Nonlinear Analysis of Frames Using Reduced Beam Section under Fire Loading

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Abstract— This paper presents numerical results of connections tested under fire loading. Understanding the behavior of steel frames under fire loading is critical since many numerical and experimental studies have been performed to investigate the behavior of various types of individual steel structural members, connections, and frames under fire conditions. Reduced Beam Section (RBS) connection is widely investigated and used in US, Japan and Europe. However, design of such type of connection is not presented and used in India. This study is conducted to learn, the advantages and usefulness of RBS connection against connection without RBS for Indian profiles. Different patterns of reduced beam sections were analyzed and compared with the simulation results of an unreduced beam section.

Key words: Reduced Beam Section, Steel Moment Frame, Mechanical Properties, Finite Element and Fire Resistance

I. Introduction

Fire hazard is one of the biggest challenges that any building could face during its service life. The response of steel structures exposed to fire loading has gained the attention of engineers and researchers in recent decades. The RBS (Fig. 1) connection is one of the most popular and most economical type amongst post Northridge (1994) and Kobe (1995) connections. Number of analytical and experimental studies has been performed on RBS moment connection to examine: flange cut reduction geometry, beam web to column flange connection detail, behaviour of panel zone, requirement of continuity plate, lateral and local instability of beam, effect of composite slab, and usefulness for retrofitting, etc.

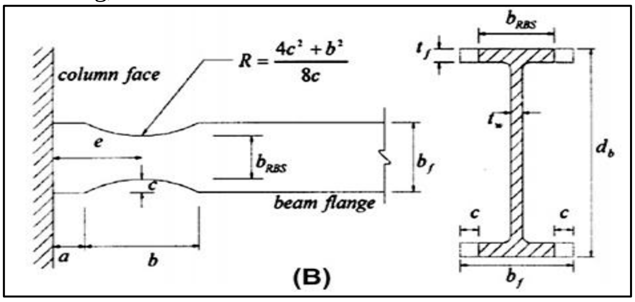


Fig. 1: Reduced Beam Section Connection Detail

Wong and Ghojel [1] conducted a sensitivity analysis in order to determine the appropriateness of the guidelines provided by Euro code 3. The parameters of thermal conductivity, specific heat, and emissivity were evaluated to determine the change in temperature of steel when subjected to a fire event. An equation for thermal conductivity variation for concrete was also proposed. Duthinh et al. [2] showed that the computational methods could be enhanced to realistically study the effects of fires on buildings by using two new interfaces in fire-thermal-structural analysis. Recently, Kodur et al. [3] offered a macroscopic finite element to predict the fire response of reinforced concrete members, in the entire range: from the pre-fire stage to the collapse stage. Rankine principal-based and 2nd- order elastic–plastic hinge approaches were also developed by to evaluate the strength and stability of steel frames exposed to fire loading [4,5]. At elevated temperatures the strength and stiffness of steel weakens, and the ability of the connections to withstand force during a fire directly affects the redistributed forces from the beams to other structural members. Iu et al. [6] presented a method for predicting the effect of heating and cooling on a multi-story frame in a real fire scenario and the temperature distribution in the frame was considered in both pre- and post-fire stages. Reduced Beam Section (RBS) connections are extensively used in moment resisting steel frames following the 1994 Northridge and 1995 Kobe earthquakes and have not previously been investigated under fire conditions for Indian profile steel sections.

II. Configuration of the Studied MRFS with RBS Connection:

Moment resisting frames (MRFs) are commonly constructed to resist lateral loads. Sections with 250 MPa grade were considered for this study. Height of the column (ISMB 200) considered was 3000 mm and length of the beam (ISMB 100) from the centre of the column was 5000 mm. Other, geometrical details are mentioned in Table 1. Table 2 shows the dimension and location of RBS connection calculated according to AISC/ FEMA formulae.

Designation	ISMB 100	ISMB 200
Depth of section, h	100	200
Width of flange, bf	75	100
Thickness of flange, tf	7.2	10.8
Thickness of web, tw	4	5.7
Moment of Inertia, Ixx	257.4×104	2235.4×104
Moment of Inertia, Iyy	40.8×104	150×104
Radius at root, r1	9	11

Table 1: Select Members for Analysis

Flange Cut Profiles	a	b	c
Radius Cut Reduced Beam Section	56 mm	85 mm	18.75 mm
RBS with Taper Cut	56 mm	85 mm	C1 = 5 mm C2 = 18 mm
RBS with Straight Cut	56 mm	85 mm	17 mm
RBS with Drilled Holes	56 mm	85 mm	10 Holes of 6 mm Dia

Table 2: Different Patterns of RBS Connections

Insulation is a material or combinations of materials that retard the flow of heat energy. 5 mm thick Gypsum boards are rigid sheets of building material made from gypsum and other materials are used for insulation purpose.

III. FINITE ELEMENT MODELLING OF THE STEEL FRAMES

The response of steel frames exposed to fire changes continuously with time due to changes in material properties at different temperature levels. In this study, finite element models, using the commercial software, ABAQUS v6.11 [7] are developed to analyze the response of the MRFs under single bay fire scenarios. Thermal–mechanical analysis is performed to simulate the effects of fire First, a transient heat transfer analysis is independently conducted to obtain the temperature distribution in frame. Once the heat transfer analysis is completed, thermal–mechanical analysis by importing the corresponding temperature from the results of the transient heat transfers analysis. Both material and geometric nonlinearities are included in the study. The models comprise of 3-D brick elements for the beams and columns which comprise of an 8-node linear heat transfer brick. Beam to column flange weld is assigned using tie constraint. Pre defined field is ambient temperature and temperature dependent material properties of steel are considered using IS 800-2007[8].

IV. VALIDATION ANALYSIS

To confirm the numerical accuracy of the analyses results of the frame, a numerical validation is conducted on previously tested and modelled frames. Double span frame shown in Fig. 2 were previously tested at elevated temperatures by Rubert and Schaumann [9, 10]. the double-span frame are commonly referred to in the literature as ZSR. All structural members are IPE80 I-sections. The structural members are uniformly heated using ISO-834 standard fire curve. The comparison includes deflection and lateral displacement at the beam-to-column nodes of the ZSR frame. The plots show that the obtained displacements versus temperature in the validation study are in good agreement with previous experimental and numerical studies.

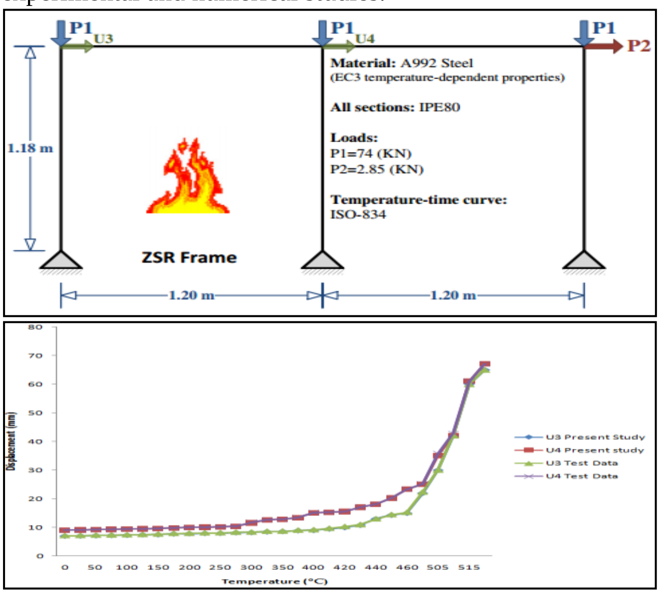


Fig. 2: ZSR Steel Frames Used In the Validation Analysis and Their Corresponding Results

V. FIRE SIMULATIONS AND ANALYSIS RESULTS

A realistic fire event is simulated in the numerical analysis using a time–temperature curve with heating Phase. There are two major standard time–temperature curves in the literature including ASTM-E119, ISO-834, which have been widely Used in the previous studies. The fire case in the frame is shown in Fig. 3.

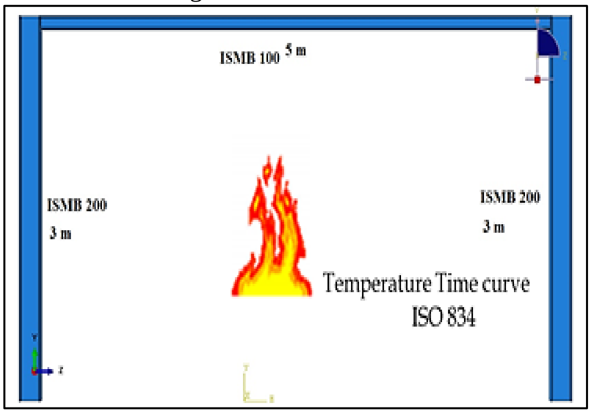
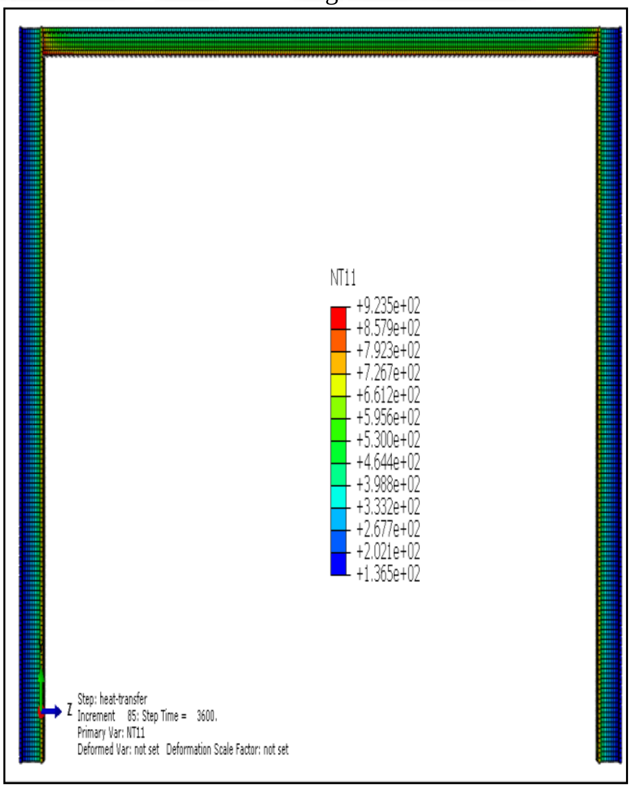


Fig. 3: Steel Frames with Fire Case

In general, when the beam first starts to heat, it expands, causing the columns to rotate. The left column rotates counter clockwise and the right column rotates clockwise. The rotation at the beam ends results in an initial upward deflection of the beam. After the initial upward deflection, the beam starts to sag due to the significant loss of stiffness at which case the end rotations caused by the column still affect the deflection of the beam, but beam sagging is more influential. The mid-span deflection continues to increase as the temperature increases because of significant stiffness reduction and material deterioration at elevated temperatures in the presence of constant applied vertical loads. The temperature distribution in frame with and without RBS is shown in fig.4.



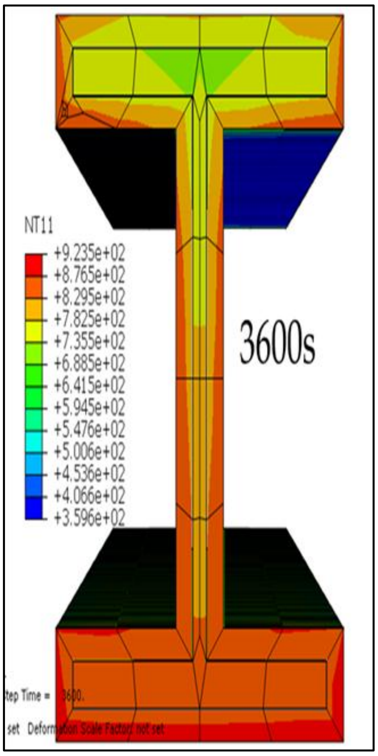


Fig. 4: Temperature Distribution in Steel Frame without RBS

Frame with radius cut RBS beam having narrow flange area hence the temperature distribution is quicker as compare with frame without RBS (Fig.5). Time temperature curve for both cases are shown in fig.6

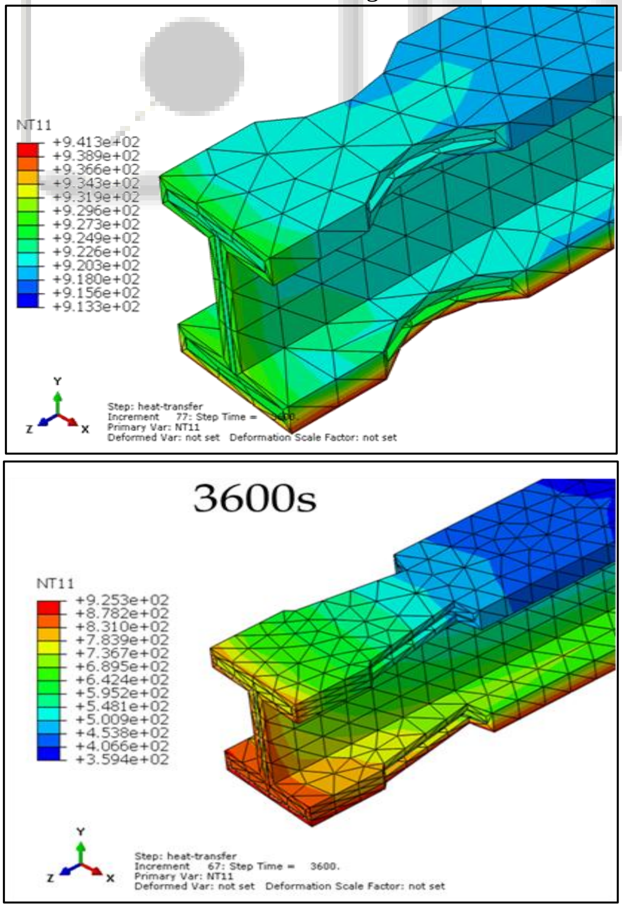


Fig. 5: Temperature Distribution in Frame with Radius Cut and Taper Cut RBS

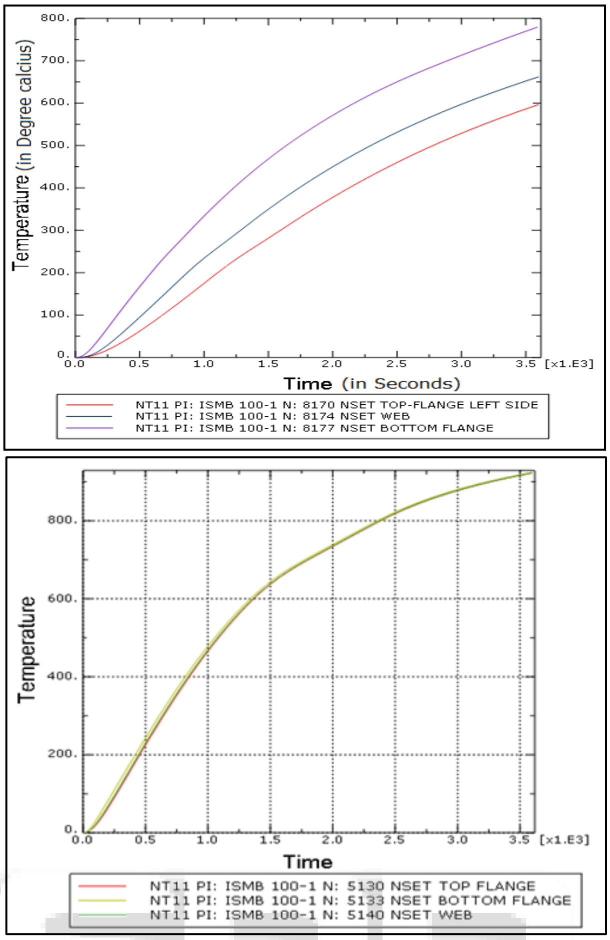


Fig. 6: Time-Temperature Curve in Frame without and With Radius Cut RBS

Comparison of time temperature distribution at different location of steel beam with and without RBS are shown in Fig.7

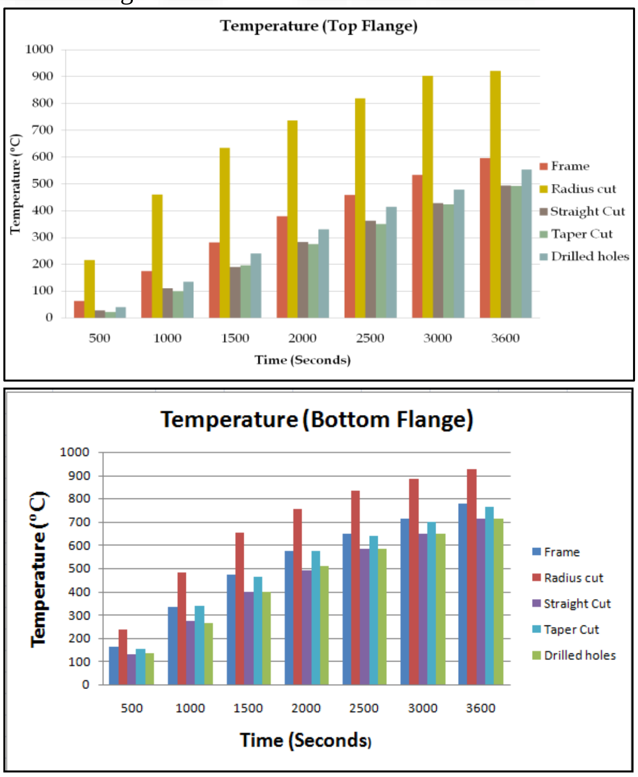


Fig. 7: Comparison of Results in Frame Without and With Different Pattern of RBS

VI. CONCLUSION

In this study, different aspects related to heat transfer mechanism for a ISMB 100 steel beam section were studied in a comprehensive manner by the use of the finite element software ABAQUS. The conclusions for different models and overall observations are discussed below.

1) From the analysis of steel model, it was observed that the temperature rise was very high for the entire beam section with all the locations in the temperature range of 700°C to 800°C.
2) Radius cut RBS is best option for high seismic zone area but at the same time its performance under fire loading is so much weak.
3) Temperature was the parameter of the study in which we concluded that the RBS using radius cut and drilled holes had more temperature at top flange and web of Beam as compare with frame without RBS.

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