International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 03 Issue: 02 | Feb-2016 www.irjet.net p-ISSN: 2395-0072

EVALUATION OF STRUCTURAL BEHAVIOR OF STRUCTURAL STEEL JOINTS AT ELEVATED TEMPERATURE

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ABSTRACT- This paper presents the mechanical properties of high strength structural steel and mild structural steel at elevated tempera- tures. Mechanical properties of structural steel at elevated temperatures are important for fire resistant design of steel structures. However, current design standards for fire resistance of steel structures are mainly based on the investigation of hot-rolled carbon steel with normal strength, such as mild steel. The performance of high strength steel at elevated temperatures is unknown. Hence, an experimental program has been carried out to investigate the mechanical properties of both high strength steel and mild steel at elevated temperatures.

1. INTRODUCTION

1.1 Outbreak Of Fire and Structural Response:-

The role and required skills of the structural engineer within the built environment is continuously changing and expanding day by day. To meet the demands from clients, structural engineers have to incorporate additional facets into structural design which includes aesthetic, environmental, economical and sustainability issues. One area where additional 'value' can be offered is in fire resistant design of a structure, particularly after world trade centre disaster due to fire.

A 'connection' is defined as the location where two or more members meet, and a 'joint' is defined as the zone where two or more members meet. A 'joint' is used as the more general term which includes the column web and the beam-end. For example, a beam-to-column joint can include two major- axis connections attached to the column flanges and the two minor-axis connections attached to the column web. Using applied fire protection remains the most common way of satisfying structural fire resistance requirements.

Typical types of protection materials consist of boards, sprays, and intumescent paints, with the choice of material depending on cost, appearance, durability, and the required architectural features. The required thickness is based on the principle of ensuring that the steel remains below 550ºC for the specified fire resistance period without the necessary consideration of the type of structural steel element. This assumes that fully stressed steel members will fail when they reach a temperature of approximately 550ºC. This temperature is known as the "limiting temperature," according to the British design code (BS5950: Part 8, 1990)[15].

1.2 Fire Design

The design for fire safety have traditionally followed prescriptive rules and may now apply fire engineering approaches, A fire engineering approach takes into account fire safety in its entirety and provides a more fundamental and economical solution than the prescriptive approaches. Within the framework of fire engineering approach, designing a structure involves four stages. The first stage is to model the fire scenario to determine the heat released from the fire and the resulting atmospheric temperatures within the building. The second stage is to model the heat transfer between the atmosphere and the structure. Heat transfer involves conduction, convection and radiation which all contribute to the rise in temperature of the structural materials during the fire event. The third stage evaluates the mechanical loading under fire conditions, which differs from the maximum mechanical loading for ambient temperature design, due to reduced partial safety factors for mechanical loading under fire. The fourth stage is the determination of the response of the structure at elevated temperature and which is the aim of the present dissertation.

1.3 Objectives Of The Present Study:-

The proposed project work consists of an analytical investigation to explore the structural behavior of the structural steel joints which contains beam elements, web angles and column under the action of elevated temperature. The following aspects would be included in the dissertation work,

1. To find the behavior of structural steel joints at different temperatures.
2. To suggest the critical areas which are responsible for failure of the structural steel joint elements due to high temperatures.
3. To establish the structural properties of steel at higher temperatures.

LITERATURE REVIEW

1.4 Introductory Remark:-

In third revision of Indian standard code of practice for general construction in steel IS:800-2007[17] the provision of fire resistance has been made. In a field of fire resistance particularly for steel-framed buildings research work emphasizes on study of the real behavior of building in fire. At international level lot of research articles have been published as outcome of experimental and analytical studies on the steel-framed buildings.

1.4. A Review of Literature:-

Prof. Colin Bailey, [1] discusses the background to the existing prescriptive approaches of structural fire design together with an introduction to the various performance-based approaches. In this article author explained standard fire test and full scale Cardington frame fire test. In standard fire test, there are approved furnaces where a standard configuration of a wall, beam, and column can be constructed and tested. The test follows the standard heating curve which shows the time-temperature relationship. Full scale test on steel-framed building was performed at Building Research Establishment (BRE) laboratories in Cardington. The detrimental effect of a collection of structural elements has been observed.

A. Rahman, R. Hawileh and M. Mahamid, Investigated the behavior of standard steel connections used in high-rise buildings subjected to severe fire loading conditions. A time-history transient FE analysis is used to model the fire loading. A 3D FE model of an extended shear tab steel connection used in a beam-column joint is developed. The shear tab plate is welded to the web of the column and it is connected to the web of the beam by tightened bolts.

PROPERTIES OF STEEL AT ELEVATED TEMPERATURE

The behavior of mechanical properties of different steel grades at elevated temperatures should be well known to understand the behavior of steel and composite structures at fire.

1.5 Stress-Strain Behavior:-

The stress-strain curves obtained by British Steel for Grade 275 steel for various temperatures is shown in figure 3.1. From the following figure it is seen that at temperatures in excess of about 550°C, steel loses about 50% of its strength at room temperature with partial load factors of 1.5 (adopted for LL+DL).

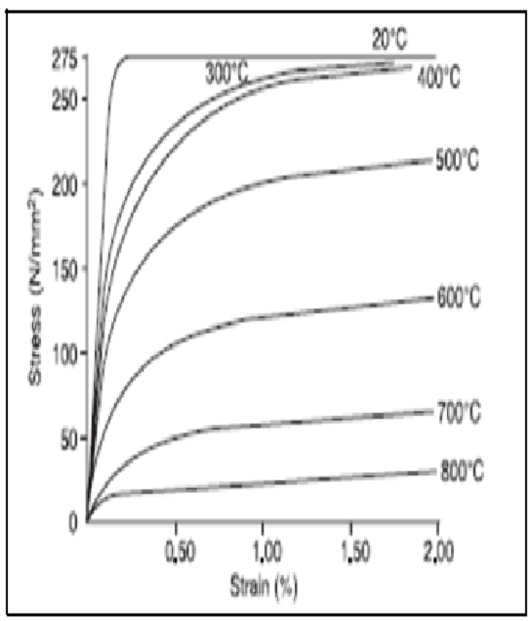


Figure 3.1 Typical Stress-Strain curves at elevated temperature for steel with Fy=275MPa

This suggests that under conditions of uniform heating and full design load, failure of the members in the form of excessive deflection may occur at about this (550°C) temperature. This drop in strength is equivalent to the erosion of safety provide by the load factor of 1.5. Hence a temperature of 550°C is referred to as the critical temperature for uniform heating. Note that in certain situations of thermal shielding (e.g. composite beam and slab, columns shielded by brickwork) and at low load levels, the hottest part of steel may reach 800°C without member collapsing. Although melting does not take place till about 1500 °C, only 23% of the ambient strength remains at 700°C, 11% at 800°C, and 6% at 900°C. It is also important to note from figure 3.1 that at elevated temperatures the stress-strain curves are more rounded with no well defined yield stress. Hence the yield stress at elevated temperatures is taken at 0.2% of the strain level. Since the slope of the initial stress-strain curves (E) also decreases with increasing temperature, the structure will deflect more at the same load level due to the temperature increase. Due to this the performance of the members at elevated temperatures will be much reduced.

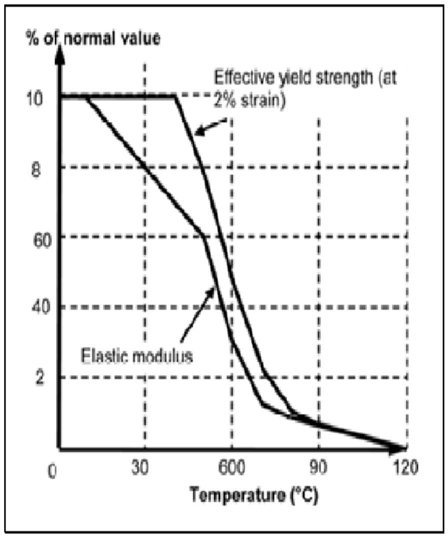


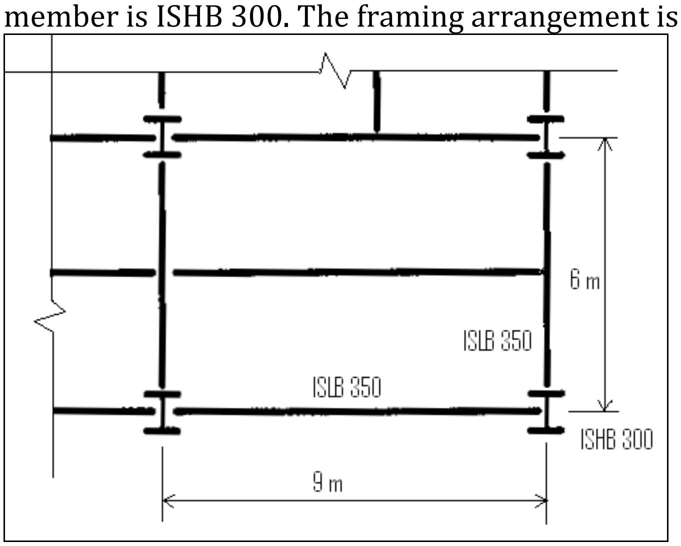
Figure 3.2 Degradation of the mechanical properties of steel at elevated temperatures.

All common building materials lose strength when heated to high temperatures. Figs. 3.2 show the deterioration of steel mechanical properties with increasing temperatures. This discussion shows that the mechanical properties such as the modulus of elasticity and yield stress vary with the temperature, generally decreasing with the increasing temperature. Thus, at a certain temperature, the strength of the member will decrease to virtually zero.

STRUCTURAL CONFIGURATION OF JOINT

1.6 Structural Arrangement:-

The given joint consists of two beam elements. The primary beam element is ISLB 350 on which one secondary beam is supported and other secondary beam is ISLB 350 is peripheral beam. The column member is ISHB 300. The framing arrangement is shown in following fig. 4.1



In connection 10 mm thick web angles & 20 mm sized bolts are used. The details of connection are given in following figure.

FINITE ELEMENT MODELING AND ANALYSIS

1.7 Introduction:-

A considerable progress has been made in recent years in understanding how structures behave when heated in fires and in developing mathematical techniques to model this behavior. It is possible to predict the behavior of certain types of structure with a reasonable degree of accuracy. The most common form of analysis is the 'finite element method'. It may predict thermal and structural performance. In fire, the behavior of a structure is more complex than at ambient temperatures. Changes in the material properties and thermal movements cause the structural behavior to become non-linear and inelastic.

1.8 Finite Element (FE) Analysis:-

In this study to carry out the finite element analysis, ANSYS 10.0 has been used. A 3D FE model of bolted web angle steel connection used in a beam-column joint was developed. The change in steel material's mechanical properties such as modulus of elasticity, yield and ultimate strength, and coefficient of thermal expansion were considered as a function of increasing temperature resulting from fire loading. Stress-Strain curves for steel at elevated temperatures based on reported experimental evaluations were used in the model. Boundary conditions are applied to represent a constrained bolted plate bounded by the structural members (beam and column).

RESULTS AND DISCUSSION

Introduction:-

The finite element analysis provides variable full field state of stresses, deflections and failure mechanism of structural steel members. This does not necessary replace valuable experimental validation and investigation, but can give more insight and focus on a specific structural component. The results shown in figures of this chapter are the deflection and stresses in the beams, column & web angle plates of the structural steel joint.

CONCLUSION AND FUTURE SCOPE

Conclusion:-

This work shows response of a beam to column bolted joint at elevated temperatures. The non-linear analysis done; is capable of predicting the stresses in the structural steel joint, deflection of the beams, flange local buckling, formation of plastic hinge, failure mechanisms of structural steel members at different temperatures. Generally applying fire protection materials remains the most common way of satisfying structural fire resistance requirements. The FEM simulation is useful to design a structure & account for fire protection rather than to design it for normal conditions and provide add on fire protection treatment.

The following conclusions can be drawn from this evaluation of structural behavior of structural steel joints at elevated temperatures.

1. In the FE model, after 500°C temperature sudden excessive deflection was observed in beam elements which is validating with the limiting temperature condition according to British design code (BS5950: Part 8, 1990)[15].
2. The model clearly shows plastic flow of metal that leads to plastic hinge formation in the joint. This can be useful result for further decision to provide fire protection area of the joint.
3. It has been observed that high temperature (up to 700°C) does not affect column much in comparison with beam elements and web angles. The deflection in column is observed to be 3.2mm maximum.
4. Up to 200°C the primary beam and secondary beam are safe in deflection criteria (Serviceability criteria) of design of beam members according to IS:800-2007.
5. High stresses in column web are observed in comparison with the column flange, so column web needs to be taken care of in fire protection process. Web may be susceptible to plastic flow during outbreak of fire as seen in figure 6.34. Thus the finite element model is very helpful in selection of the material for the fire protection of structural elements.

Future Scope:-

- During fire in steel framed building, temperature of structural steel elements may not be same as seen in Cardington large building test facility[18]. Generally connection is having less temperature compare to beam & column because of the surrounding column & beam flanges. Such models should be developed which is having different temperature conditions.
- Detailed studies are needed on structural behavior of bolts in the different types of connections at elevated temperatures.
- Structural behaviors of different components of structures can be studied to know its response during fire hazard.
- Experimental backup is required to be generated to establish structural response at elevated temperature. The data thus generated may be useful in providing guidelines for design; which are presently not available in IS:800-2007.

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