# Thermal Structural Analysis of Cantilever Beam and Application of ANN in Thermal load Detection

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**Abstract:** In any steel structural analysis, the performance of steel structures is very important. The performance is considered on the basis of external conditions like water, fire, air etc., considering fire applied on steel structure, 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, Indian Standard beam is considered, which is exposed to differential temperature conditions with varying time on both solid beam and a notched beam. Different characteristics and behaviour of the considered beam is studied to know the responses of a beam under different temperature conditions. This study gives an overview of material behaviour and tells us to design considering various conditions. The experiment on actual steel structure under controlled fire is not always feasible as it requires time, money, and space as well. Hence, the thermal analysis is carried out using finite element software (ANSYS).

**Keywords**: T***hermal analysis, fire loading, stress, coupled analysis, ANN.***

## 1. INTRODUCTION

The steel has a major application in construction as structural components. Higher load carrying capacity, reduction in cross section area and ease of erection of building with structural and architectural advantages made it a top priority in the construction field. But steel structures predominantly have shown high rate of failure under thermal load. This is one of the major concerns that overtook since last few decades. The reduction in strength and stiffness of steel member under thermal load, has led to an extensive study on steel structures, and improvised the behaviour as a fire protection system. Mechanical properties of steel structures are important in any steel structure analysis. The study of mechanical properties of steel structural members at regular temperature is conventionally different from behaviour of steel structure at elevated temperature. Mechanical properties of a steel structure are important in any steel structure analysis study. The mechanical properties at regular temperature are conventionally different from varying elevated temperature a steel structure behaves identically different at every elevated scenario.

## 2. LITERATURE REVIEW

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. 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.

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 optimised and processed to thermal analysis. 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. 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.

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. 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.

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 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.

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.

## 3. MODELLING

For the present study, I- section steel cantilever beam of length 1200 mm is considered. Initially, thermal analysis on the structures is performed. The solid steel beams are analysed for various thermal loads varying time intervals. Also, for the study of transfer of temperature, three different nodes are selected at different positions. Similarly, notched beams, with notches provided at 5mm, 50mm, 200mm and 400mm from the fixed end are considered with similar thermal loads at different time intervals. The table 1 below shows the details of the thermal load and durations considered.

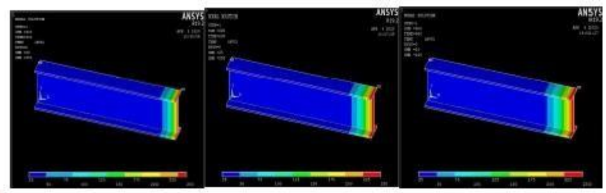
Table 1 Thermal load and duration

| Sl. No | Thermal Load | Maximum Time of Thermal load application (seconds) | Thermal load location |
|---|---|---|---|
| 1 | 25°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 2 | 100°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 3 | 150°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 4 | 200°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 5 | 250°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 6 | 300°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 7 | 350°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 8 | 400°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 9 | 450°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 10 | 500°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 11 | 550°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 12 | 600°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 13 | 650°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 14 | 700°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 15 | 750°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |
| 16 | 800°C | 300, 600, 900 | L, L/2 and L/4 from fixed end |

Table 2 Thermal load, duration and notch details

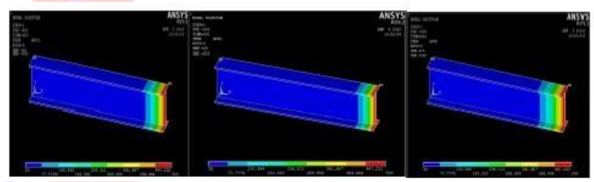
| Sl No. | Thermal Load | Maximum Time of Thermal load application | Rectangular Notch Location |
|---|---|---|---|
| 1. | 500°C | 600 seconds | 5mm, 50mm, 200mm, 400mm |
| 2. | | 900 seconds | 5mm, 50mm, 200mm, 400mm |
| 3. | 750°C | 600 seconds | 5mm, 50mm, 200mm, 400mm |
| 4. | | 900 seconds | 5mm, 50mm, 200mm, 400mm |

## 4. RESULTS AND DISCUSSIONS



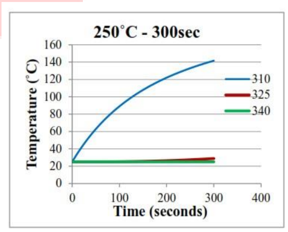
300 600 900

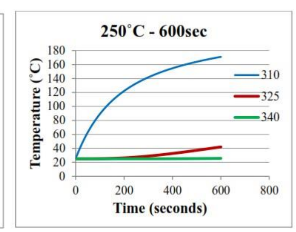
Fig1: 250degrees load at duration in seconds

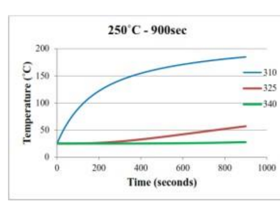


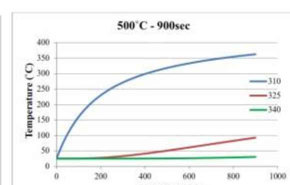
300 600 900

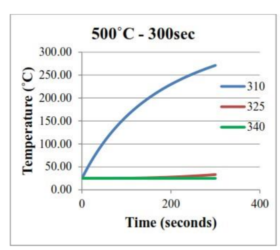
Fig2: 500degrees load at duration in seconds



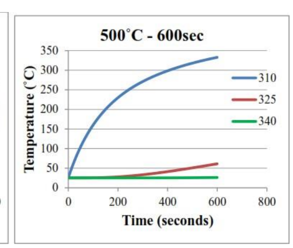
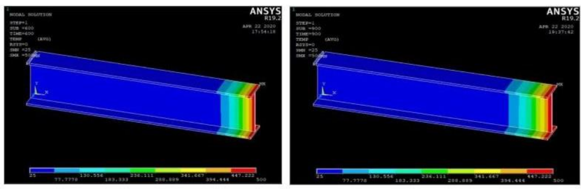



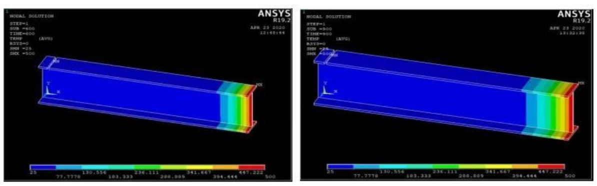
Fig3:Temparature variation with respect to time

Fig1, Fig2 and Fig3 shows the heat transfer rate aggregating with the period of fire on the structure.



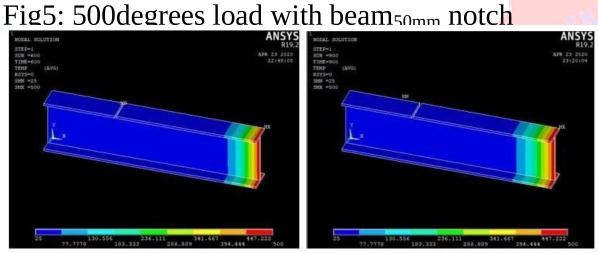
(a) 600 Seconds (b) 900 Seconds

Fig4: 500degrees load with beam$_{5mm}$ notch



(a) 600 Seconds (b) 900 Seconds

Fig5: 500degrees load with beam$_{50mm}$ notch



(a) 600 Seconds (b) 900 Seconds

Fig6: 500degrees load with beam$_{400mm}$ notch

Fig4, Fig5 and Fig6 shows the heat transfer for structure with damage (notch).

## 5. ANN APPLICATION FOR FIRE LOAD DETECTION

Artificial Neural Networks (ANN) have received increasing attention for use in detecting damage in structures based on vibration modal parameters. However, uncertainties existing in the finite element model used and the measured vibration data may lead to false or unreliable output result from such networks. In this study, Feed forward back propagation network is made used to detect damage in beam. The fire load applied on beam is considered as damage location.

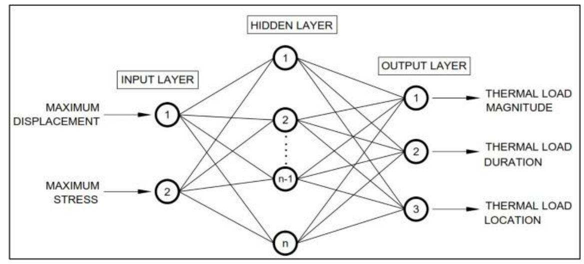



Fig7: ANN model

Table 3 ANN model properties

| | |
|---|---|
| Type of network | Feed Forward Backpropagation network |
| Training function | TRAINLM (Levenberg-Marquardt backpropagation) |
| Performance function | MSE (Mean Squared Error) |
| Calculations | MEX |
| Data division | Random (dividerand) |
| Number of neurons in hidden layer | 8, 10, 12, 14, 16 and 18 |
| Total number of samples | 144 - [Training 70% = 100 samples; Validation 15% = 22 samples; Testing 15% = 22 samples] |

Table 4 ANN model results

| Sl No. | Number of neurons | ANN Structure | Number of Iteration | Regression value (%) |
|---|---|---|---|---|
| 1. | 8 | 2 – 8 – 3 | 32 | 96.695 |
| 2. | 10 | 2 – 10 – 3 | 53 | 96.204 |
| 3. | 12 | 2 – 12 – 3 | 37 | 97.265 |
| 4. | **14** | **2 – 14 – 3** | **89** | **98.639** |
| 5. | **16** | **2 – 16 – 3** | **55** | **98.592** |
| 6. | 18 | 2 – 18 – 3 | 29 | 96.415 |

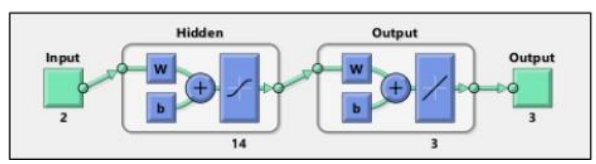



Fig8: Best ANN model

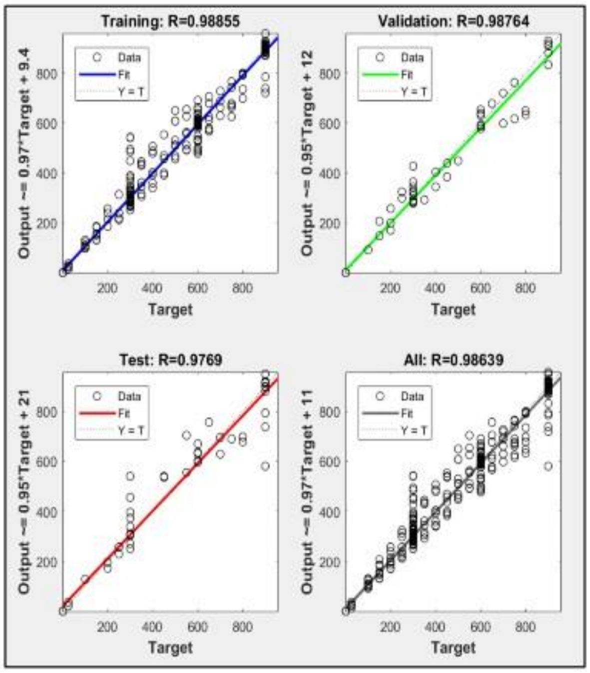



Fig9: Regression study of best ANN model

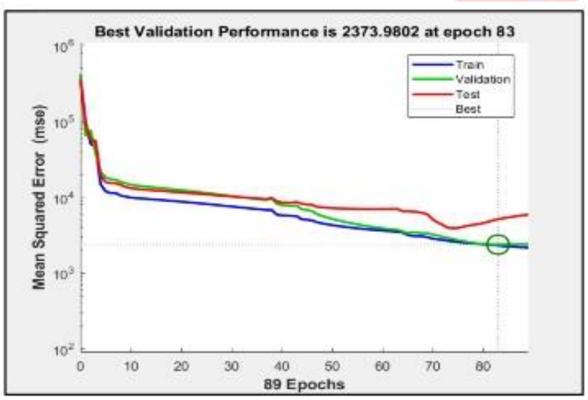



Fig10: Best validation performance of ANN model

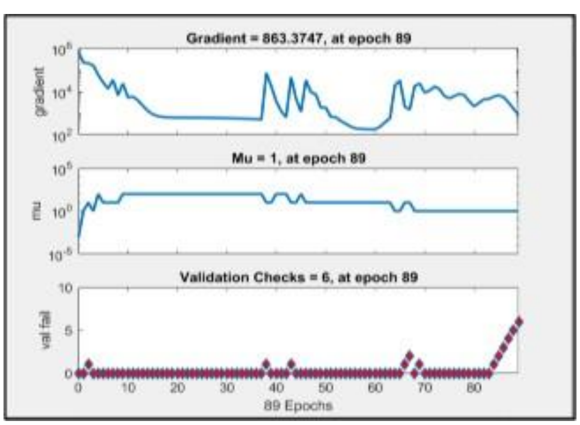



Fig11: Gradient, Mu and Validation checks of best ANN model

## 6. CONCLUSIONS

Based on the results and discussions, the following conclusions are drawn,

i. Higher the intensity of thermal load applied, higher is the rate of heat transfer along the beam length.
ii. The duration of thermal load on the surface is directly proportional to the rate of heat transfer along the length of beam.
iii. Displacement and Stress intensity in a cantilever beam is higher for thermal load applied for a longer duration than for thermal load for shorter duration, and is also higher for high intensity thermal load than lesser thermal load.
iv. The thermal load transfer and rate of flow of heat had less effect due to the introduction of notch. The introduction of notch in the beam reduces the stiffness in the beam and hence increased the displacement compared to solid beam.
v. The stress distribution patter varied predominately for notched beam compared to solid beam.
vi. The change in location of notch along the beam had less effect on the heat transfer.
vii. The probability of ANN method predicting the damage existence is higher and by varying the neurons count optimum results can be obtained.

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