Thermal Structural Coupled Analysis of Steel Beam for Different Support Conditions using ANSYS

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***Abstract*— Economic considerations dictate that building structures be able to resist extreme events, such as a major earthquake or a fire, without collapse but with some structural damage. Steel is one of the alloys that with the high end of application from discrete part to structural member components. Higher load carrying capacity, reduction in cross section area and ease of erection of building with structural and architectural advantages make it a top priority in the construction field. But Steel Structures predominantly are shown a high rate of failure in the case of thermal load, which is one of the major concerns that overtook since last few decades. Hence in the present paper, study is carried out on the behaviour of steel beam when subjected to fire load. Cantilever beam and fixed beams are modeled in ANSYS and coupled thermal – structural analysis is carried out to get displacement and stress variation for different thermal loads. The results showed an increasing displacement and stress magnitude for increasing thermal load.**

Keywords— Thermal analysis, fire loading, stress, coupled analysis.

I. INTRODUCTION

Fire is one of the natural disasters that can affect human life and property. Fire can occur due to the presence of combustible substances like wood, paper etc. Very often fire occurs in buildings due to electrical short circuit. In India majorly used construction material for buildings are RCC buildings and Steel structures. The urbanization and rapid development of the cities requires the construction of high rise buildings and apartments with lesser construction time. Hence steel structures has the more advantages compared to RCC structures for constructing high rise building. But unlike RCC structures, steel structures are less thermal resistant and can be vulnerably affected due to fire. Hence in the present paper, study is carried out on the behaviour of steel beam when subjected to fire load.

II. LITERATURE REVIEW

Bhavana B and Abhishek N Naik (2017) studied the behaviour on non-coated and protective coated steel beam structures under direct thermal loading with relation with the total deformation and stress- strain are investigated with help of FEM based software. In general effects of rising of temperature in the fire hour induce an expansion in beam components. If the expansion is restrained, stress induces over the region of restraining, resulting in the change or rise in deformation. Load bearing capacity of steel structural components drastically reduces in the fire condition. The performance of steel structural components under accidental fire loads is investigated.

Harshad D Mahale and S.B Kandekar (2016) studied material degradation at elevated temperature and restraint stiffness are the different variables on any steel structure when a fire load is applied with the help of advanced structural software. Beam components of the critical section are optimized and processed to thermal analysis. Egle Rackauskaite et al (2017) presented an overview on travelling fire and a traditional design fires in a multi storey steel frame in any large open plan compartments travelling temperature. When 2–38% of smallest travelling fire is applied, irregular oscillations are observed, which are regularly not observed in any of the uniform fire.

Bramhanand V. Patil and Milind S. Ramgir (2016) studied the effect of temperature on mode shape and modal frequency of a steel structure using ANSYS. Crosti (2009) studied the structural response of a simple steel structure building using different scenarios to understand the responses of structural element under different fire loads and also differential behaviour of a steel structure for multiple fire loads. Effect of temperature on mode shape and modal frequency of a steel structure using ANSYS is performed. Madan et al (2016) studied behaviour of steel plane frame under different fire exposure conditions using ANSYS. The performances of different protective materials in FE model under different fire exposure conditions are studied.

Lenka Lausova et al (2016) presented the behaviour of non-linear temperature distributed across a section of steel structure. Increase in temperature result in additive internal forces due to restrained conditions and compared the study of temperature in two different areas, one with non-protected steel hollow cross section of different size and other with protected steel hollow cross section using a Finite Element Analysis. In any steel structural analysis, the performance of steel structures under increased temperature is very important. The performance is considered on the basis of external environmental conditions like water, fire, air etc., considering fire applied on steel structure. The strength and performance of steel structure depends on many different conditions like material degradation at elevated temperature and restraint stiffness of member. In order to face minimal damage fire resisting studies and implementation is to be performed on the structure for which structural behaviour studies are very important. For this study, the Indian Standards I-beams are

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considered, and are exposed to differential temperature conditions with varying time on both solid beam and notched beam. Since the experimental study on actual steel structure is not always feasible as it requires time, money, space and controlled fire, finite element software's like ANSYS is the best alternative. The behaviour of these steel beams is studied under different temperature conditions, for healthy/original/ undamaged and damaged/notched beams.

Hemangi et al (2013) described the structural behaviour of a steel structure when exposed to fire including the earthquake loads with the help of advanced structural FE software. In general effects of rising of temperature in the fire hour induce an expansion in beam components. The reduction in stiffness and strength when a structure is exposed to high temperature is observed. This study gives an overview of material behaviour and tells us how to design and construct steel structures. This paper focused on the characteristics and behaviour of the solid steel beams and notched steel beams when exposed to exponentially increasing fire. Three dimensional Isection steel cantilever beams, ISMB 300@44.2 kg/m steel section, of length 1200mm are considered for the present study. The beam is analysed using ANSYS/Thermal with various fire loads at various interval of time. The beams are modeled as solid beams and notched beams. The results obtained from the coupled structural thermal analysis of solid beam and notched beam are compared.

III. THERMAL ANALYSIS

Thermal analysis includes analysis of structures for different temperatures. The varying temperature input is called thermal load. In thermal analysis, the behaviour of the structure for different rising thermal load and the rate of transfer of the load throughout the structure can be studies. The thermal load can be applied at any single or multiple points on the structure or it can also be applied throughout the structure like uniformly distributed load.

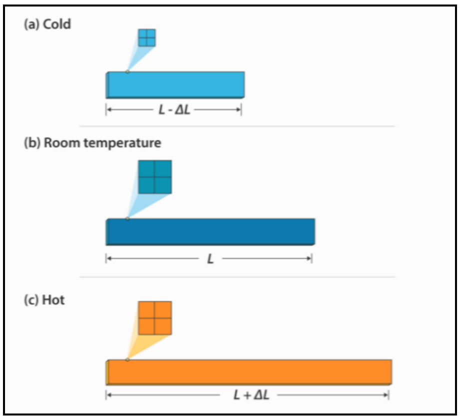

Fig. 1. Effect of temperature on length and cross section of structural member

The parameters that can be studied in thermal analysis are the rate of transfer of heat, intensity of heat at the point of application of load, maximum temperature, thermal gradient, and thermal flux. Displacements, stress variation, stress concentration due to varying thermal loads can also be used for predicting the behaviour of the structure subjected to thermal load. The key requirement will be the material properties of the structure, since the rate of transfer of the heat and the thermal analysis depends on the material. Thus, mathematically thermal stresses can be written as:

$$\sigma_T = E\,\alpha\,\Delta T \qquad (1)$$

Where,
σ_T is the thermal stresses in N/mm^2
E is the Young's modulus of elasticity in N/mm^2
α is coefficient of thermal expansion in /℃
$\Delta T = (T_f - T_i)$ is the change in temperature in ℃
T_i is the initial temperature in ℃,
T_f is the final temperature in ℃

Coupled field analysis in ANSYS provides provision to perform two or more discipline analysis on a structure. This ensures to carry the results of the structure after one analysis to another. For example, in structural thermal analysis, thermal analysis (Steady state thermal analysis or transient thermal analysis) can be performed on the structure first. The results in the form of thermal load transfer through the structure can be obtained. This can be used as the load input, along with other loads (like liveload, dead load, dynamic load) in structural analysis (like static analysis, modal analysis, harmonic analysis, etc) to obtain the structural behaviour results.

IV. MODEL SPECIFICATION AND RESULTS

An ISMB 300 @ 44.2 kg/m steel beam of length 1.2m is modeled in ANSYS with Poisson's ratio 0.3, Density of steel 7850 kg/m^3, Young's modulus of steel 2×10^5 N/ mm^2, Coefficient of Thermal conductivity 45 W/m K and Coefficient of Thermal expansion 12 x 10^{-6} /˚C. Initially thermal analysis is performed for the model, followed by structural analysis by switching the element type and the result of thermal analysis is imported to perform structural analysis. Then static structural analysis is performed and the results such as displacement and stress variation are noted. The thermal loads applied are as shown in Table 1.

TABLE 1. THERMAL LOAD APPLIED ON BEAM

Case	Beam Type	Thermal load applied at right end of beam
Case 1	Cantilever Beam	25˚C, 150˚C, 200˚C, 250˚C, 500˚C
Case 2	Fixed Beam	25˚C, 150˚C, 200˚C, 250˚C, 500˚C

Case 1: Results of Cantilever Beam model

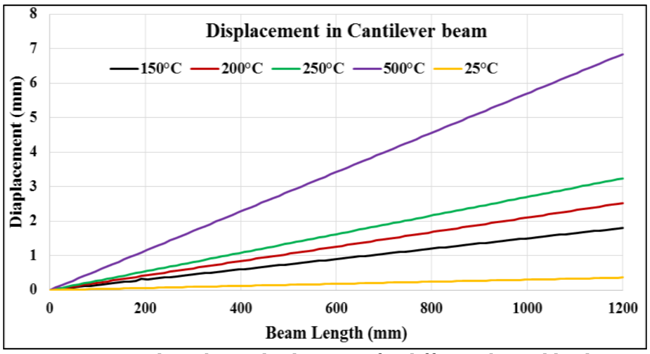

Fig. 2. Cantilever beam displacement for different thermal loads

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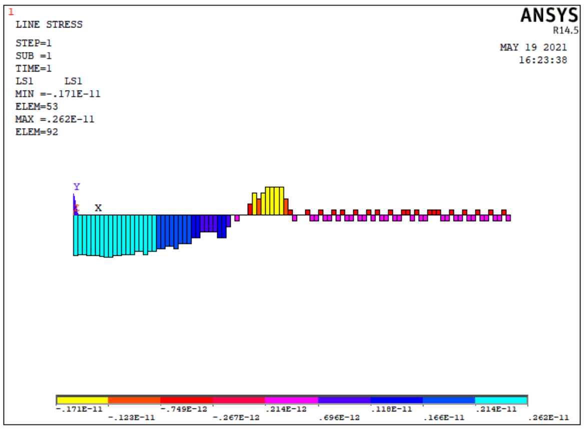
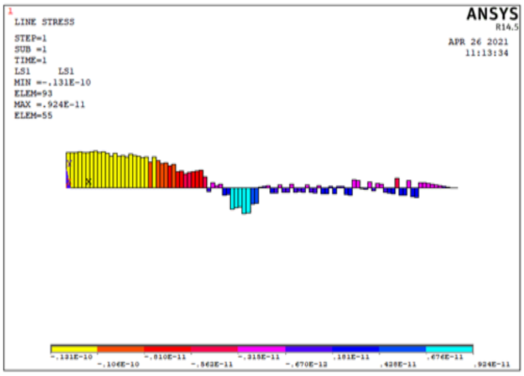
Fig. 2 shows the plot of displacement in cantilever beam, when sujected to different thermal loads. The displacement increases from zero at the fixed end to maximum at the free end. The reference thermal load considered is 25˚C (room temperature). The displacements are also calculated and tabulated in the table 2. The calculated value matches with the displacement values obtained in the software analysis.

TABLE 2. MAXIMUM DISPLACEMENT CALCULATED FOR CANTILEVER BEAM

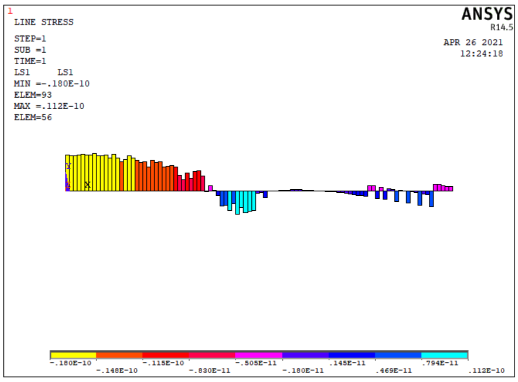
Thermal load	**Displacement** $\Delta L = \alpha \times L \times \Delta T$	**Displacement from ANSYS**
150˚C	1.8 mm	1.8 mm
200˚C	2.52 mm	2.52 mm
250˚C	3.24 mm	3.24 mm
500˚C	6.84 mm	6.84 mm



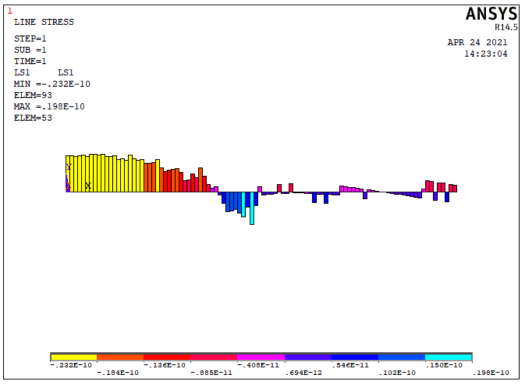
25˚C



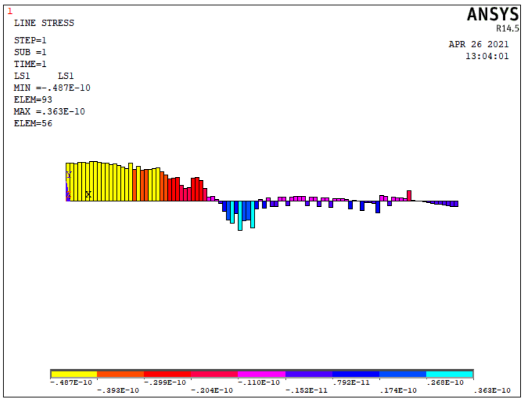
150˚C



200˚C



250˚C



500˚C

Fig. 3. Elemental stress distribution of cantilever beam for 25˚C, 150˚C, 200˚C, 250˚C and 500˚C thermal loads in ANSYS

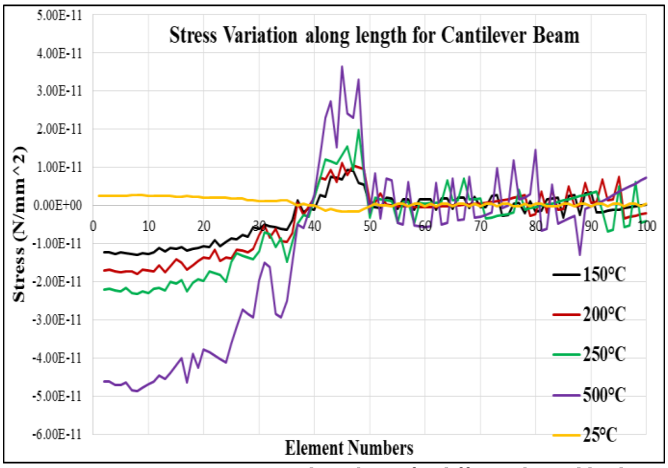


Fig. 4. Stress variations in Cantilever beam for different thermal loads

Fig. 3 shows stress variation in elements of cantilever beam subjected to thermal and structural load as obtained from ANSYS. Thermal stress variation for cantilever beam has to be zero as it can easily expand through the free end. The magnitude of stresses obtained in ANSYS for cantilever beam is also very less, which can be considered equal to zero. But the internal variation of stresses as shown in Fig. 4, for different temperature, shows that stress is directly proportional to the thermal load. The maximum stress was found at element 8 for all the thermal loads.

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Case 2: Results of Fixed Beam model

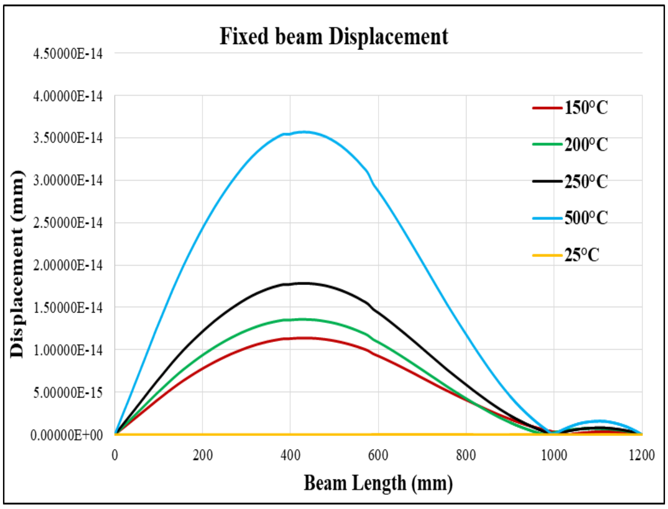
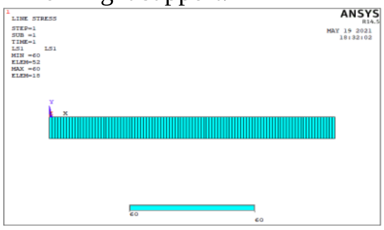
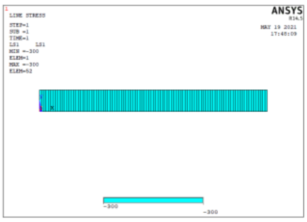


Fig. 5. Fixed beam displacement for different thermal loads

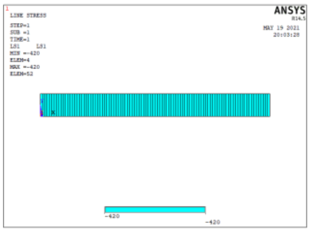
Fig. 5 shows the displacement of fixed beam after thermal and static structural analysis of fixed beam. The displacement is maximum around mid-span. The thermal load applied at the right end of the fixed beam effects the displacement for around 200mm from right support.



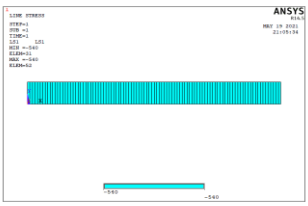
25˚C



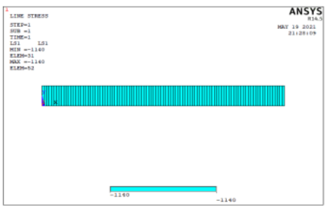
150˚C



200˚C



250˚C



500˚C

Fig. 6. Elemental stress distribution of fixed beam for different thermal loads in ANSYS

TABLE 3. STRESS FOR DIFFERENT THERMAL LOAD FOR FIXED BEAM

Thermal load	**Stress** $\sigma_T = \alpha \times E \times \Delta T$	**Stress from ANSYS**
150˚C	300 N/mm^2	300 N/mm^2
200˚C	420 N/mm^2	420 N/mm^2
250˚C	540 N/mm^2	540 N/mm^2
500˚C	1140 N/mm^2	1140 N/mm^2

Fig. 6 shows the stress variation for 25°C, 150°C, 200°C, 250°C and 500°C thermal load. It can be observed that unlike the cantilever beam the stress variation is constant throughout the beam, since both the ends are restrained the stress distribution is constant and the magnitude of stress are tabulated in table 3.

V. CONCLUSIONS

The variation of thermal load varies the static behaviour of the beam. From coupled thermal structural analysis in ANSYS, the displacement and stresses for different thermal loads can be obtained for beams, which match with the calculated value. The results obtained can be further used for understanding the behaviour of structure subjected to fire.

REFERENCES

[1] Egle Rackauskaite, Panagiotis Kotsovinos, Ann Jeffers, Guillermo Rein, Structural Analysis of Multi-Storey steel frames exposed to travelling Fires and traditional design fires, Elseier-Engineering Structures, Vol. 150, 1 November 2017, pp. 271-287.

[2] Lenka Lausova, Iveta Skotnicova, Vladimira Michalcova, Thermal Transient Analysis of Steel Hollow Sections Exposed to Fire, Elseier-Perspectives in Science, Vol. 7, March 2016, pp. 247-252.

[3] Igor Dzolev, Meri Cvetkovska, Dorde Ladinovic, Vlastimir Radonjanin and Andrija Raseta, Fire analysis of a Simply Supported Reinforced Concrete Beam using Ansys Workbench, Association of Structural Engineers of Serbia, Symposium 2016, 15-17 Sept. 2016, pp 322-327.

[4] Kada A, Lamri B, Mesquita M.R. L and Bouchair A, Finite element analysis of Steel beams with web apertures under fire condition, Asian Journal of Civil Engineering (Building and Housing) 2016 , Vol. 17 , Number 8, pp. 1035-1054.

[5] Essam H El-Tayeb, Salah E. El-Metwally, Hamed S Askar, Ahmed M. Yousef. "Thermal analysis of reinforced concrete beams and frames". HBRC Journal (2017) 13, 8-24.

[6] M Mehdi Mirzazadeh and Mark F Green. "Non-linear finite element analysis of reinforced concrete beams with temperature differentials". Engineering Structures 152 (2017) 920-933.

[7] Harshad D Mahale and S B Kandekar. "Behaviour of Steel Structure under the Effect of Fire Loading". IJERA Vol.6 pp.42-46 (2016).

[8] Bramhanand V Patil and Milind S Ramgir. "Study of structural steel members under thermal loading". IJSETR Vol.5 (2016)

[9] Hemangi K Patade and M.A. Chakrabarthi. "Thermal Stress Analysis of Beam Subjected to Fire". IJERA Vol.3 pp.420-424 (2013) C Crosti. "Structural analysis of steel Structures under fire loading". Acta Polytechnica Vol.49 No. 1/2009.

[10] S. Alih, A. Khelil, Tension Stiffening Parameter in Composite Concrete Reinforced with Inoxydable Steel, Laboratory and Finite Element Analysis, World Academy of Science, Engineering and Technology (2012)

[11] K. Behfarnia, The effect of tension stiffening on the behavior of R/C beams, Asian J. Civ. Eng. (Building and Housing) 10 (3) (2009) 243–255

[12] R. Nayal, H. Rasheed, Tension stiffening model for concrete beams reinforced with steel and FRP bars, J. Mater. Civ. Eng. 18 (6) (2006) 831–841