

STRUCTURAL BEHAVIOUR UNDER EXTREME THERMAL CONDITIONS

Avuthu Sagar Reddy¹, Batta Jaya Naga Satish

¹PG Student, Structural Engineering, VFSTR Deemed to be University, sagarreddya1994@gmail.com

²Assistant Professor, Department of Civil Engineering, VFSTR Deemed to be University, satishbjnvnignan@gmail.com

Abstract – In the structural point of view steel structures are more popular because of its strength and ductile properties. This ductile property of steel is playing a major role during the earthquakes. In some of the cases there has an impact of fire after the earthquake. This fire may induce extreme thermal stresses in the structure and steel is more vulnerable to extreme thermal conditions. This research mainly focuses on the behavior of a steel building under extreme temperatures after the event of earthquake. In this research a G+3 storey steel building has been modeled and analyzed according to the current design practices using IS 800-2007. In this research a uniform temperature distribution has been assumed across the structure. The structure has been analyzed for Gravity load, Seismic Load and for Thermal Conditions by using a Finite Element Package ANSYS 16.0. The variation of the deformation, principal stress, and shear stress, steady state temperature of steel structure under different thermal conditions and the breaking thermal point of the structure has been observed. Detailed parametric study has been conducted to identify the failure case thermal condition of the structure. The effects of steady state thermal across the structure have been discussed in detail as a part of this research.

Key words: - Steel, Thermal analysis, Steady State Thermal analysis, ANSYS software.

I. INTRODUCTION

In India, every year, approximately **25,000 persons die** due to fires and related causes. According to the National Crime Records Bureau (NCRB), fire accounts for approximately **5.8% (23,281)** of the total deaths reported due to natural and unnatural causes during the year 2012. Likely many of these deaths might have been prevented, had we taken sufficient fire protection measures, while the national average was approximately 4.4 fires per 1000 population. However, according to estimate of the Indian Insurance Companies in the year 2007-2008 demonstrate that approximately **45% of the claims are due to fire losses**. In U.S.A on **Sept 11, 2001 World Trade Center Building 7**, was collapsed and the primary reason for its collapse has been identified as fire. The collapse could have been prevented if the automatic sprinkler systems had functioned As per other estimate approximately **Rs. 1000 crores lost every year only due to fire**. In 2013, Fire Risk Survey (FRS) was carried out by Pinkerton & Federation of Indian Chambers and Industry, in India, and they said fire **accounted for 8.45% of the overall ranking of risks**. FRS revealed that **fires have been rated as the 5th highest risk in industry in 2013**. Due to the low heat conductivity and larger thermal inertia, concrete is considered to be an inherently safe material from a fire safety point of view (Buchanan, 2001). Steel structures are generally considered to be more susceptible to failure in fire. Due to the high conductivity and smaller thermal inertia of steel members, steel structures require application of a fire protective material to keep the steel from heating up rapidly. The fire safety of structural components is rated based on the time it takes for steel members to reach a particular temperature .By increasing the thickness of the insulating material; temperature rise in the steel can be slowed. However, it is estimated that fire protection can cost up to 30% of the total construction cost of a steel building (Lawson, 2001).

II. LITERATURE REVIEW

Anil Agarwal, et al (2016) observed that the behavior of axially loaded steel columns subjected to thermal gradients through their cross sections. Experimental tests were conducted on full-scale wide-flange steel columns with W8 × 35 and W14 × 53 sections made from standard grade 50 steel. Thermal gradient along the flanges caused bowing of column specimens toward the hotter side.

A.S. Usmani ,et al(2001) implemented their work on theoretical descriptions of the key phenomena that govern the behaviour of composite framed structures in fire. These descriptions have been created in parallel with large scale computational work undertaken as a part of a research to demonstrate the full-scale fire tests on composite steel framed structure at Cardington (UK). Behaviour of composite structures in fire has long been understood to be dominated by the effects of strength loss caused by thermal degradation, and that large deflections and runaway resulting from the action of imposed loading on a 'weakened' structure. Thus 'strength' and 'loads' are quite generally believed to be the key factors determining structural response

Graeme Flint, et al (2007) implemented their work on investigation of the effects of fire on long span truss floor systems in a tall building environment. The local and global response of the model is described over the course of a concurrent fire on three floors reaching a peak compartment temperature of 800°C

III. LOADS ON STRUCTURE

DEAD LOAD - It is a gravity load due to the structure essentially calculated as the product of volume and material density of the structure.

Dead Load=Thickness of Slab *Density of Steel = (0.05m)*(78.5Kn/m³) = **3.925KN/m²**

IMPOSED LOAD - The imposed loads to be assumed in the design of buildings might be the greatest loads that likely will be produced by the intended use or occupancy, but should not be less than the equivalent minimum loads. In our analysis only Commercial building loads are considered.

Live Load=**2.5KN/m²** , Live Load On Roof=**1.25KN/m²** as per IS 875 PART-2

SEISMIC LOAD - If a structure is situated in an earthquake prone region, the earthquake or seismic forces are given due consideration in the analysis. An earthquake causes vertical and horizontal forces in the structure that will be proportional to the weight of the structure. IS: 1893 Part-1 is referred for the actual design loads.

$A_h = (S_a / g) * (I/R) * (Z/2)$, For Medium Soil Sites $S_a / g = 2.50$ (Based on T Value) $T = (0.075 * h^{0.75}) = 0.55$

Seismic Weight(W)= 31.048KN

THERMAL LOAD- It is characterized as the temperature that causes the impact on buildings, such as outdoor air temperature, solar radiation, underground temperature, indoor air temperature and the heat source equipment inside the building.

IV. THERMAL ANALYSIS

II. www.slideshare.net

III.

Thermal analysis is a branch of materials science where the properties of materials are studied as they change with temperature. A few methods are commonly used from one another by the property which is measured. Thermal analysis is carried out for the structure at different thermal conditions (200°C, 300°C, 400°C, 500°C, 600°C) to identify the variation of the structure in deformation, principal stress, shear stress and also directional deformation. This process is carried out in two processes one is with earthquake load and other is without earthquake load.

V. STEADY STATE THERMAL ANALYSIS

Steady state thermal calculates the effects of thermal loads on a system/component/structure .It determines temperature, thermal gradients, heat flow rates of a object that are caused by the thermal loads which do not vary overtime. It may be either linear, with stable material properties or non linear with material properties that depend on temperature. The thermal properties of most materials will vary with temperature. So, analysis is non linear.

VI. IMPACT OF FIRE ON STEEL

The strength of all engineering materials reduces as their temperature increases. Steel has no exception. In any case, a major advantage of steel is that it is incombustible and it can completely recover its strength when undergoes fire. During the fire steel absorbs a significant amount of thermal energy. After this exposure to fire, steel returns to a steady condition after cooling to ambient temperature. With in the process of warming and cooling, steel members can be slightly damaged, without influencing the strength of the total structure. From the point of view of economy, a significant number of steel members may be salvaged following a post-fire review of a fire affected steel structure. Using the principle “If the member is straight after exposure to fire – the steel is O.K”, many steel members could be left undisturbed for the rest of their service life. Steel members which have slight deformity might be reusable by using simple straightening strategies with its specified mechanical properties. The members which have become unusable due to excessive deformation may simply be scrapped. In effect, it is easy to retrofit steel structures after fire. On the other hand concrete exposed to fire beyond say 600°C, may undergo an irreversible degradation in spalling and mechanical strength.

VII. DESCRIPTION OF STRUCTURAL MODEL

Considering the demands from the analysis tool it was decided that a commercially available FEM based software will be used for modeling and analyzing the building system. Commercial software's tend to offer a large pool of finite elements and material models to pick from, which helps in greater flexibility for modeling different aspects of the building behaviour in fire. Moreover, the mathematical solvers of these software's are better optimized for different types of analysis procedures. As the emphasis of the present research work is on the behaviour aspects of a building and not the development of an analysis tool, it was decided that a popular FEM based software ANSYS WORKBENCH 16.0 will be used for the heat transfer as well as the structural analysis part of the case study. A three-storey building was designed according to current building codes and design specifications, Specification for Structural Steel Buildings (IS: 800 : 2007 – Code of Practice for general construction in Steel) and for fire safety IS1642:1989 is used. Each story of the building is 3 m high and length 16 m high. There are a total of 25 equally spaced columns in the building. The plan layout is shown in Figure 1.

Design Requirements: The building is designed for recommended combinations of dead load (IS 875 PART -1), live load (IS 875 PART-2), and earthquake load (IS 1893 PART-1 2002). All the floors are designed for nominal dead loads and live loads equal to 3.925 kN/m² and 2.0 kN/m² respectively. The building comes under seismic design category zone 3 and the seismic load is 31.816 kN.

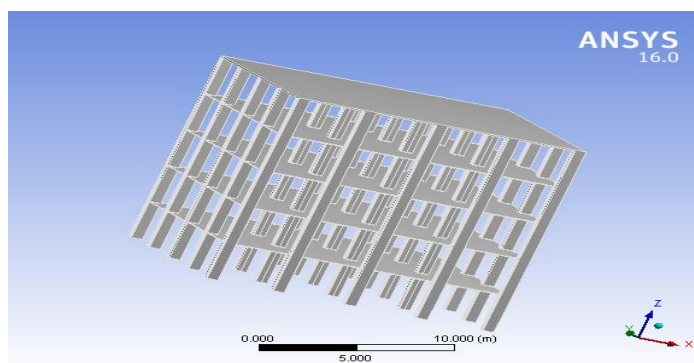


Figure – 1: Structural plan of a building

VIII. RESULTS AND DISCUSSIONS

To check the behavior of the structure at different thermal conditions by considering the earthquake load and also without it. Breaking point temperature was also noticed during the analysis process and also floor wise analysis was done for the structure in steady state thermal condition. The complete results were discussed below. Different graphs were plotted at various temperatures for structure and also detailed graphs were drawn for the total deformation, directional deformation, principal stress, shear stress and temperature of the structure.

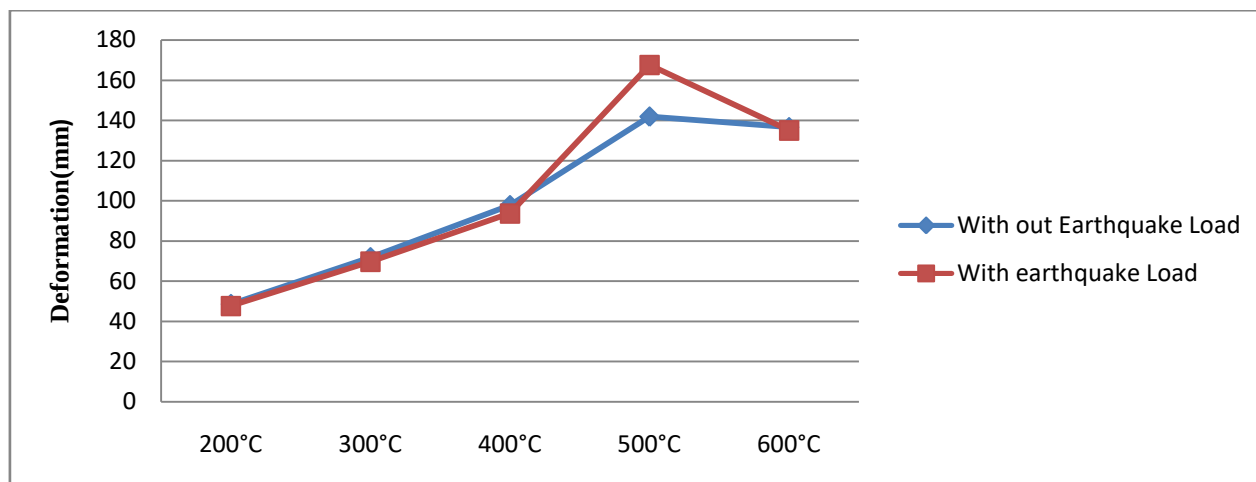


Figure-2 Deformation of the Structure in Thermal Analysis

Table 1: Thermal Analysis Deformation of Structure

Without Earthquake Load		With Earthquake Load	
Temperature	Deformation(mm)	Temperature	Deformation(mm)
200 ⁰ C	48.60	200 ⁰ C	47.70
300 ⁰ C	71.90	300 ⁰ C	69.70
400 ⁰ C	97.80	400 ⁰ C	93.70
500 ⁰ C	141.90	500 ⁰ C	167.50
600 ⁰ C	136.60	600 ⁰ C	135

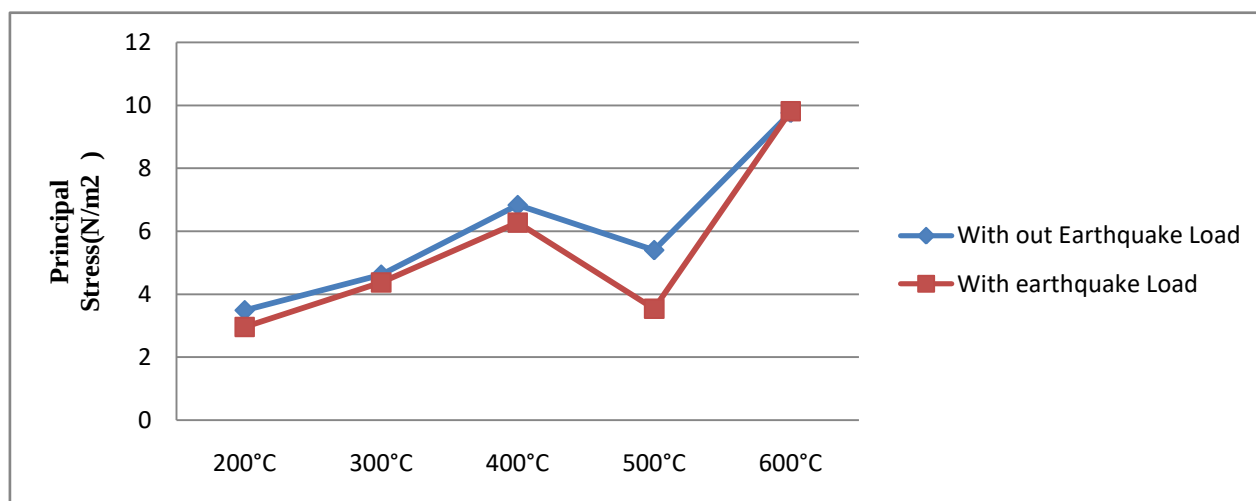


Figure-3 Principal Stress of the Structure

Table 2: Principal Stress of Structure

With out Earthquake Load		With Earthquake Load	
Temperature	Principal Stress(N/m ²)	Temperature	Principal Stress(N/m ²)
200 ⁰ C	3.49	200 ⁰ C	2.96
300 ⁰ C	4.62	300 ⁰ C	4.37
400 ⁰ C	6.83	400 ⁰ C	6.27
500 ⁰ C	5.40	500 ⁰ C	3.54
600 ⁰ C	9.76	600 ⁰ C	9.81

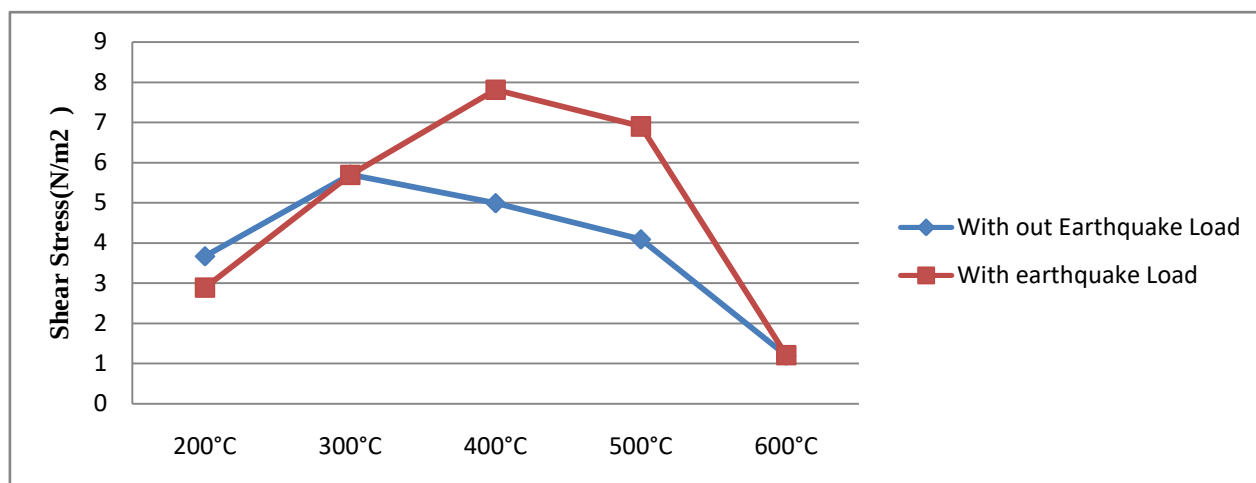


Figure-4 Shear Stress of the Structure

Table 3: Shear Stress of Structure

With out Earthquake Load		With Earthquake Load	
Temperature	Shear Stress(N/m ²)	Temperature	Shear Stress(N/m ²)
200 ⁰ C	3.67	200 ⁰ C	2.89
300 ⁰ C	5.70	300 ⁰ C	5.69
400 ⁰ C	4.99	400 ⁰ C	7.81
500 ⁰ C	4.09	500 ⁰ C	6.90
600 ⁰ C	1.20	600 ⁰ C	1.21

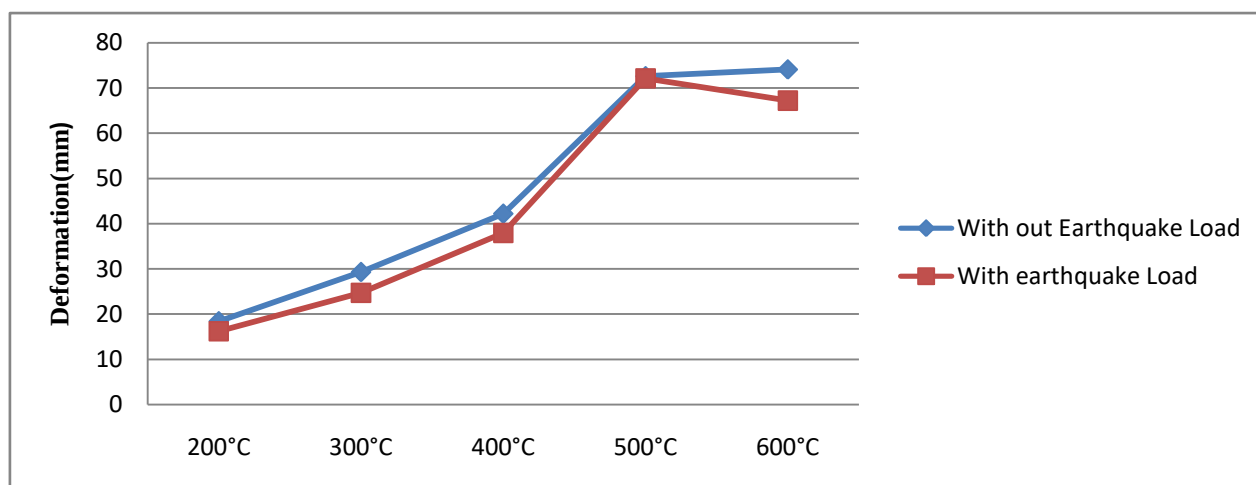


Figure-5 Deformation of the Structure in Steady State Thermal Analysis

Table 4: Steady State Thermal Analysis Deformation of Structure

With out Earthquake Load		With Earthquake Load	
Temperature	Deformation(mm)	Temperature	Deformation(mm)
200 ⁰ C	18.40	200 ⁰ C	16.20
300 ⁰ C	29.30	300 ⁰ C	24.70
400 ⁰ C	42.20	400 ⁰ C	37.90
500 ⁰ C	72.60	500 ⁰ C	72.10
600 ⁰ C	74.10	600 ⁰ C	67.20

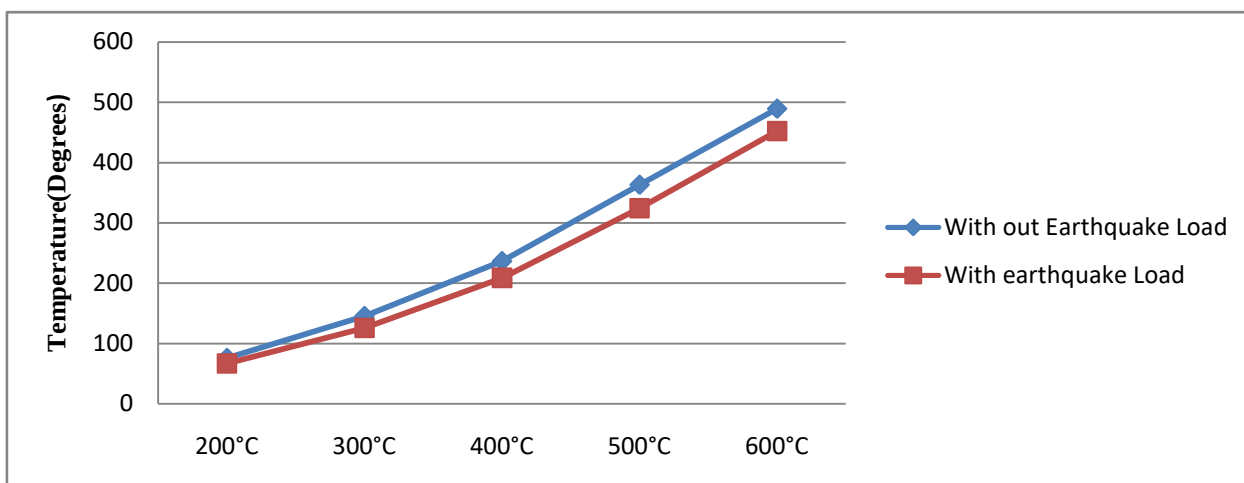


Figure-6 Temperature Variation of the Structure in Steady State Thermal Analysis

Table 5: Steady State Temperature of the structure

With out Earthquake Load		With Earthquake Load	
Temperature	Steady State Temperature(Degrees)	Temperature	Steady State Temperature(Degrees)
200 ⁰ C	76.14	200 ⁰ C	67.17
300 ⁰ C	145.67	300 ⁰ C	125.83
400 ⁰ C	236.79	400 ⁰ C	208.96
500 ⁰ C	363.40	500 ⁰ C	324.30
600 ⁰ C	489.51	600 ⁰ C	452.29

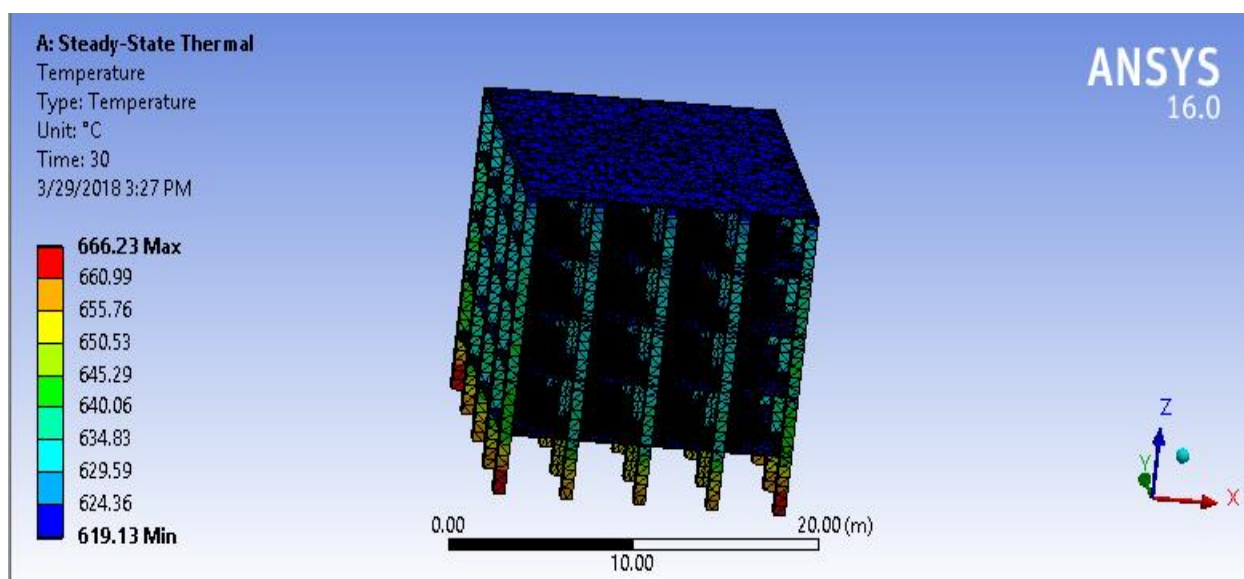


Figure 7 Breaking Point Temperature of the structure in Steady State Thermal Condition.

The above tables give performance of the structure under various thermal conditions. In each condition different thermal values were applied on the structure. The performance was carried out in two stages one is without considering earthquake load and other is by considering the earthquake load. Thermal analysis also carried out in the same process. Steady state thermal analysis is carried out in two process one is giving different thermal values on the building and other analysis was carried out in floor wise also and there is a slight variation in the results. Breaking point thermal value was also identified and the value is 620 degrees. At this thermal value the steady state temperature was crossed the given thermal value and this was identified the breaking thermal point of the structure. At 620 degrees centigrade the structure has shown variation in the temperature results for entire structure as well as floor wise analysis also.

IX. CONCLUSIONS

The following are the observations drawn from the present analysis

1. Performance of the steel structure for different thermal conditions has been performed with and without earthquake load and there is a slight variation in the results of the both cases.
2. From the graphs we have been observed that deformation, principal stress, shear stress, temperature have been varied slightly in thermal analysis and steady state thermal analysis.
3. For the case of thermal analysis the stresses are gradually varied at the different temperatures .
4. Steady state thermal analysis values have been varied with the normal analysis and thermal analysis.
5. Breaking point of the structure was identified at 620⁰ C at this point the structure has crossed the given temperature value.
6. Comparison of the behavior of these buildings brings out the fact that good structural engineering practices can save a building in fire conditions and approach has been used for designing buildings for fire safety.
7. According to the simulation results, fire safety materials are the most important components for overall structural stability in fire conditions. If all the structural components are protected for equal FRR value, then structure will have capability to resist under thermal conditions.

X. REFERENCES

- [1] IS 875(Part-1), "Code of Practice for Design Loads (Dead Load) ", *Bureau of Indian Standards*, India, 1987.
- [2] IS 875(Part-2), "Code of Practice for Design Loads (Live Load) ", *Bureau of Indian Standards*, India, 1987.
- [3] IS 1893 (Part-1), "Criteria for Earthquake Resistant Design of Structures", *Bureau of Indian Standards*, India, 2002
- [4] IS 800 , "Code of practice for general construction in steel ", *Bureau of Indian Standards*, India, 2007.
- [5] IS 1642 , "Code of practice for fire safety of buildings (general): Details of construction", *Bureau of Indian Standards*, India, 1989
- [6] ANSYS(2014), "ANSYS Release 16.0 WORK BENCH User's manual guide", ANSYS Inc;Canonsburg,PA.
- [7] Lisa Choe, Anil Agarwal, Amit H. Varma, "Steel Columns Subjected to Thermal Gradients from Fire Loading", *American Society of Civil Engineers*, 2016.
- [8] Amit H. Varma, Anil Agarwal, Andrea Surovek, "Fundamental Behavior of Steel Beam-Columns and Columns under Fire Loading", *American Society of Civil Engineers*, 2011.
- [9] Anil Agarwal, Amit H. Varma, "Fire Induced Progressive Collapse of Steel Building Structures", *School of Civil Eng., Purdue Univ., West Lafayette, IN 47907*.
- [10] A.S. Usmani, J.M. Rotter, S. Lamont, A.M. Sanad, M. Gillie "Fundamental principles of structural behaviour under thermal effects", *Fire Safety Journal* 36 (2001) 721–744/722.
- [11] Anil Agarwal, Kristi L. Selden, and Amit H. Varma, "Stability Behavior of Steel Building Structures in Fire Conditions", *Journal of Structural Fire Engineering* Volume 5 · Number 2 June 2014.
- [12] NIST NCSTAR 1-9 (2008), Structural Fire Response and Probable Collapse Sequence of World Trade Center Building 7, *National Institute of Standards and Technology, Gaithersburg, MD*.
- [13] Lie, T.T. and Almand, K.H. (1990), "A Method to Predict Fire Resistance of Steel Building Columns," *Engineering Journal*, AISC, pp. 158-167.
- [14] Lawson, R.M. (2001), "Fire Engineering Design of Steel and Composite Buildings", *Journal of constructional steel research*, Vol.57, pp.158-167.
- [15] Anil Agarwal, Amit H. Varma (2009), "Behavior of Floor Systems under Realistic Fire Loading", *Proceedings of the 2009 Structures Congress*, ASCE.