x 5m is analysed with a pressure of 3500 N/m^2 and compared with a slab of same dimension excited to a temperature of 748°C at the bottom and 30°C (room temperature) at the top surface for time duration of **15 min**.

The displacement along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.13 respectively.

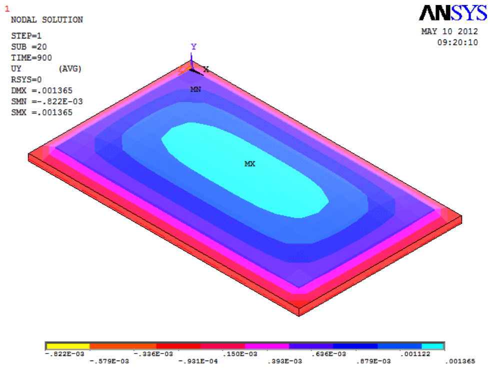

Fig 4.13 Displacement considering both thermal and applied load

The elevation of temperature of 6 nodes with respect to time along the cross section of the slab at mid span is as given in Fig 4.14 and Fig 4.15.

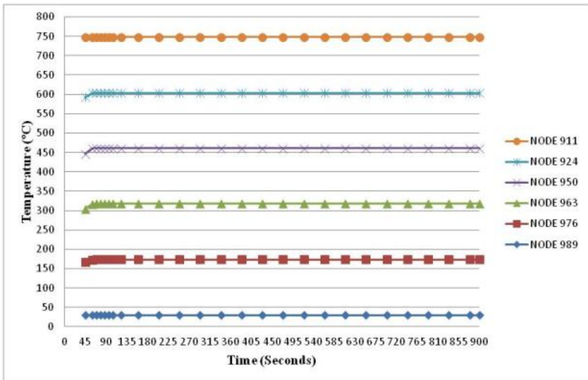

Fig 4.14 Temperature variation with time along the c/s of slab

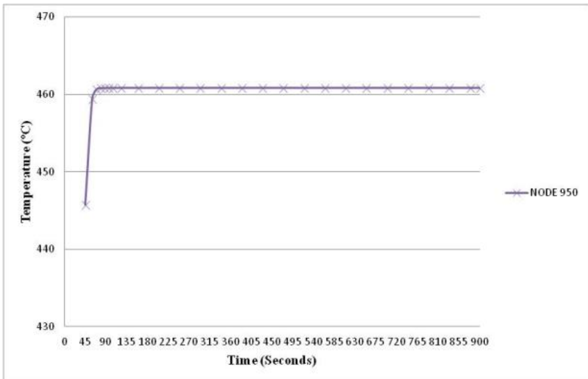

Fig 4.15 Temperature variation of a node with respect to time

The variation of temperature along the cross section at six different nodes spaced at 25 mm at the mid span of the slab with respect to temperature is given in Table 4.3.

Table 4.3 Time-Temperature variation along cross section of slab

Time (Sec)	Temperature (ºC)					
	Node 911	Node 924	Node 950	Node 963	Node 976	Node 989
45	748	593.096	445.74	304.196	166.213	30
60	748	603.468	459.401	315.876	172.809	30
69	748	604.265	460.592	316.998	173.477	30
78	748	604.38	460.769	317.169	173.581	30
87	748	604.397	460.795	317.195	173.597	30
96	748	604.399	460.799	317.199	173.6	30
105	748	604.4	460.8	317.2	173.6	30
123	748	604.4	460.8	317.2	173.6	30
159	748	604.4	460.8	317.2	173.6	30
204	748	604.4	460.8	317.2	173.6	30
249	748	604.4	460.8	317.2	173.6	30
294	748	604.4	460.8	317.2	173.6	30
339	748	604.4	460.8	317.2	173.6	30
384	748	604.4	460.8	317.2	173.6	30
429	748	604.4	460.8	317.2	173.6	30
474	748	604.4	460.8	317.2	173.6	30
519	748	604.4	460.8	317.2	173.6	30
564	748	604.4	460.8	317.2	173.6	30
609	748	604.4	460.8	317.2	173.6	30
654	748	604.4	460.8	317.2	173.6	30
699	748	604.4	460.8	317.2	173.6	30
744	748	604.4	460.8	317.2	173.6	30
789	748	604.4	460.8	317.2	173.6	30
834	748	604.4	460.8	317.2	173.6	30
879	748	604.4	460.8	317.2	173.6	30
900	748	604.4	460.8	317.2	173.6	30

The bending stress along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.16 respectively.

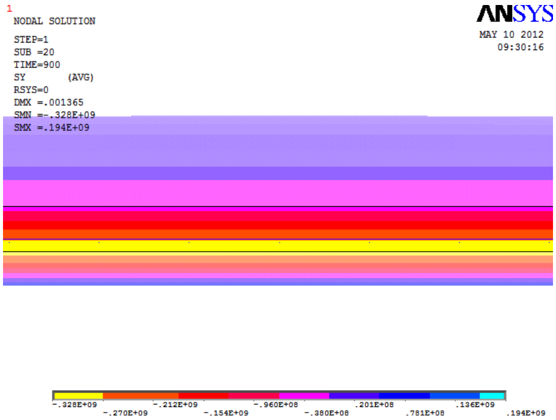

Fig 4.16 Bending stress considering both thermal and applied load

RESULTS:

Maximum bending stress = 145.32 kPa.

Maximum bending stress including thermal load = 194 Mpa.

Maximum displacement = 1.54 mm.

Maximum displacement including thermal load = 2.8 mm.

4.1.3 Thermal structural analysis (case 4)

A fixed slab of dimension 3m x 5m is analysed with a pressure of 3500 N/m^2 and compared with a slab of same dimension excited to a temperature of 851°C at the bottom and 30°C (room temperature) at the top surface for time duration of **30 min**.

The displacement along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.17 respectively.

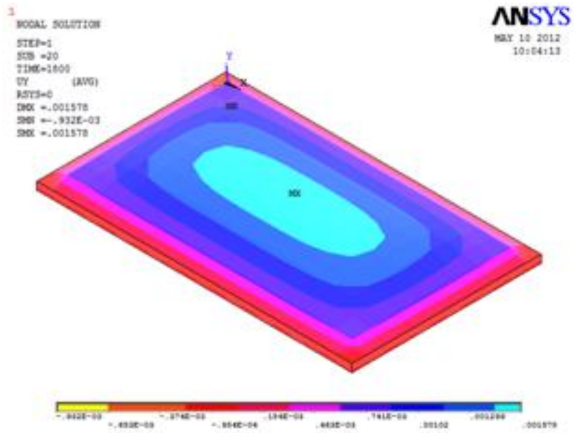

Fig 4.17 Displacement considering both thermal and applied load

The elevation of temperature of 6 nodes with respect to time along the cross section of the slab at mid span is as given in Fig 4.18 and Fig 4.19.

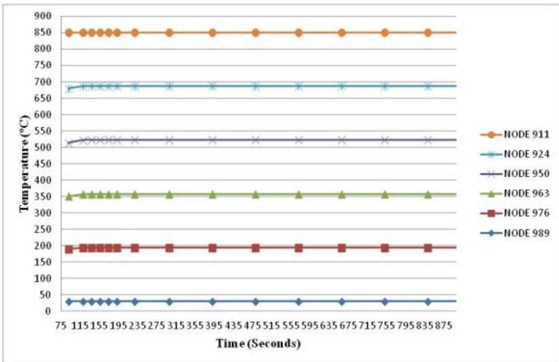

Fig 4.18 Temperature variation with time along the c/s of slab

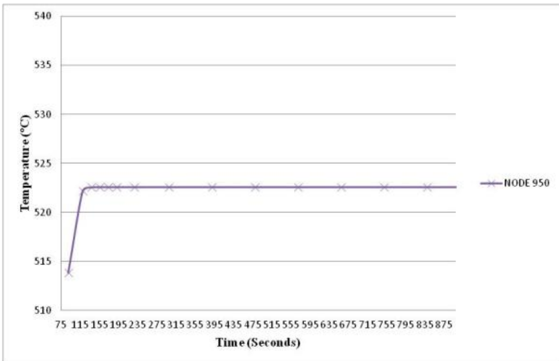

Fig 4.19 Temperature variation of a node with respect to time

The variation of temperature along the cross section at six different nodes spaced at 25 mm at the mid span of the slab with respect to temperature is given in Table 4.4.

Table 4.4 Time-Temperature variation along cross section of slab

Time (Sec)	Temperature (ºC)					
	Node 911	Node 924	Node 950	Node 963	Node 976	Node 989
90	851	680.241	513.845	350.828	189.894	30
120	851	686.516	522.173	357.995	193.958	30
138	851	686.778	522.566	358.366	194.18	30
156	851	686.798	522.597	358.397	194.198	30
174	851	686.8	522.6	358.4	194.2	30
192	851	686.8	522.6	358.4	194.2	30
228	851	686.8	522.6	358.4	194.2	30
300	851	686.8	522.6	358.4	194.2	30
390	851	686.8	522.6	358.4	194.2	30
480	851	686.8	522.6	358.4	194.2	30
570	851	686.8	522.6	358.4	194.2	30
660	851	686.8	522.6	358.4	194.2	30
750	851	686.8	522.6	358.4	194.2	30
840	851	686.8	522.6	358.4	194.2	30
930	851	686.8	522.6	358.4	194.2	30
1020	851	686.8	522.6	358.4	194.2	30
1110	851	686.8	522.6	358.4	194.2	30
1200	851	686.8	522.6	358.4	194.2	30
1290	851	686.8	522.6	358.4	194.2	30
1380	851	686.8	522.6	358.4	194.2	30
1470	851	686.8	522.6	358.4	194.2	30
1560	851	686.8	522.6	358.4	194.2	30
1650	851	686.8	522.6	358.4	194.2	30
1740	851	686.8	522.6	358.4	194.2	30
1800	851	686.8	522.6	358.4	194.2	30

The bending stress along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.20 respectively.

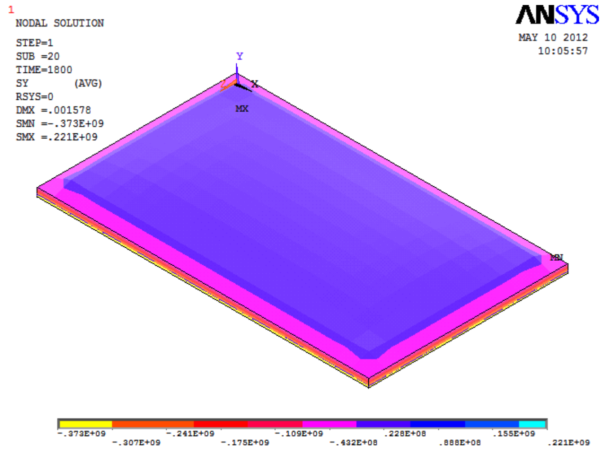

Fig 4.20 Bending stress considering both thermal and applied load

RESULTS:

Maximum bending stress = 145.32 kPa.

Maximum bending stress including thermal load= 221 Mpa.

Maximum displacement = 1.54 mm.

Maximum displacement including thermal load = 3 mm.

4.1.4 Thermal structural analysis (case 5)

A fixed slab of dimension 3m x 5m is analysed with a pressure of 3500 N/m^2 and compared with a slab of same dimension excited to a temperature of 955 °C at the bottom and 30°C (room temperature) at the top surface for time duration of **60 min**.

The displacement along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.21 respectively.

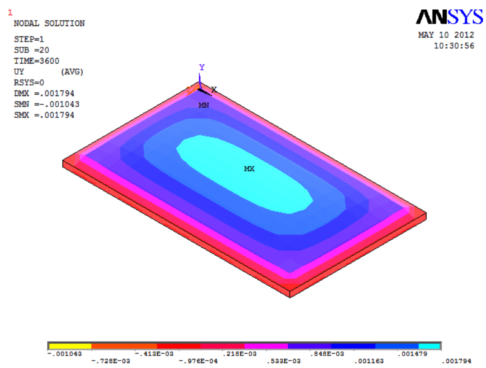

Fig 4.21 Displacement considering both thermal and applied load

The elevation of temperature of 6 nodes with respect to time along the cross section of the slab at mid span is as given in Fig 4.22 and Fig 4.23.

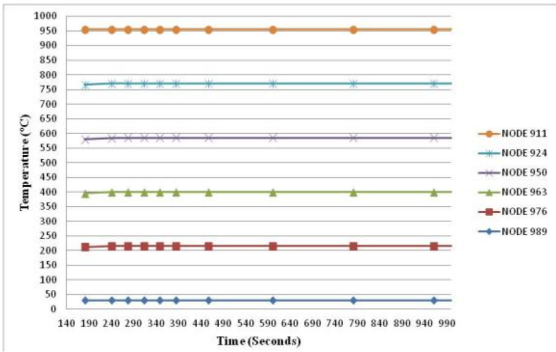

Fig 4.22 Temperature variation with time along the c/s of slab

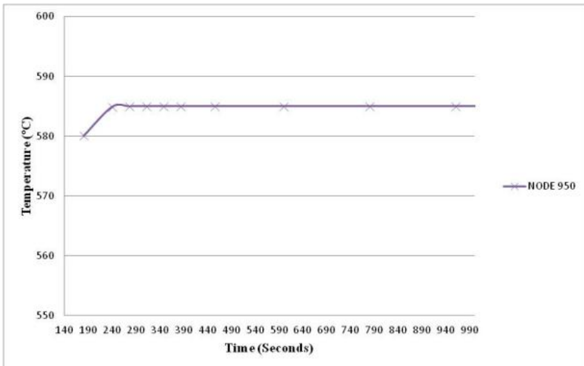

Fig 4.23 Temperature variation of a node with respect to time

The variation of temperature along the cross section at six different nodes spaced at 25 mm at the mid span of the slab with respect to temperature is given in Table 4.5.

Table 4.5 Time-Temperature variation along cross section of slab

Time (Sec)	Temperature (ºC)					
	Node 911	Node 924	Node 950	Node 963	Node 976	Node 989
180	955	766.277	580.026	395.695	212.551	30
240	955	769.917	584.876	399.882	214.929	30
276	955	769.997	584.995	399.995	214.997	30
312	955	770	585	400	215	30
348	955	770	585	400	215	30

384	955	770	585	400	215	30
456	955	770	585	400	215	30
600	955	770	585	400	215	30
780	955	770	585	400	215	30
960	955	770	585	400	215	30
1140	955	770	585	400	215	30
1320	955	770	585	400	215	30
1500	955	770	585	400	215	30
1680	955	770	585	400	215	30
1860	955	770	585	400	215	30
2040	955	770	585	400	215	30
2220	955	770	585	400	215	30
2400	955	770	585	400	215	30
2580	955	770	585	400	215	30
2760	955	770	585	400	215	30
2940	955	770	585	400	215	30
3120	955	770	585	400	215	30
3300	955	770	585	400	215	30
3480	955	770	585	400	215	30
3600	955	770	585	400	215	30

The bending stress along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.24 respectively.

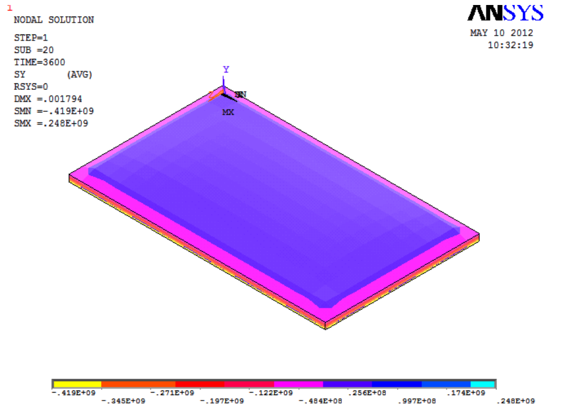

Fig 4.24 Bending stress considering both thermal and applied load

RESULTS:

Maximum bending stress = 145.32 kPa.

Maximum bending stress including thermal load= 248 Mpa.

Maximum displacement = 1.54 mm.

Maximum displacement including thermal load= 10 mm.

4.1.5 Thermal structural analysis (case 6)

A fixed slab of dimension 3m x 5m is analysed with a pressure of 3500 N/m^2 and compared with a slab of same dimension excited to a temperature of 1016 °C at the bottom and 30°C (room temperature) at the top surface for time duration of **90 min**.

The displacement along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.25 respectively.

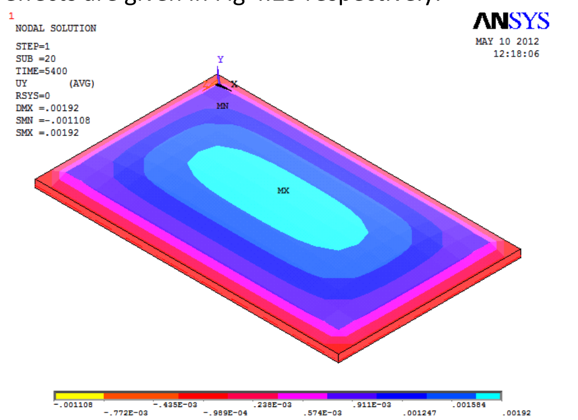

Fig 4.25 Displacement considering both thermal and applied load

The elevation of temperature of 6 nodes with respect to time along the cross section of the slab at mid span is as given in Fig 4.26 and Fig 4.27.

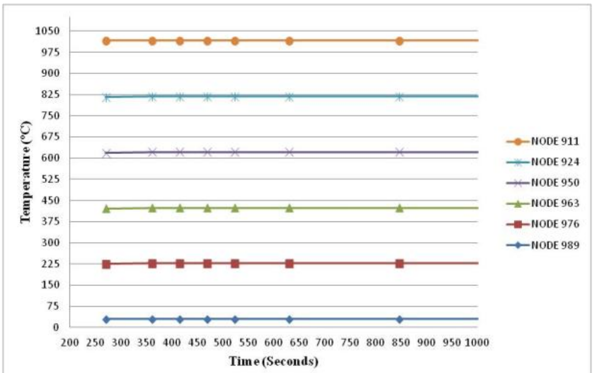

Fig 4.26 Temperature variation with time along the c/s of slab

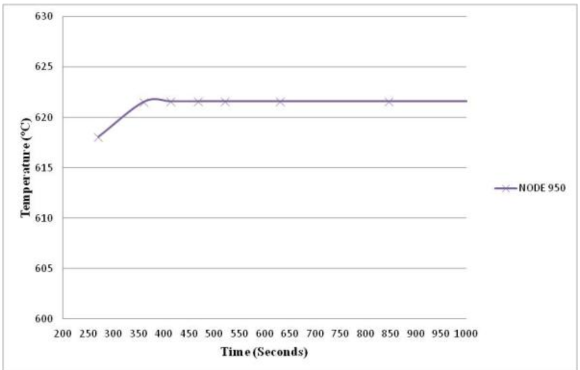

Fig 4.27 Temperature variation of a node with respect to time

The variation of temperature along the cross section at six different nodes spaced at 25 mm at the mid span of the slab with respect to temperature is given in Table 4.6.

Table 4.6 Time-Temperature variation along cross section of slab

Time (Sec)	Temperature (ºC)					
	Node 911	Node 924	Node 950	Node 963	Node 976	Node 989
270	1016	816.148	618.055	421.331	225.454	30
360	1016	818.76	621.54	424.343	227.166	30
414	1016	818.799	621.598	424.398	227.199	30
468	1016	818.8	621.6	424.4	227.2	30
522	1016	818.8	621.6	424.4	227.2	30
630	1016	818.8	621.6	424.4	227.2	30
846	1016	818.8	621.6	424.4	227.2	30
1116	1016	818.8	621.6	424.4	227.2	30
1386	1016	818.8	621.6	424.4	227.2	30
1656	1016	818.8	621.6	424.4	227.2	30
1926	1016	818.8	621.6	424.4	227.2	30
2196	1016	818.8	621.6	424.4	227.2	30
2466	1016	818.8	621.6	424.4	227.2	30
2736	1016	818.8	621.6	424.4	227.2	30
3006	1016	818.8	621.6	424.4	227.2	30
3276	1016	818.8	621.6	424.4	227.2	30
3546	1016	818.8	621.6	424.4	227.2	30
3816	1016	818.8	621.6	424.4	227.2	30
4086	1016	818.8	621.6	424.4	227.2	30
4356	1016	818.8	621.6	424.4	227.2	30
4626	1016	818.8	621.6	424.4	227.2	30
4896	1016	818.8	621.6	424.4	227.2	30
5166	1016	818.8	621.6	424.4	227.2	30
5400	1016	818.8	621.6	424.4	227.2	30

The bending stress along the cross section of the slab due to the applied loads and including temperature effects are given in Fig 4.28 respectively.

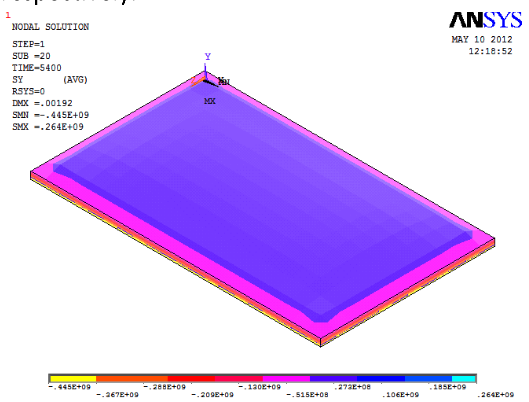

Fig 4.28 Bending stress considering both thermal and applied load

RESULTS:

Maximum bending stress = 145.32 kPa.

Maximum bending stress including thermal load= 264 Mpa.

Maximum displacement = 1.54 mm.

Maximum displacement including thermal load = 10 mm.

4.2 LIMITING DEFLECTION CRITERIA

The thermal structural analysis determined the magnitude of deflection in two-way slab of 5m span subjected to static and fire load at various time intervals. The results were obtained for each 30 min time intervals.

Time-temperature curve specified by IS 1309:1979 was used to simulate the transient fire temperature. Downward deformation exceeding L/30 was considered as the failure criteria. Here the failure criteria is 83.33 mm. Fig 4.29 shows the post mid span downward deflection Vs fire exposure time plot of fixed and simply supported slabs.

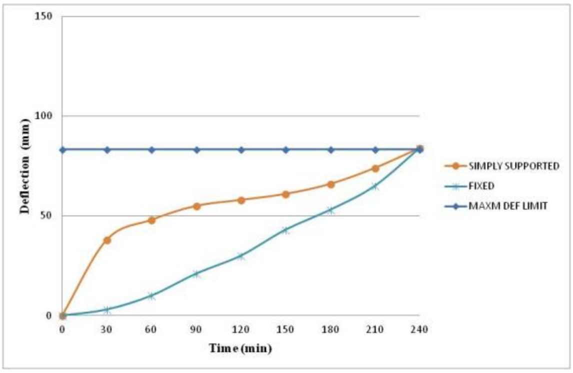

Fig 4.29 Post mid span downward deflection Vs fire exposure time

CONCLUSION

- The study shows that the slab thickness has a significant effect on the fire resistance of the concrete slabs and fire resistance increases with the slab thickness.
- Fire resistance of reinforced concrete slabs is significantly influenced by the thickness of concrete cover to steel. Slabs with greater cover thickness provide higher resistance.
- The model's predictions of the thermal response of concrete slabs subjected to IS 3809 and ASTM E119 with available experimental results is found to be satisfactory.
- It was observed that the applied service load level has little influence on slab deflection under fire scenario.
- Proposed design curves based on thermal criteria can be utilized to determine the fire endurance of one way slabs with different thicknesses, concrete cover to bottom steel and type of steel reinforcement.

REFERENCES

[1] Bushev V. P., Pchelintsev V.A., Fedorenko V.S., and Yakovlev A.I. (1972),'Fire Resistance of Buildings', Moscow: Construction Literature Publishers.

[2] Cooper L.Y. and Franssen J.M. (1999), 'A basis for using fire modelling with 1-D thermal analyses of partitions to simulate 2-D and 3-D structural performance in real fires', *Fire Safety Journal*, Vol. 33, pp. 115-128.

[3] Concrete Reinforcing Steel Institute (1980),'Reinforced Concrete Fire Resistance', Chicago.

[4] Hurst James P. and Ahmed Gamal N. (1998),'*Validation and application of a computer model for predicting the thermal response of concrete slabs subjected to fire*', Vol. 95, pp. 480-487.

[5] Kirby B.R. (2004), 'Calibration of Euro code 1: action on structures – Part 1.2: action on structures exposed to fire', *The structural Engineer,* Journal of the Institution of Structural Engineers, London, UK, Vol. 82, pp 38-43.

[6] Kodur V.K.R and Bisby .L (2005),'Evaluation of fire endurance of concrete slabs reinforced with fibre-reinforced polymer bars, *journal of structural engineering,* Vol. 131, pp 34-42.

[7] Lie T.T. and Lin T.D. (1985),'*Fire performance of reinforced concrete columns*', Fire Safety: Science and Engineering, Philadelphia, pp. 176-205.

[8] Lie T.T. (1992),'Structural Fire Protection. (Technical Report No. 78)', New York: American Society of Civil Engineers.

[9] Linus Lim (2004), 'computer modelling of restrained reinforced concrete slabs in fire conditions, *journal of structural engineering,* Vol. 130, pp. 1964-1971.

[10] Munukutla V.R. (1989), '*Modelling fire performance of concrete walls* (Research Report No. 89/5)', Christchurch, New Zealand: Department of Civil Engineering, University of Canterbury.

[11] Malhotra H.L. (1982),'*Design of Fire resisting Structures*, First Edition, Surrey University Press, New York.

[12] Wade C. (1993),' Summary report on a finite element program for modelling the thermal response of building components exposed to fire (Study Report No. 51), Judgeford: BRANZ, The Resource Centre for Building Excellence.

[13] Indian standard code of practice for fire resistant test of structures, IS 3809:1999, Bureau of Indian Standards, New Delhi.

[14] Indian standard code of practice for plain and reinforced concrete, IS 456:2000, Bureau of Indian Standards, New Delhi.