FIRE ANALYSIS OF STEEL BRIDGE GIRDERS USING ANSYS

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ABSTRACT. Steel is versatile construction material and is very rapidly replacing concrete. Metal needs protection against corrosion and fire. The concern of fire safety arises with the utilization of steel in social infrastructure. Of recent cases of fire attack has been on the rise. When subjected to fire attack, steel loses its strength and can cause serious losses to life and property. When a structure is under fire attack it is required to maintain its stability for a reasonable amount of time, so its occupants can escape to a safe place. When exposed to a fire, the structure is under mechanical and thermal action. The mechanical actions arise from the dead load and superimposed loads at the time of fire outbreak while the thermal action arises from increase of gas temperature in the fire compartment. The thermal action leads to thermal elongation, deterioration of mechanical properties, thermal induced stresses leading to the circumstances which may cause the structure to collapse (partially or fully). The concept of fire safety has been focused and practiced on buildings but very little attention is paid to bridges. Hence limited information and research work on enhancing structural fire safety of steel bridges are available. This paper focuses on the fire response of a steel bridge girder under different conditions using Ansys workbench. The mechanical, as well as thermal action and the major factors such as fire scenario, fire insulation, magnitude of loads, axial restraints are accounted for. On the steel bridge girder are studied. In the present analysis, temperature variations, total heat flux variations and directional heat flux are quantified.

Keywords: Bridge fires, Steel girders, ANSYS, Fire scenario, Thermal gradients, Deflections.

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INTRODUCTION

Making use of the principle "If the member is straight following exposure to fire – the steel is O.K", many steel members could be left untouched for the remainder of their service life. Steel members which have small distortions may be made dimensionally reusable by simple straightening methods and the member may be put to continued usage with full anticipation of performance with its quantified mechanical properties. The members which have turn out to be unusable due to excessive deformation may solely be scrapped. In effect, it is unproblematic to retrofit steel structures after a fire. In contrast, concrete exposed to fire past 600^{o}c, may experience an irreversible dilapidation in mechanical strength and spalling. However, it is beneficial to discern the behavior of steel at higher temperatures and methods available to protect it from impairment done by the fire. Provisions linked to fire protections are given in section 16 of the IS 800 code. Nearly all buildings integrate certain fire safety measures. In an episode of fire, structures are necessitated to maintain their stability for a good enough period of time to facilitate occupants to evacuate and to offer safety to attending firefighters. This is described as fire resistance rating which is the competence of a building element to perform its function as a barrier or structural component for a stipulated time during the course of a fire. It is frequently specified in combination with a critical steel temperature as established by a competent engineer. Durations may vary with statutes around the world, but conventional fire ratings may be 60,90,120 minutes. The base for the rating is typically specified in accord with design standards and guidance documents. These documents differ in nature around the world, but fire resistance requisites are strongly associated with the risk of fire (occupancy use), the height of the structure and may be linked with provision system. Within India, fire resistance ratings are fixed in accordance with Indian standards and go up to 120 minutes for archetypal structures in the built environment. Even though life safety is the most important goal of fire protection measures, there is also a secondary advantage in terms of asset or property protection. If suitable structural fire protection is provided in a building then any needed repair can be minimalized and business continuity can be heightened. The reaction of a steel structure in a fire is a function of the maximum temperature achieved at the degree to which it is loaded.

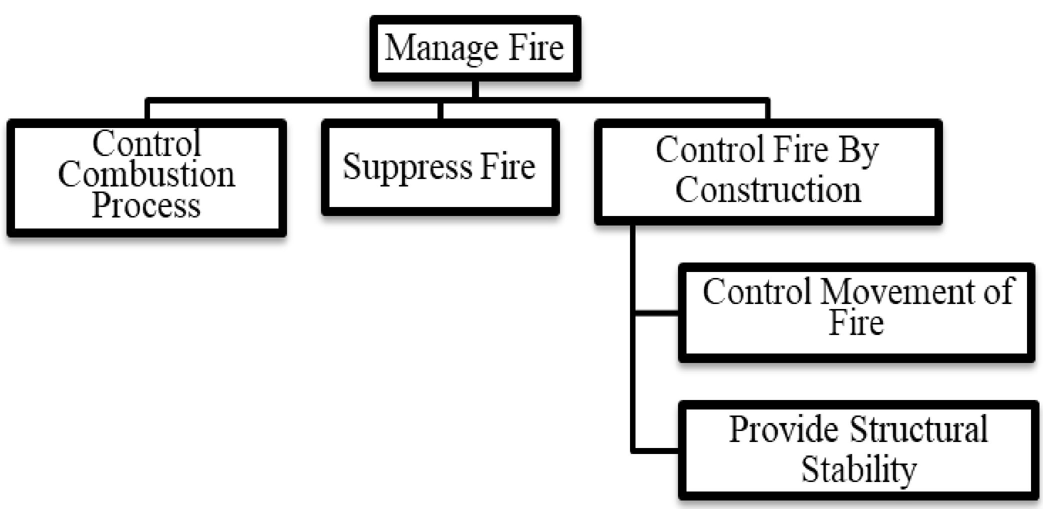


Figure 1 Ways to suppress a fire (INSDAG 2014)

LITERATURE SURVEY

Parametric studies were conducted on the fire resistance of fire resistant steel members [1]. Non –linear FEM based software ANSYS was employed to implement parametric study on the basis of 2-D and 3-D models. Beams and axially compressed columns were tested by Nippon Steel Corporation to verify the software results. The influence of various parameters on the fire resistance of FR steel was studied. The experimental and software results had a close resemblance in terms of values obtained. The following observations very deduced 1) fire duration time for normal steel was only 55% that of FR steel. 2) The critical temperature of a member was greatly influenced by load ratio and slenderness ratio while the loading pattern and eccentricity ratio had no influence.

The fire response of steel girders of a bridge was evaluated using ANSYS under various conditions [2]. The crucial factors, for instance, fire insulation, fire scenario and the complex action on account of steel concrete interaction were taken into account. SOLID 70 element was used to stimulate thermal response while SHELL 181 and SOLID 65 elements were used for structural response. At present, there is a very little literature available on bridge girders subjected to a fire. It was concluded that bridge girder behaves differently from structural elements (beams and columns) in case of a fire thus available data of buildings cannot be correlated directly with bridges. Also the fire resistance of bridge girder was noted to be improved due to composite steel concrete interaction.

A 3-D numerical analysis of an overpass bridge subjected to hydrocarbon fire was carried out using commercial software LUCAS [3]. The axial restraints and magnitude of dead and live loads were varied and the response of the overpass was evaluated. The results shockingly indicated that the time of collapse in case of hydrocarbon fire was less than 9.5 mins. In the event of a fire, this time is hardly sufficient for fireman to reach the site of fire. The conclusion thus drawn was that protective measures for bridges prone to a fire were inevitable.

The numerical and experimental research was conducted on the critical temperature of I steel beams which were laterally unrestrained [4]. A specially designed reaction portal frame was used to test beam elements under fire conditions. Electro-ceramic resistances were made use of to heat the specimen while the thermal efficiency was increased by using a fibre mat cover. The experiment focused on providing constant mechanical action paired with rising thermal load conditions. Material and geometric nonlinear analysis was used to arrive at geometric solution. The numerical and experimental values showed great resemblance but the critical temperatures obtained way above those obtained from calculation done following Eurocode. This indicated that Eurocode calculations presented conservative results. Also the non-uniform distribution of temperature at supports lead to a minute increase in beam stiffness.

FIRE ENGINEERING OF STEEL STRUCTURES

The study of steel structures subjected to fire and its design prerequisite are known as ‘fire engineering’. The essential idea is that the structure must not collapse ahead of time without giving sufficient time for the inhabitants to escape to safety. There are two means of providing fire resistance to steel structures. In the former method of fire engineering, the structure is designed using ordinary temperature of the material and then the significant and required members may be insulated against fire. For the intention of fire protection, the notion of 'section factor' is utilized. In the situation of fire behavior of structures, an imperative factor which affects the rate of heating of a specific section is the section factor which is stated as the ratio of the perimeter of section exposed to fire (Hp) to that of the cross-sectional area of the member (A). As understood from Fig. 2, a section, which has a low (Hp/A) value, would usually be heated at a gradual rate than the one with high (Hp/A) value, and thus achieve a higher fire resistance. Members with low Hp/A value would necessitate less insulation. For instance, sections at the heavy end (deeper sections) of the structural range have low Hp/A value and thus they have slow heating rates. The section factor can be applied to portray either protected or unprotected steel. The section factor is employed as a measure of determining whether a section can be used without fire protection and also to make certain the amount of protection that may be needed. Usual values of Hp of some fire-protected sections are presented in Fig. 3.

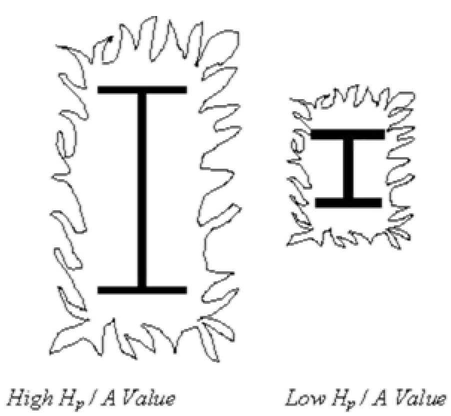


Figure 2 Section factor concept

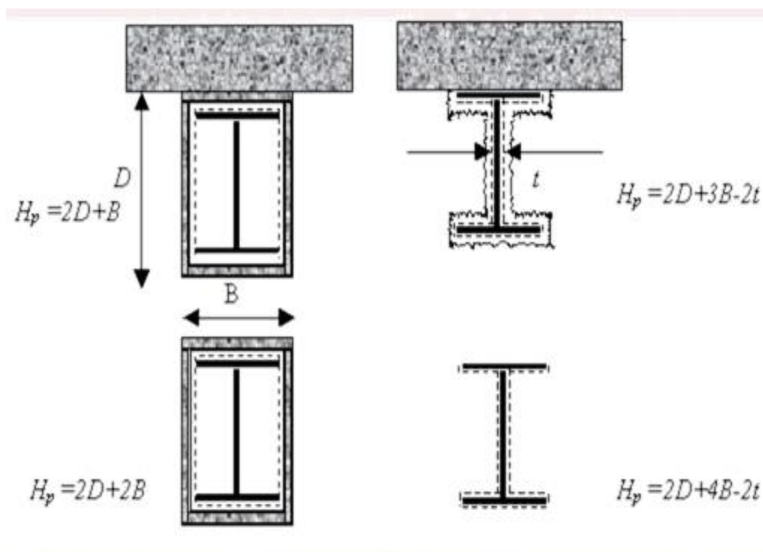


Figure 3 Some typical values of Hp of fire-protected steel structures

In the second method of fire engineering, the high-temperature property of steel is taken into account in design using equation (5)-(9). If these are taken into account in the design for strength, at the rated elevated temperature, then no insulation will be required for the member. The structural steelwork then may be an unprotected one. There are two methods of assessing whether or not a bare steel member requires fire protection. The first is the load ratio method which compares the 'design temperature' i.e. maximum temperature experienced by the member in the required fire resistance time, and the 'limiting temperatures', which is the temperature at which the member fails. The limiting temperatures for various structural members are available in the relevant codes of practice. The load ratio may be defined as:

$$Load\ ratio = \frac{\text{load applied at fire limit state}}{\text{load causing the member to fail under normal condition}}$$

If the load ratio is less than 1, then no fire protection is required. In the second method, which is applicable to beams, the moment capacity at the required fire resistance time is compared with the applied moment. When the moment capacity under fire exceeds the applied moment, no fire protection is necessary.

MODELLING USING ANSYS

ANSYS is a finite element analysis tool for structural analysis, containing linear, non-linear and dynamic studies. This computer simulation product caters finite elements to model performance and supports material models and equation solvers for a wide range of mechanical design problems. It is a general purpose software used to simulate collaboration of all disciplines of physics, structural, vibration, fluid dynamics, heat transferred electromagnetic for engineers. ANSYS meshing is a general purpose, intelligent programmed, high performance product. It generates the most suitable mesh for accurate, efficient multi-physics solutions. In the lifetime of a structure, a fire attack can be the most severe environmental hazard it can be subjected to. Of recent, bridge fires are a major concern. The occurrence of bridge fires is increasing and these fires can cause collapse or at least significant traffic delays, detours, and costly repairs. Structural fire safety has been traditionally focused on buildings, but the behavior of a structural member under fire attack can vary from that of a building due to the following reasons.

1. **Fire source**
   In buildings the cause of a fire is usually the combustion of materials in a compartment. While the source of fire in a bridge is the burning of fuel in close proximity of the bridge or crashing of a fuel laden truck.
2. **Fire ventilation**
   Building fires occur in closed areas and have limited access to air while bridge fires occur out in the open and have unlimited oxygen supply.
3. **Fire protection**
   Buildings are provided with system of active systems of fire protection eg. Sprinklers and also the members are passively protected while in case of bridge members no protection measures are taken.
4. **Fire severity**
   Building fires are less intense when compared to bridge fires. The cause of a bridge fire is mostly attributed to gasoline involvement and hence represents a hydrocarbon fire.
5. **Beam depth**
   Bridge beams are much deeper than common building beams and therefore are more susceptible to web buckling.
   Multiple factors for example composite action between slab and girder, type of fire curve, presence/ absence of stiffeners , insulation, depth of girder , effect of end constraints, gravity loading , live loading etc. can be quantified and research has been done on those fields. The analysis in this thesis throws light on the type of fire scenario a bridge is subjected to precisely external fire and hydrocarbon fire curve.

MODEL

To illustrate the response of a steel girder exposed to fire, a numerical study is carried out using the FEM computer program ANSYS WORKBENCH. A simply supported steel bridge girder was used for the analysis. The bridge girder comprises of a girder and stiffeners. Thermal analysis was carried out. Total span of plate girder is 18m. Clear width of roadway is 7.5m with 1m footpath on either side. For analysis purpose an intermediate segment of 4 m is chosen.

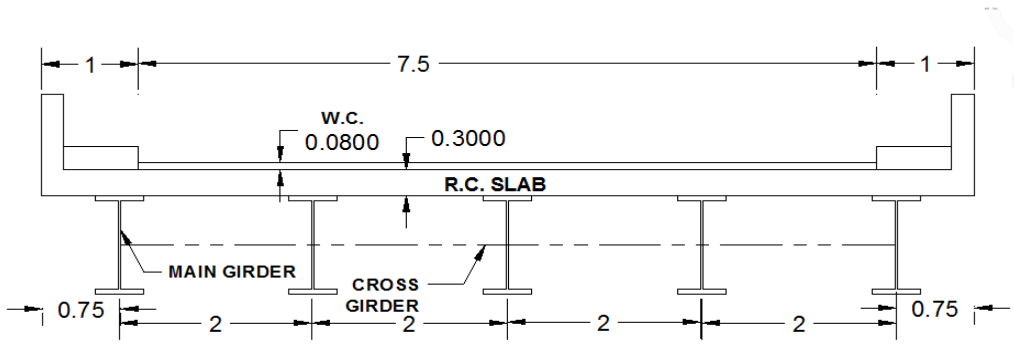
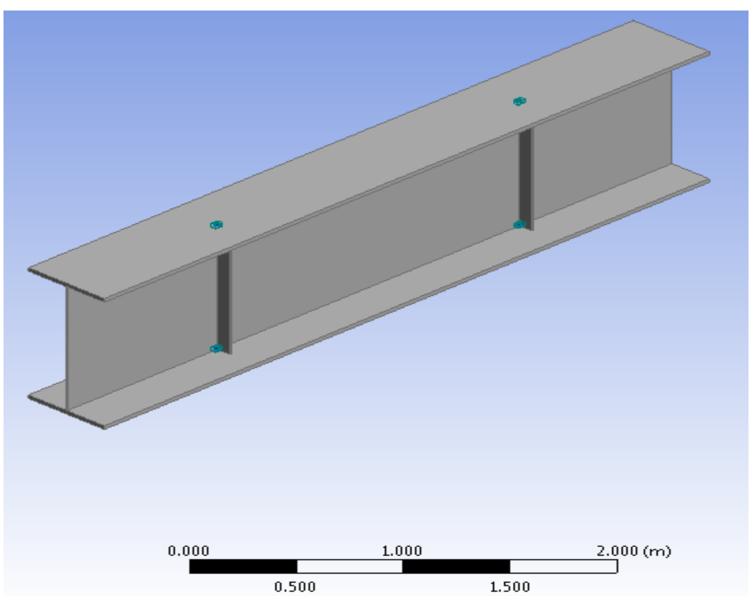


Figure 4 Schematic of the bridge

The dimensions of I section are as follows:
b= 500mm; t_w = 10mm; t_f = 30mm; d = 1000mm; size of stiffener is 80×15mm



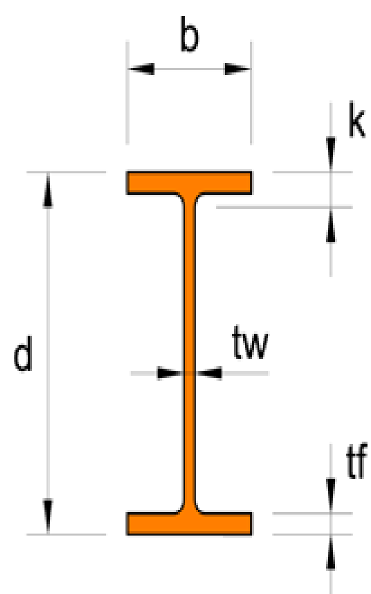


Figure 5 Three dimensional girder cross section for thermal analysis

MESHING

The mesh details are as shown below:

Details of "Mesh"	
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Medium
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Fast
Span Angle Center	Coarse
Curvature Normal Angle	Default (70.3950 °)
Min Size	Default (1.0388e-003 m)
Max Face Size	Default (0.103880 m)
Max Size	Default (0.207760 m)
Growth Rate	Default (1.850)
Minimum Edge Length	1.49e-002 m

Figure 6 Mesh details

LOADING

According to EN 1991 -1-2 (2002) [5] heat convection and radiation loads are applied to exposed surface areas of member. The temperatures for different fire curves are calculated using excel sheets.

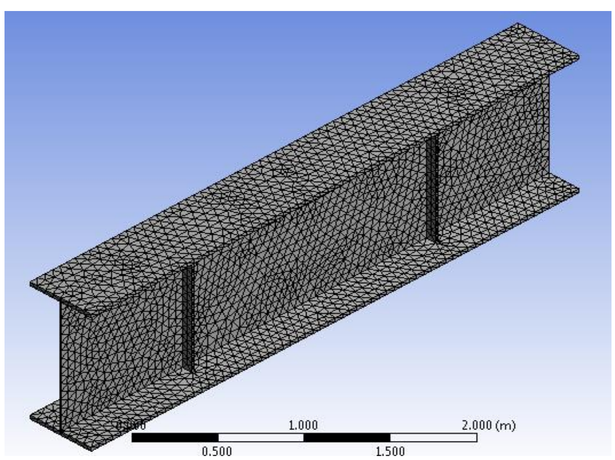


Figure 7 Meshed model

CALCULATIONS

1. Thermal action for temperature analysis

The heat flux is given according to EN 1991 -1-2 (2002) is given by the following equations.

$$\dot{h}net = \dot{h}netc + \dot{h}netr \quad (4)$$

$$\dot{h}\ net\ r = \phi \varepsilon_m \varepsilon_t \sigma[(\theta_r + 273)^4 - (\theta_m + 273)^4] \quad (5)$$

Ø = configuration factor

ε_m= surface emissivity of member

ε_t= emissivity of fire

$\sigma = steffan\ boltzman\ constant$=5.67×10^{-8} W/m^{2}K^4

θ_r= effective radiation temperature of fire environment

θ_m= surface temperature of member

2. Standard Time vs Temperature Curve

$$\theta_g = 20 + 345 \log_{10}(8t + 1) \quad (6)$$

θ_g= gas temperature in ℃

α_c = 25 W/m^{2}K

3. External Fire Curve

$$\theta_g = 660(1 - 0.687e^{-0.32t} - 0.313e^{-3.8t}) + 20 \quad (7)$$

α_c = 25 W/m^{2}K

4. Hydrocarbon Fire Curve

$$\theta_g = 1080(1 - 0.325e^{-0.167t} - 0.167e^{-2.5t}) + 20 \quad (8)$$

α_c = 50 W/m^{2}K

RESULTS

1. External fire curve

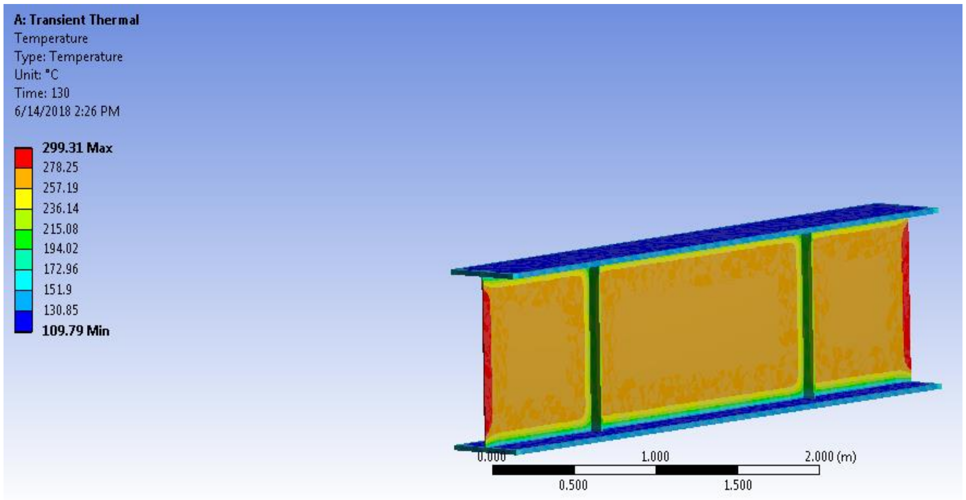


Figure 8 Temperature variation

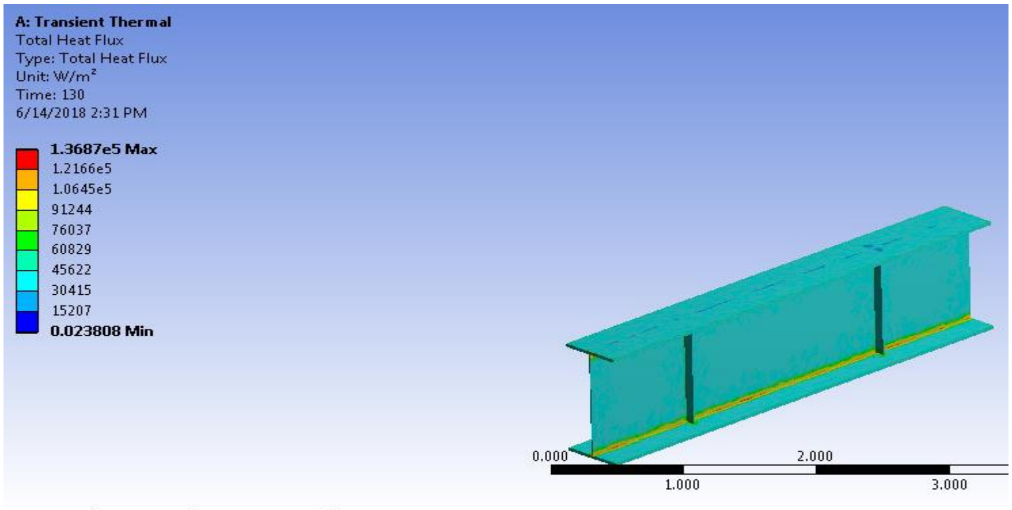


Figure 9 Total heat flux variation

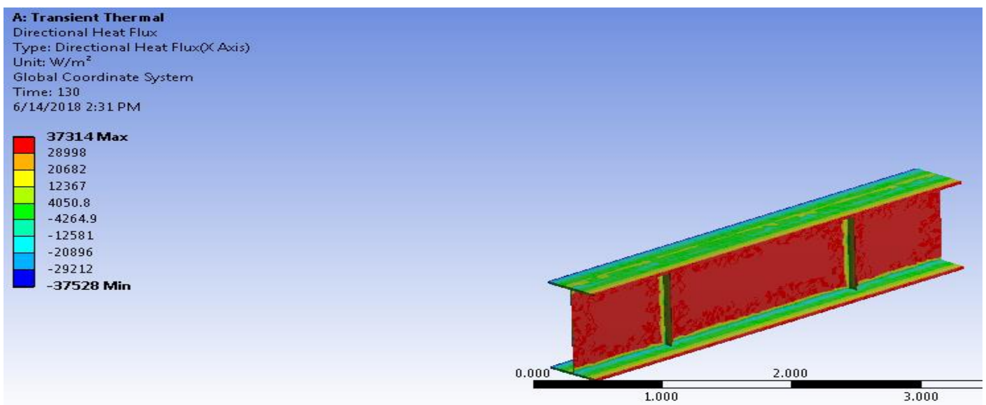


Figure 10 Directional heat flux

2. Hydrocarbon fire curve

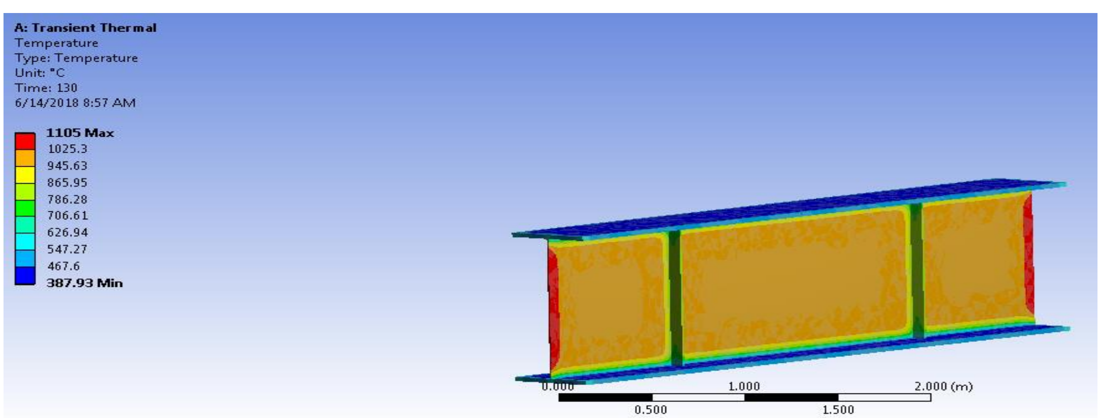


Figure 11 Temperature variation

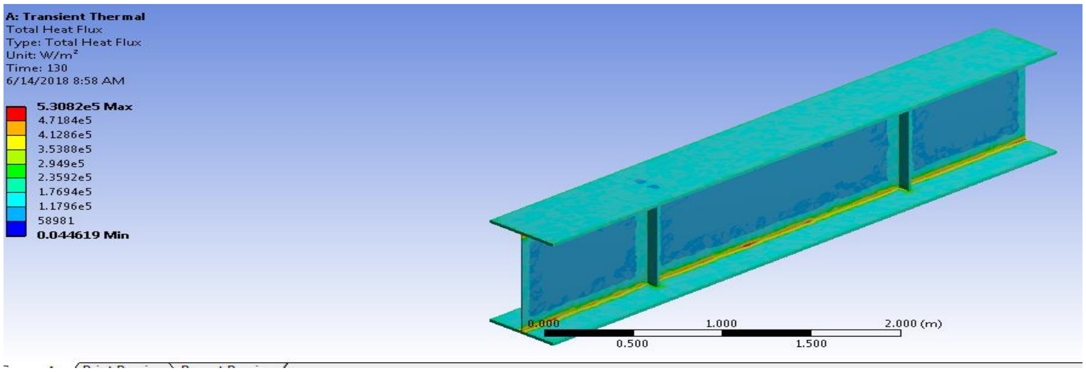


Figure 12 Total heat flux variation

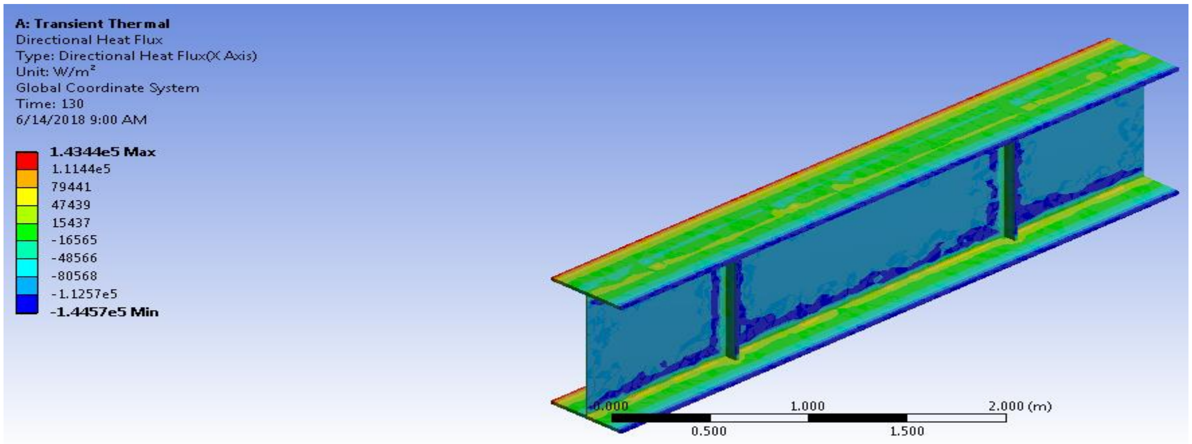


Figure 13 Directional heat flux

Table 1 Heat Flux

	UNITS	External fire curve	Hydrocarbon fire curve
Temperature	ºC	109.79	1105
Total heat flux	W/m^2	136870	530820
Directional heat flux	W/m^2	37314	143440

CONCLUDING REMARKS

Under some scenarios, fire can be a significant hazard in steel girder bridges. On account of different fire, loading, geometry and sectional properties the behavior of bridge girders is totally different from the beams in buildings. More resources and time have to be spend on studying the effects of a fire attack on steel bridges as very little data is available at the moment. Steel buildings are built with fire safety measures while fire safety in bridges is neglected. Behavior of bridge under fire attack is different from that of buildings, therefore special attention has to be given to fire safety in bridges if there is a fire risk situation. The following conclusions can be drawn from the study carried out in this paper. A hydrocarbon fire will have greater impact on a bridge girder as compared to an external fire. External fire is more severe than hydrocarbon fire. Heating rate in hydrocarbon fire is more than external fire. The web temperatures are slightly higher than those in the bottom flange, and this is attributed to the fact than thickness of web is lesser than that of flanges. The temperature distribution across the stiffener is similar to that of the web. Web loses it strength faster rate than the flanges due to faster rise in temperature. If the composite action of concrete slab and girder is taken into account, the top flange temperatures are much lower than the bottom flange due to dissipating effect of concrete. The rise in temperature lead to the deterioration of strength and stiffness properties of member. The support condition has an appreciable influence in the mode of failure and the final deflections but not on the time the bridge can withstand a fire.

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