International Journal of
Advances in Scientific Research and Engineering (ijasre)

E-ISSN : 2454-8006

DOI: http://dx.doi.org/10.7324/ IJASRE.2017.32513

Vol.3 (9) Oct - 2017

Analytical Investigation of Thermal Behaviour of Steel Structural Beam Component

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ABSTRACT

The architectural flexibility of steel structure dominates over other conventional structures, but fire and its associative load are one of the major accidental loads, which could be fatal in steel structures. Load bearing capacity of steel structural components drastically reduces in the fire condition. In this paper, the performance of steel structural components under accidental fire loads is investigated. Constraints in the experimental investigation lead to the analytical investigation by the method of finite elements. ISO 834 is adopted as standard fire curves for modelling up-to temperature of 680^0 C. Computational structural models including the earthquake loads will be analysed with the help of advanced structural software. Beam components of the critical section are optimised and processed to thermal analysis. 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. In this attempt, the study of 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.

Keywords*: Thermal loading, Finite element method, Steel beam structures, ISO 834.*

1. INTRODUCTION

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. Reduction in strength and stiffness of member led to an extensive study on steel structure under thermal load, improvised the behaviour and laid the footing to fire protection system. Under the severe thermal action on the surface of steel structures lead to failure of the structure, it is found to be a drastic change in the parameters such as deflection, elongation and sectional form. Resistance to fire is normally expressed in terms of hours against fire load. Fire safety is one of the components in building safety which comprise of a balanced design of active and passive fire protection. As active fire protection is actively installed in the multi-storey building, improvisation of efficient passive fire protection in under lame. In passive protection, structural components are coated with fire resistant material such as gypsum boards, concrete cover, carbon foam and mineral wools. An experimental study on actual steel frame sections is not feasible as it requires time, assets and controlled fire environment. The components are to be analysed as a discrete particle to understand the behaviour under thermal load. Hence computational model with the temperature with reference to ISO834 standard fire curve is analysed through finite element method based software such as ANSYS AIM.

2. LITERATURE REVIEW

Kwasniewski and C Couto[1]concluded three type of stress analysis can be performed on structural components i.e. structural, thermal and coupled. Strain due to elastic and plastic deformation is taken in to account in Structural stress analysis. For coupled thermal-structural analysis thermal elongation is taken in to consideration. Highlighted two types of loading i.e.direct loading and time-dependent loading

Prof.MilindS and Bramhanand[2]studied the steel member under thermal loading and concluded stress and deflection values show the degrading performance of member with increasing the temperature. Therefore combine effect of thermal and mechanical loading should be taken in to account. FEA found to be most promising for analysing the thermal condition of steel sections. Even though result matches with experimental, flame heating is the cause of slight variation in the result.

Harshad D Mahale[3]concluded that heat transfer behavioural study simplify with FE program. Standard fire curve ISO834 is adopted for computation model for Temp v/s Time curve. At 600^0C it is found that deflection of the beam is 10 times the deflection in room temperature. At 900^0C it is 100 times the ambient temperature. Whenthetemperature reaches 600^0C, change in the material property cause high rate of deflection.

3. OBJECTIVE OF THE STUDY

I. To understand the behaviour of steel beam section under thermal load.
II. To understand the behaviour of passive fire protection such as protective cover.
III. To know the effect of Solid box , hollow box and offset profile geometry based protective cover on beam section
IV. To know the efficient geometrical cover for thermal loading exposure to 3 sides of the beam member.
V. Comparison of results obtained from different parameter is reviewed.

4. METHODOLOGY

I. Steel Structure is modelled, designed as per code IS-8002007.
II. Analysed the frame including Earthquake load(IS-1893 2002) with help of Structural analysis software(ETABS)
III. Analysed section is taken in to account with maximum Shear force and Roof Beam is selected with the load.
IV. Selected beam is modelled with the help of Autodesk Inventor to a high level of precise with the protective coating such as 05mm, 10mm thick coating, Solid and hollow box profile coating.
V. Model of beam section is imported to Finite element software such as ANSYS AIM for multi-physics analysis with imported fire load from ISO834 fire curve.
VI. Result data attained from thermal analysis of section with coated and non-coated is compared.

5. MODELLING AND ANALYSIS

Table 1: Structural Description (ETABS)

Grid	6X6(4m)	Zone	II
Column size	375x375 mm	Response Reduction Factor	5
Beam section	Auto beam(IS-800) • ISJB200 • ISJB225 • ISLB175 • ISLB200 • ISLB225 • ISMB175	Importance Factor	1.5
		Site type	II
		Seismic Zone Factor	0.1
		Live load Roof Live load	$4kN/m^2$ $2kN/m^2$
Thickness of Deck slab	162 mm	Floor Finish load	$1\ kN/m^2$
Grade of Steel Section	Fe250	Cladding load	2kN/m
Grade of Concrete	M25	Height between two floors	3 m

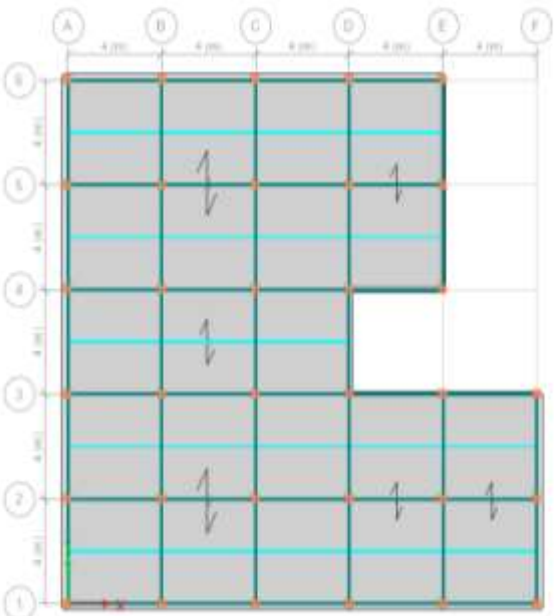


Fig.1. Plan

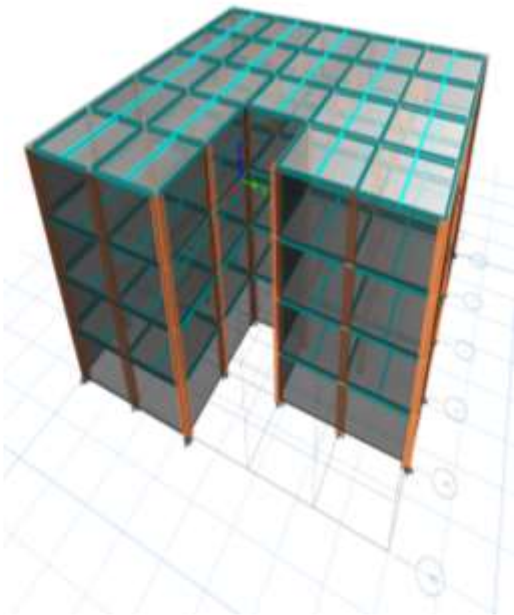
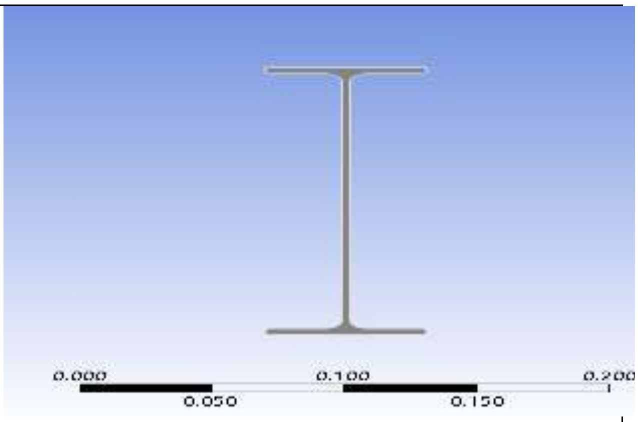
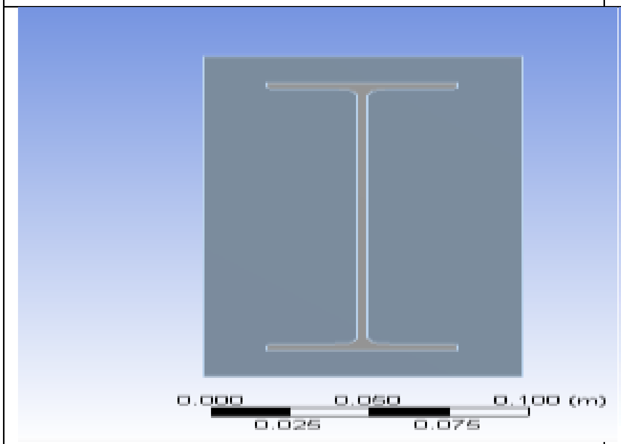
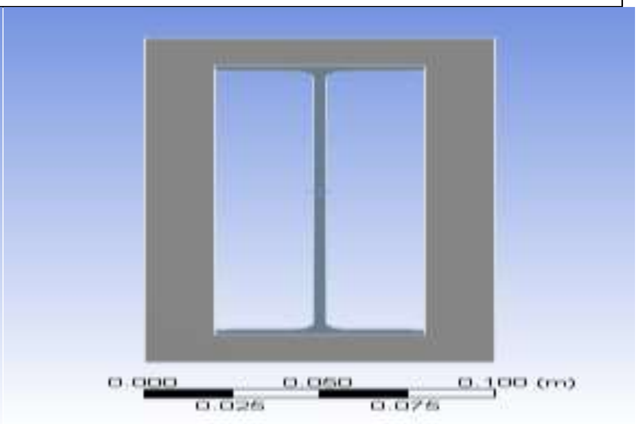
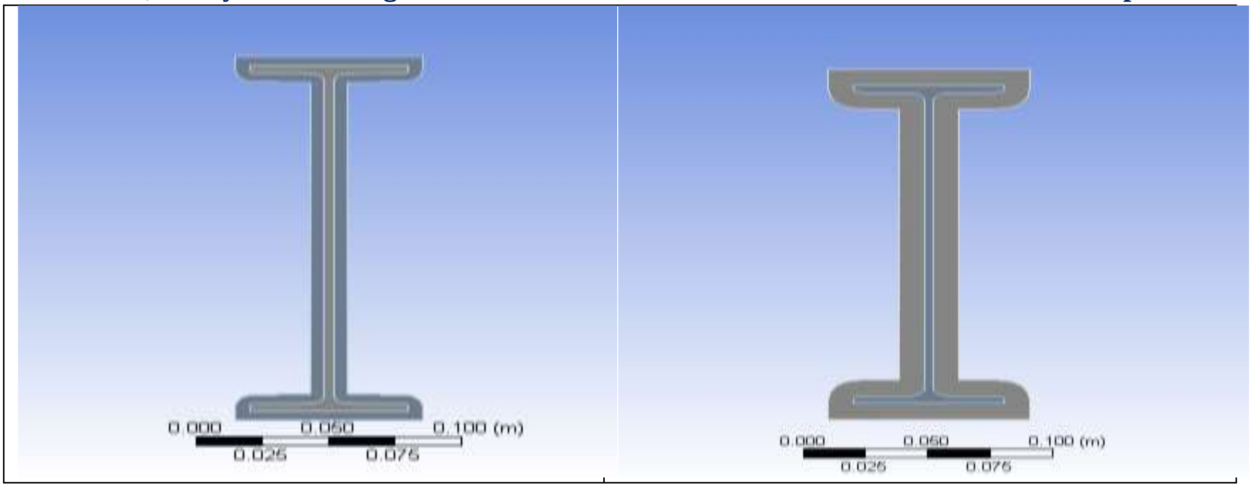


Fig.2. 3D view

5.1 Types Of Model

Table 2: Various type of models

<table>
<tr><td>Model.1 ISJB 200@9.9kg/m</td><td rowspan="7">
</td></tr>
<tr><td>Properties</td></tr>
<tr><td>$A=12.64cm^2$</td></tr>
<tr><td>h=200mm</td></tr>
<tr><td>b=60mm</td></tr>
<tr><td>t_f=5mm</td></tr>
<tr><td>t_w=3.4mm</td></tr>
<tr><td>Model.2 ISJB 200@9.9kg/m
With Solid box protective Cover of 100mmx240mm</td><td>Model.3 ISJB 200@9.9kg/m
With Hollow box protective Cover of 100mmX240mm with thickness 20mm</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Model.4 ISJB 200@9.9kg/m
With 5mm offset protective cover</td><td>Model.5 ISJB 200@9.9kg/m
With 10mm offset protective Cover</td></tr>
</table>



ISO834 Curve

ISO834 curve is international standard of time-temperature curve.It is the standard fire curvethatadopted for thermal input for ANSYS AIM Multi-physics. Temperature till 600secmin (680^{0}C) is adopted from this curve. ISO 834 defined by

$Tp=345 \log10 (8t_m+1) +T_0$

Where, t_m is time in minutes and T_0 is the ambient temperature in degree Celsius.

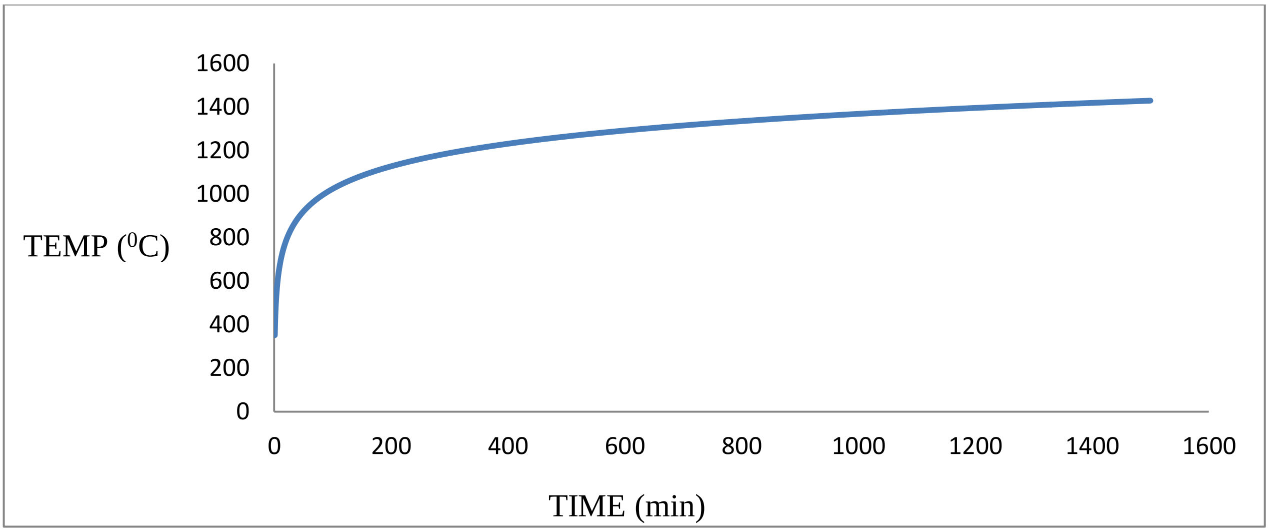
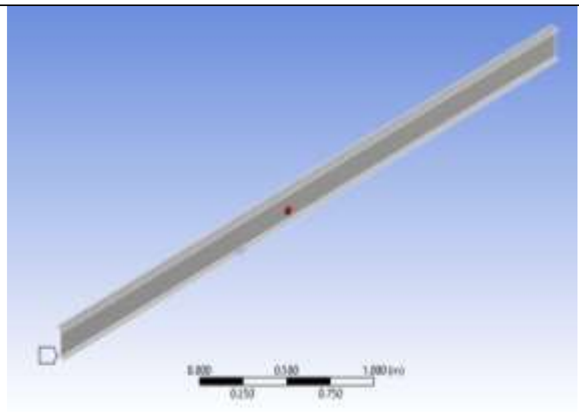


Fig.3 ISO 834 time-temperature curve

5.2 Model Validation

Table.3 Properties

Length of beam	4000mm with 0.22MPa on top flange	
Restrain	At both End	
Material Property(ambient Temp)		
	Steel	Concrete
Density	7850kg/m^3	2300 kg/m^3
Poisson's ratio	0.3	0.18
Young's Modulus	2E+11Pa	3E+10Pa
Coefficient of Thermal Expansion	1.2E-05C^{-1}	1.4E-05 C^{-1}



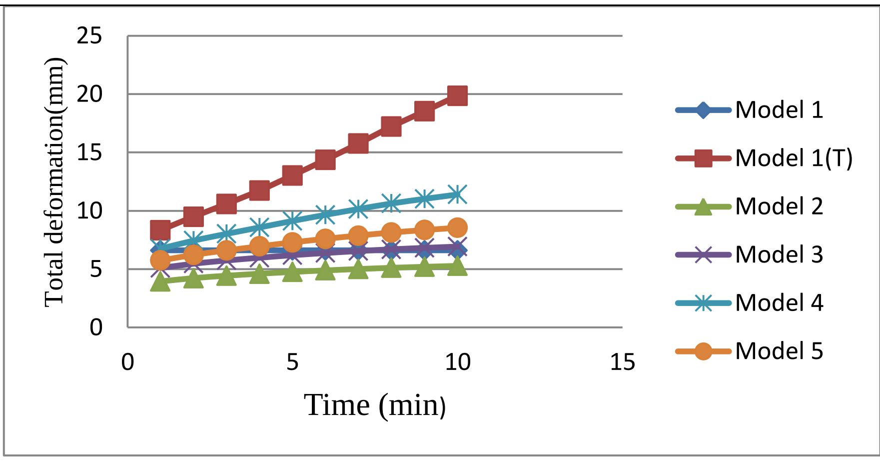
6. RESULTS AND DISCUSSION

ISJB 200 beam member with the thermal loading adopted from ISO 834 is analysed. Variation of total deformation, equivalent stress and equivalent total strain is compared with different parameterized ISJB 200 models.

Total Deformation

Thermal action on the beam section contributes the drastic change in the total deformation. It is found that deformation value in Model 1 with thermal load is thrice the value of Model-1 without thermal load. By the reference of Table.4 Model-2 is the least deformed section under combination of thermal and mechanical load.

Table.4 Total deformation

Case	Maximum (mm)	Graph Total deformation v/s Time
Model 1 (without temp)	6.6122	
Model 1	19.853	
Model 2	5.2763	
Model 3	6.931	
Model 4	11.39	
Model 5	8.542	

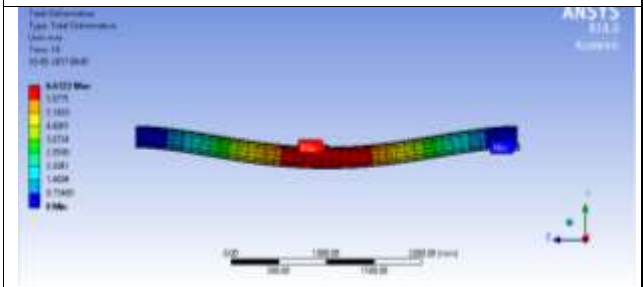
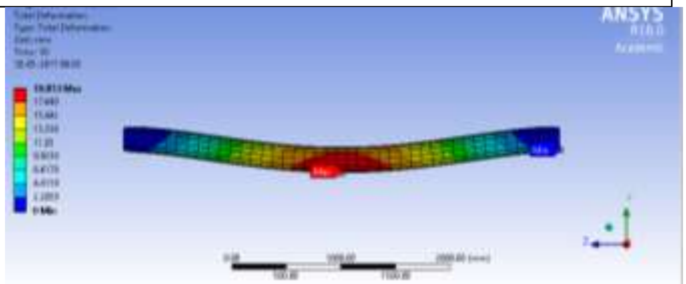
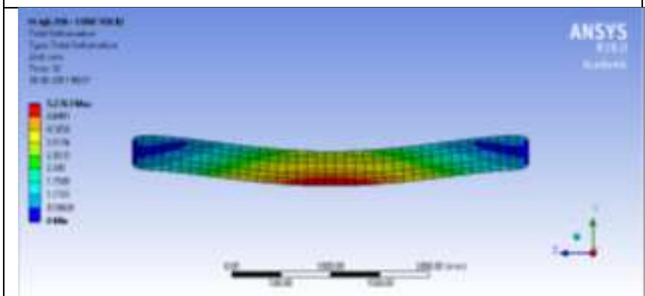
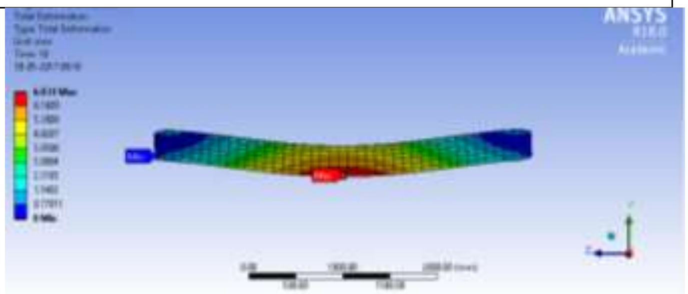
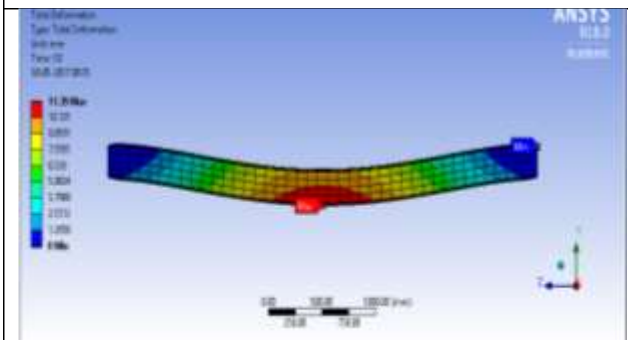
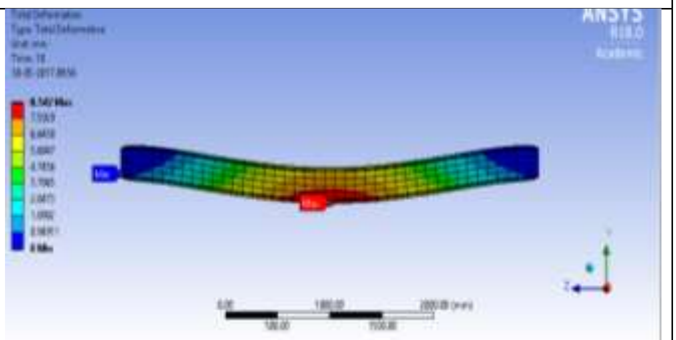
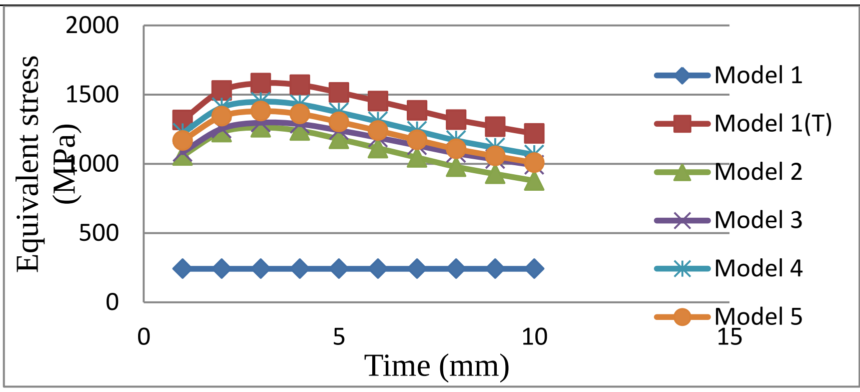
Model 1(without temp)	Model 1
	
Model 2	Model 3
	
Model 4	Model 5
	

Fig.4 Total deformation in ANSYS AIM

Equivalent (Von-Mises) Stress

Stress in the Model-1 with thermal loading is comparatively high. Thermal load cause same structural component to undergo increase in 500% of Equivalent stress in 10min of fire time. Least stress in protective cover induced is solid box profile (Model-2).

Table.5 Equivalent Stress

Case	Maximum (MPa)	Graph Equivalent Stress v/s Time
Model 1 (without temp)	242.08	
Model 1	1219.2	
Model 2	878.56	
Model 3	991.02	
Model 4	1066.5	
Model 5	1008.4	

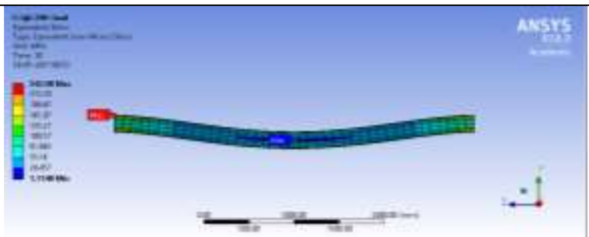
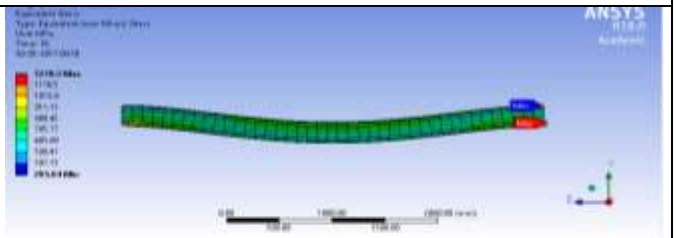
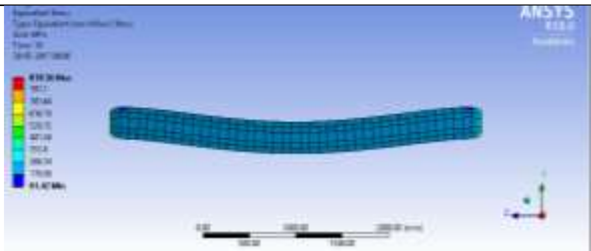
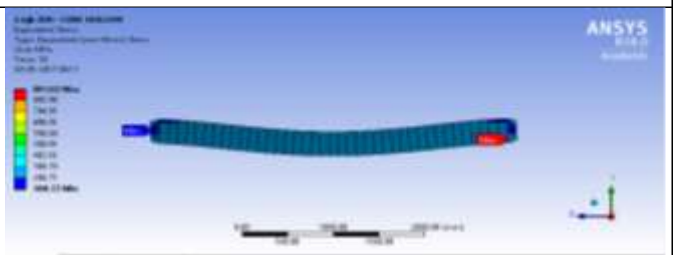
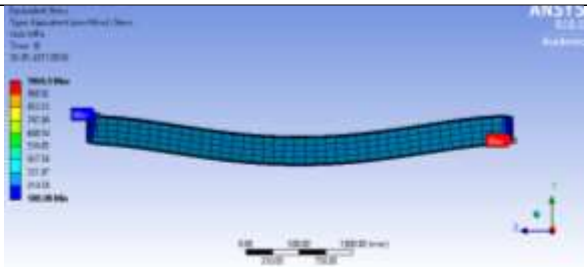
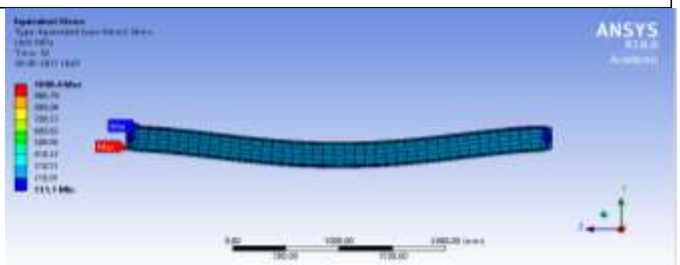
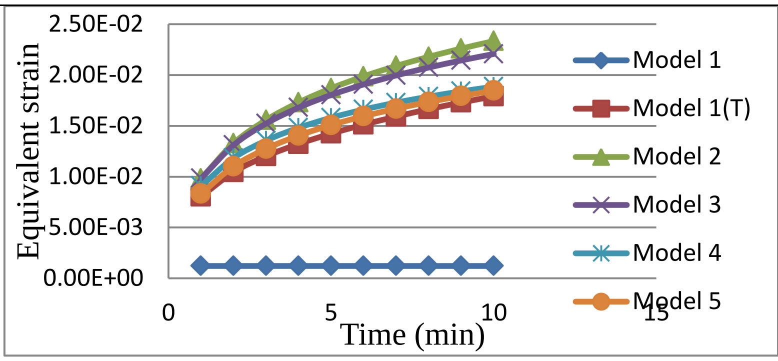
Model 1(without temp)	**Model 1**
	
Model 2	Model 3
	
Model 4	Model 5
	

Fig.5 Equivalent stress in ANSYS AIM

Equivalent Total Strain

It is the total strain that developed in the Model section including thermal. It is found that comparatively total strain is more in the Model-2. Sectional area and thermal loading introduction cause the increase in Total strain.

Table.6 Equivalent Total Strain

Case	Maximum (mm/mm)	Graph Equivalent Total Strain v/s Time
Model 1 (without temp)	1.21E-03	
Model 1	1.79E-02	
Model 2	2.33E-02	
Model 3	2.21E-02	
Model 4	1.89E-02	
Model 5	1.85E-02	

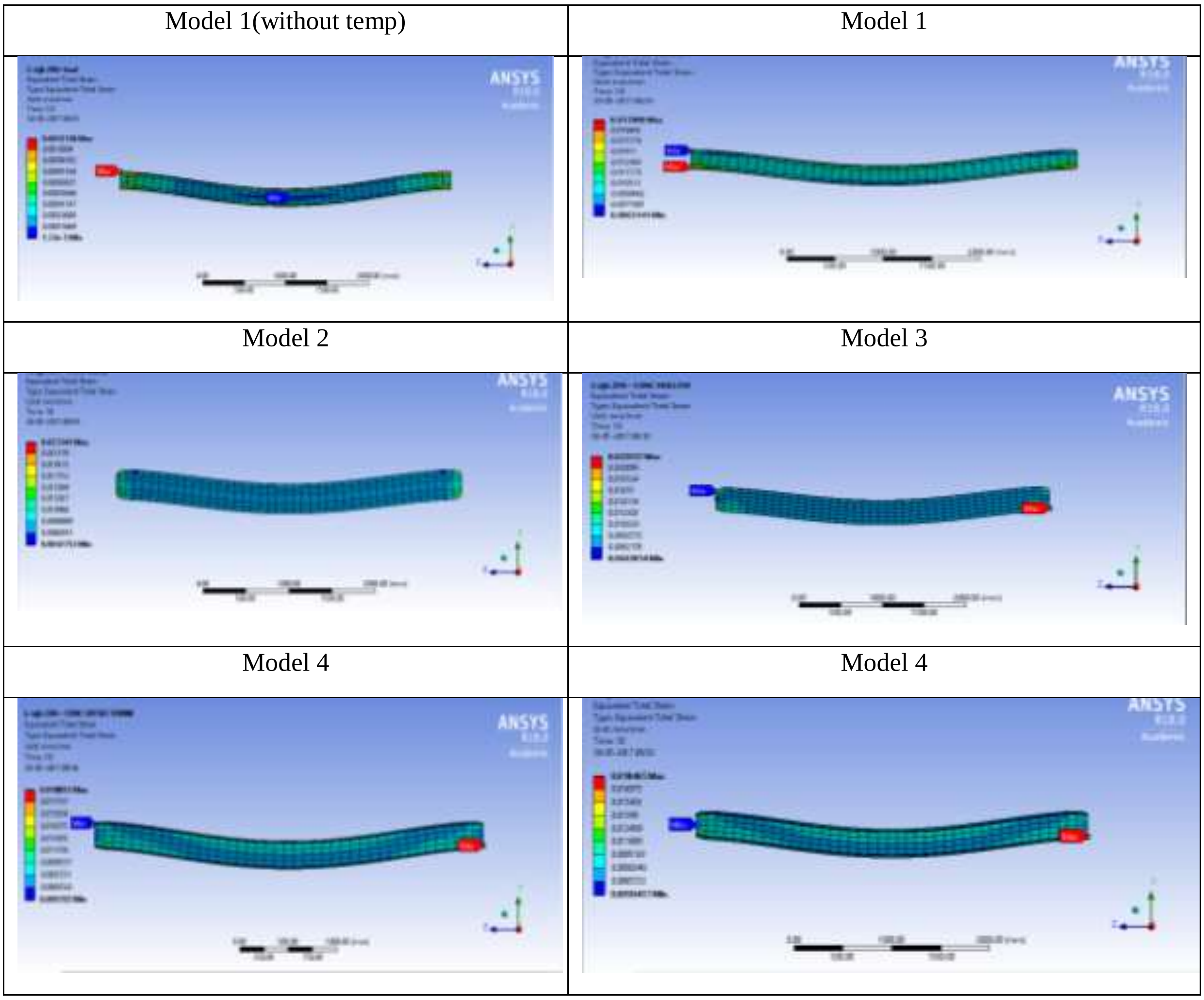


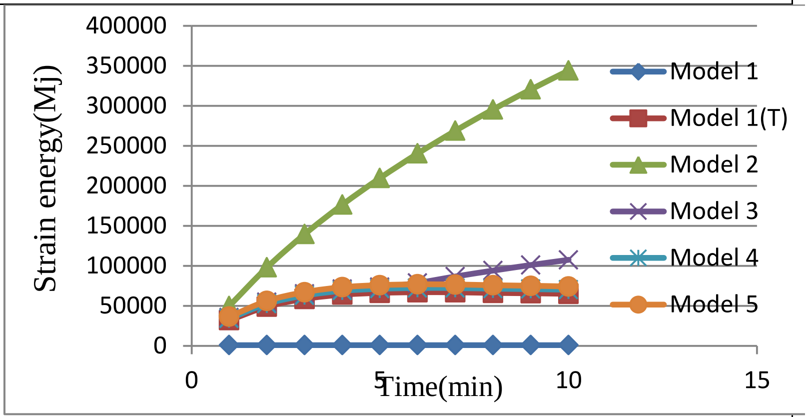
Fig.6 Equivalent strain in ANSYS AIM

Strain Energy

It is the internal work that causes deformation of the section member by the action of externally applied load. Introducing the thermal load approximately increase the strain energy by 87 times in the ISJB 200 beam sections. I-section beam with solid pro file cover (Model 2) consist of high value of strain energy in that comparative model sections.

Table.7 Strain Energy

Case	Maximum (Mj)	Graph Strain Energy v/s Time
Model 1 (without temp)	739.24	
Model 1	64972	
Model 2	3.44E+05	
Model 3	1.07E+05	
Model 4	70050	
Model 5	74112	

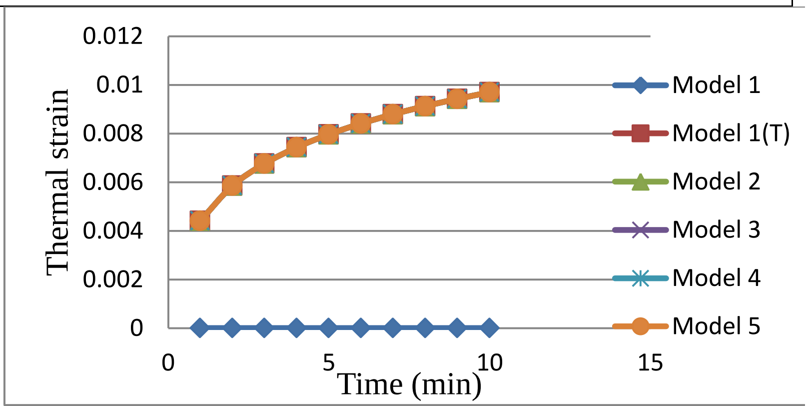


Thermal Strain

These are the strain developed due to the thermal action on the member section. By the reference of the Table.8 thermal strain developed in different fixed end beams section with thermal loads are same in nature.

Table.8Thermal Strain

Case	Maximum (mm/mm)	Graph Thermal Strain v/s Time
Model 1 (without temp)	0	
Model 1	9.69E-03	
Model 2	9.69E-03	
Model 3	9.69E-03	
Model 4	9.69E-03	
Model 5	9.69E-03	



7. CONCLUSIONS

Following conclusions are drawn from analysing the beam section with the help of Finite Element Method

- Beam section tends to decrease in the performance by introducing a large amount of stress and strain due to thermal loading.
- Due to mechanical and thermal loading deflection of the ISJB 200 beams increased by 300% compared to the model without thermal load for a period of 10 minute.
- It is found that the stress maximum at end of the beam sections, hence chance of progressive collapse at the end portion of the beam.
- From the results, it is found that coating reduces the average large deformation due to thermal load. Solid box coating, Hollow box coating and profile coating of 5 and 10mm thickness resist the deflection due to thermal load and increase the stiffness of model.
- I-Section beam with solid box coating well performance against thermal load compare to other all models. The deflection and Equivalent stress is found the minimum in the solid box coating model.
- In profile coating model it is found as the increase in the thickness of offset would decrease the value of deflection as stiffness of member increase.

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