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Behaviour of steel structure under the effect of fire loading

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ABSTRACT
Performance of steel structures in fire depends upon a number of variables such as material degradation at elevated temperature and restraint stiffness of members surrounded by fire. In order to face minimal structural damage, limited casualties particularly in high rise structures and for the purpose of selecting suitable fire resisting measures structural response to fire need to be understood. Carrying out experiments on actual steel structure is not always feasible as it requires time, money, space and controlled fire as well hence the use of finite element software's like ANSYS is the best alternative instead. The material properties that affect the behavior of structural steel members exposed to fire have been reviewed. Global structural response of simple steel building is studied by considering three different scenarios to have an understanding of interaction of structural elements.
Keywords- fire load, heat transfer, ISO 834, thermal analysis, ANSYS, Global structural response of simple steel building.

I. INTRODUCTION

Structural steel has been widely used throughout the world. It is one of a designer's best options in view of its advantages over other materials. Steel is available in a range of discrete size, and its ductile behavior allows plastic deformation upon yielding, therefore avoiding brittle failures. In reinforced concrete structures, steel enhances the concrete strength by carrying the tensile forces. It is also commonly used to reinforce timber constructions. In spite of its advantages, steel on its own is vulnerable in fire. Elevated temperatures in the steel cause reduction in its strength and stiffness which eventually leads to failure due to excessive deformations. This is crucial in steel in compared with concrete or timber members as steel conducts heat very well and often comes in thin or slender elements.

Fire has always been a very destructive natural phenomenon. There have been countless occasion s throughout the history of make kind in which people lost valuable goods, estates, of even their lives because of fire accidents. In welfare, fire has been used as weapon against enemy structure, fortification, and houses. It's severe damaging effects on structure, which could range from a building being functionally disabled up to it's collapse, have been known for centuries.

Review of Prior Work

Stress-strain –temperature relationship for structural steel: K.W. poh,(2001). A study of the effect of high temperature on structural steel framing: konstantinousmiamis,(2007). Design of steel structures under fire loading: sanjeevam,(2005). Structural Analysis of Steel Structures under Fire Loading: C. Crosti,(2009). Effect Of Support Conditions On Steel Beams Exposed Of Fire,(2004). The Behavior of Steel Columns in Fire : Jacqueline Pauli. (2012). Fundamental principle of structural behavior under thermal effects: A.S. Usmani, J.M. Rotter, S. Lamont, A.M. Sanad, M.Gillie, (2001). The Role of Connections in the Response of Steel Frames to Fire: Andrea Frangi& Markus Knobloch. (2007). Behavior of Steel plate connections subjected to fire loading: Serdar Selamet and Maria Garlock, (1995). Ultimate Temperature of Steel Columns subject to Thermal Elongations of Adjacent Beams at Fire: Fuminobu Ozaki,(2005). Analysis Of Thermally Induced Forces In Steel Columns Subjected To Fire: C. HO,(2010)

II. METHODOLOGY

The science of heat transfer is an important aspect in the study of structural performance during a fire vent. Heat transfer mechanisms involve numerous mathematical equations that describe the temperature distribution through a structure/material. Heat transfer is a discipline of thermal energy and heat between physical systems. Engineers also consider the transfer of mass of differing chemical species, either cold or hot, to achieve heat transfer. While these mechanisms have distinct characteristics, they often occur simultaneously in the same system.

2. 1 Finite Element Method:

FEM is best understood from its practical application, known as finite element analysis (FEA). FEA as work or suggest applications and extensions. applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements, as well as the use of software program coded with FEM algorithm.

2.2 ANSYS:

Software features: ANSYS is general purpose tool used to computer –simulate thermal problems. The version of ANSYS which is used for this project is Version, and it was developed in 1970 by Dr. John A. Swanson as Swanson Analysis Systems, Inc. SASI. ANSYS provides the user with a single, integrated, graphical and interactive environment for model generation, execution and post-processing of the results. The provision of command prompt and session editor to facilitate data input for avoiding common input errors makes ANSYS a user friendly software. The generation of brick elements and full use of boundary conditions helps in developing the model more precisely in order to achieve reasonable results. Three-dimensional geometry can be created using two-dimensional plate and Three-dimensional brick element. The addition of heat sources in the form of condition and convection sources facilities the process of modeling heat transfer. Arrays for different properties and parameters, such as thermal conductivity, specific heat, and temperature can be provided in the form of temperature, temperature difference. Heat loads can be supplied at specified points, locations or regions in the form of nodal or surface loads. ANSYS uses a finite elements technique to model and solve the governing equation. This offers the versatility to easily create complex models involving many of nonlinear cases often encountered. These 43 include radiation, temperature-dependent thermal conductivity

3.3 Modeling and Result Output:

ANSYS is the software which deals with the problem with finite element analysis principles. Modeling and analyzing steel structure for general problem either structural or thermal could be done in following ways:

In this, initially geometry of structure is created and then material properties are given as per the selected material.

Then Element type is selected (depending upon the structure type e.g. for beam BEAM 188, for truss member link1, for solid structure member solid 185 etc.)

After modeling and material selection, meshing is done. Depending upon degree of accuracy mesh size is finalized

Now, next step is to select analysis type (steady state or transient or time step based), any one of this one has to define at this step.

Then the model is loaded (i.e. dead load, live load etc.)

Finally analysis is done by selecting “solve current LS” option

Results are obtained from general “postprocessor” tab. (i.e. shear force diagram, bending moment diagram, stress intensity, principle stresses, deflections etc.)

2.4 Limitations:

One of the drawbacks of ANSYS is that it does not handle combined structural-thermal analysis with single element type. For combined analysis it is required to go for thermal analysis first with a particular element type, then by switching element type and by importing thermal analysis results, structural analysis can be done. This is collectively known as couple field analysis.

III. ISO834 FIRE

ISO 834 is a standard fire used as input in computer analysis. It is the international standard of time-temperature curve, which is defined by

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

Where, t is time in minutes and T_o is the ambient temperature in degree Celsius.

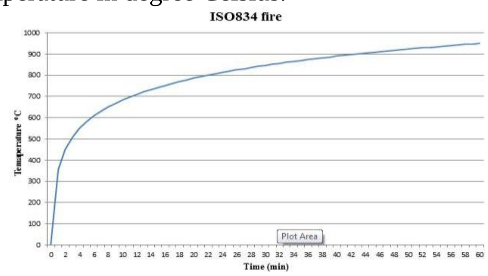


Fig.1. ISO fire834 time-temperature curve

IV. MATERIAL PROPERTIES

Material degradation should be considered for analysis of structure subjected to fire. Guidelines are provided in Eurocode 1993-1-2 [8] are summarized below.

4.1. Mechanical properties

Unit mass: The unit mass of steel is independent of temperature. Its value is taken as 7850kg/m3

Ultimate and yield strength: The generalized stress-strain relationship is described in the Eurocode. It is

used to obtain the strength and deformation properties of steel to determine the resistance to tension, compression, moment or shear.
Coefficient of thermal elongation: Thermal elongation is assumed as function of temperature as given in eurocode3, shown in fig.7

4.2. Thermal properties

Conductivity and specific heat: variation of thermal conductivity and specific heat can be obtained from formulas given in Eurocode 3.

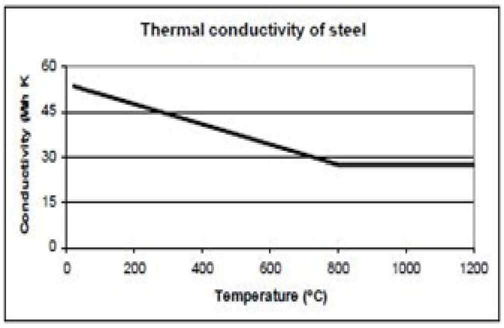


Fig.2 Thermal conductivity of steel as a function of temperature

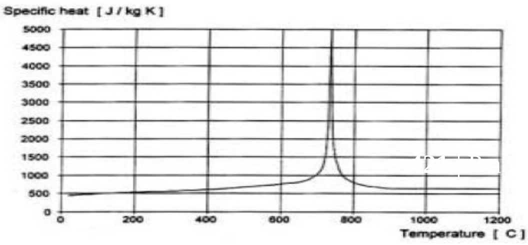


Fig.3 Specific heat of steel as a function of temperature

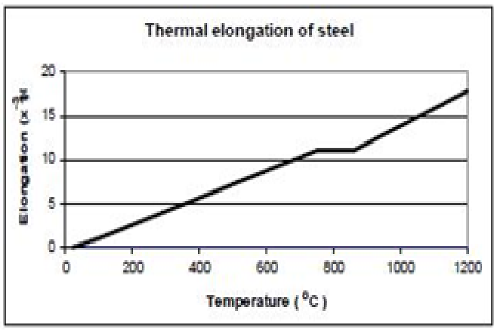


Fig.4 Thermal elongation of steel as a function of temperature

V. MODEL VALIDATION

The analyses are based on investigation work of J.Seputro [16] on a single span steel beam supported at both ends. A span of 8m of universal I-beam, 610UB101 with the dimensions and properties lay out in Table 4.1.Uniformly distributed static load. of 25KN/m is acting on beam. Flange bottom face of beam is subjected to fire load. At ambient conditions, the yield strength and the elastic modulus of the steel are 430 MPa and 210 GPa respectively, with a Poisson's ratio, μ of 0.3. The beam is analyzed for four types of support conditions. And deflection behavior is observed in each case.

Table 1 At elevated temperature deformation of I section with two software

SR NO	Temperature in ^{0}C	Deformation at mid-point of span In meter	
		ABAQUS 6.12-3 (as per graph plot)	ANSYS 16 (as per analysis)
1	100	0.013	0.016
2	400	0.067	0.08
3	600	0.092	0.12
4	700	0.140	0.14
5	800	0.156	0.16
6	900	0.177	0.18
7	1000	0.198	0.20

VI. EXAMPLE ANALYSIS

6.1Building Configuration:

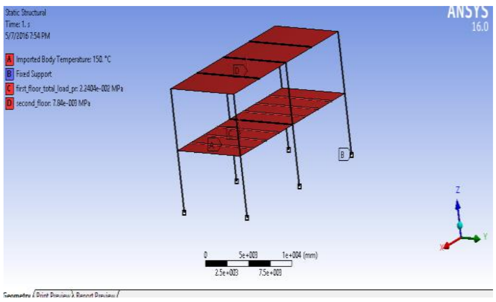


Fig 5 structural loading diagram in ANSYS 16

The structure under inquiry is two story steel framed industrial building, 8 meters long, 4 meters wide, with a maximum height of 8 meters. The first floor slab consists seven primary beams supporting six secondary beams.

First floor slab is made of steel grating and its expansion is allowed by keeping space on either sides there by not allowing steel grating to induce any force on supporting system. All the floor beams are laterally supported by angle sections, hence noticeable effect of lateral torsion buckling is not expected as it reduces unsupported length. AC sheets are provided at roof level.

Following contents show the different values of dead loads and live loads to which first floor is subjected.

- Self-weight of steel grating – 3kN/m2
- Live load – 5kN/m2

Following contents show the different values of dead and live loads to which roof is subjected.

- Dead load (Roofing Material) – 2kN/m2
- Live load – 0.75kN/m2

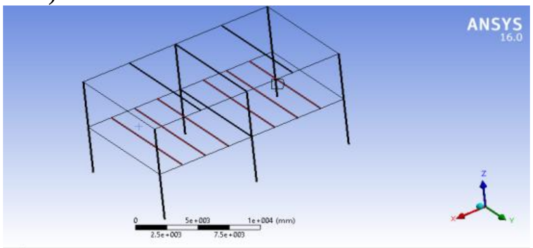
Peripheral beams are subjected to an additional load of brick wall of 1.2m height, density of which is 10 kg/m3. first floor system supports six equipment's of 0.5 tone each. All the equipment's are directly placed on secondary beams. Wind load is not considered for many reasons like small height of building, high amount of ventilation availability and presence of heavy mass makes earthquake loads as the governing one. Earthquake load is calculated as per Euro code 8 (part 1.1)

To achieve this, in the first and second cases, fire only applied to the primary and secondary beams on ground floor. In the third cases, fire applied to the first floor which involves secondary beam, primary beam and column. Third test is conducted on first floor to have simplicity in understanding the interaction.

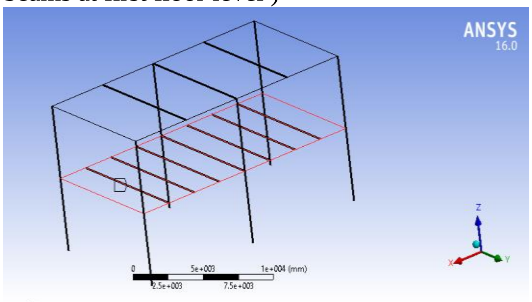
Table 2 following table shows section obtained from STADD analysis

SR NO	DESCRIPTION	STEEL SECTION
		(As per IS code)
	FIRST FLOOR	
1	9 m peripheral beams (along 18 m)	ISWB 350
2	10 m peripheral beams (along 10 m)	ISWB 350
3	10 m inner primary beams (along 10 m)	ISWB 350
4	10 m secondary beams (0.5 Tn m/c)	ISMB 300
	TERRACE LEVEL	
5	9 m peripheral beams (along 18 m)	ISWB 350
6	10 m peripheral beams (along 10 m)	ISWB 350
7	10 m inner primary beams (along 10 m)	ISWB 350
8	10 m secondary beams (0.5 Tn m/c)	ISMB 300
9	Columns (ground floor)	ISHB 400
10	Columns (first floor)	ISHB 400

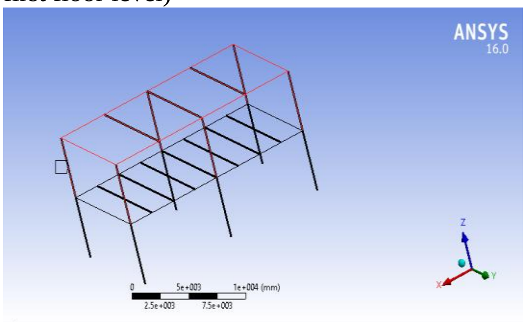
1st CASE: (Fire load to secondary beams at first floor)



2ND CASE: (fire load to secondary and primary beams at first floor level)

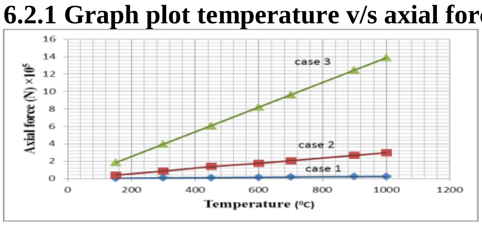


3RD CASE: (Fire load to secondary beams and primary beam at second floor level and column at first floor level)

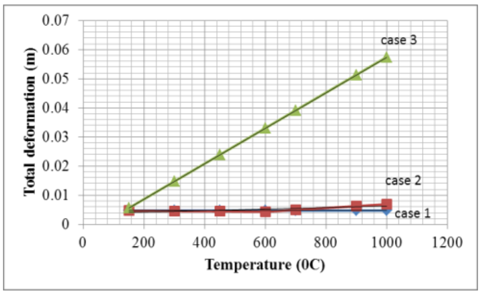


6.2 Result and Output

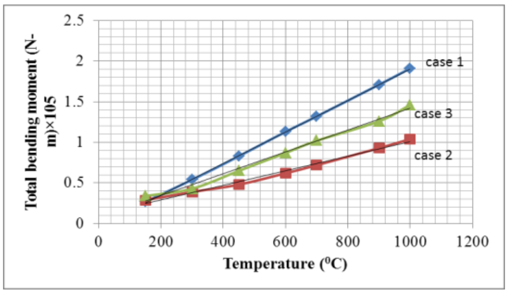
6.2.1 Graph plot temperature v/s axial force



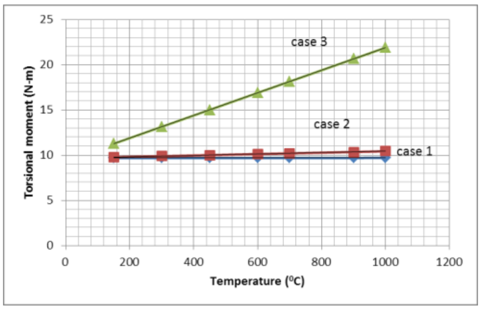
6.2.2 Graph plot temperature v/s total deformation



6.2.3 Graph plot temperature v/s total bending moment



6.2.4 Graph plot temperature v/s torsional moment



VII. CONCLUSION

Following conclusions are drawn from the analysis work done.

1. With finite element program, the study of heat transfer in any structure subjected to thermal loads becomes easy and less effort consuming.
2. With previous research work, degradation behavior of material is standardized and is modeled for analysis of structure subjected to fire. Standard fire curves like ISO834 can be modeled for analysis as it is temperature vs. time curve. Hence response of structure can be noted related to time and provisions can be made in fire safety design.
3. Due to static load present on structure and material is degraded to elevated temperature; deflection is excessive at fire case than that at ambient temperature in steel beam. At around 600^{0}C temperature, deflection of beam is ten times than deflection at ambient temperature condition. And at around 900^{0}C and above temperature, deflection is hundred times of that at ambient temperature.
4. When temperature reaches more than 600^{0}C, deflection of beam increases excessively as material properties changes to large extend at this temperature.
5. Global behavior of deflection of Fire load to secondary beams and primary beam at second floor level and column level is Three times more than reaming two cases
6. Finite element program ANSYS 16 deals successfully with fire loading and modeling of degradation of material properties and stiffness. With finer mesh and correct element type for analysis accuracy can be achieved.

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