Experimental and Analytical Studies on Steel Beam-to-Column Connections under Elevated Temperature

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***Abstract* - The welded flange-web with seat and cleat angle type moment connections are commonly used in the construction of modern steel buildings. The behaviour of this connection under extreme loads especially fire load is limited. In this paper the experimental studies on SHS (Square Hollow Section) as column and H- section as beam welded with cleat and seat angle and exposed to elevated temperature are presented. The beam-to-column connection are subjected to elevated temperature of 600ºC and cooled at room temperature. And subsequently subjected to monotonic loading on the beam with an axial compression load to the column. The inelastic connection behaviour in terms of moment rotation is studied. It is observed that the connection failed at lower loads due to combination of p-Δ effect along with high temperature. The theoretical and analytical results has been compared.**

Keywords: moment connection, elevated temperature, monotonic loading.

I. INTRODUCTION

The use of welded joints has been widely adopted in recent years in the design of steel frame structures and proved to be economical. In the fire design of steel building structures required to have enough strength to resists the service load and thermal force induced during the fire event to prevent catastrophic collapse of the building structures, the members need to possess adequate strength at specified temperature for a period of time. The thermal forces induce in beams and columns are strongly affected by the detail of the beam- to- column connections, such as rigid, semi-rigid, and flexible [1-4]. The connection member's response to fire has been examined by Lawson [5] under varied moment. Three types of typical joints were studied: an extended end plate, a flush end plate and double-sided web cleat and demonstrated that significant moments (upto two-thirds of their ambient temperature design moment capacity) could be sustained in fire conditions. A series of elevated temperature connection tests was conducted by Al-Jabri et al. [6] to study the influence of parameter member size end plate type and thickness and composite slab characteristics, on the joint response on fire. However, there is limited information on the connection behavior of SHS column and H-section as beam. Hence at CSIR-SERC, efforts has been put forward to understand the connection behaviour of Square Hollow Section as column welded with H-section as beam (SHCWHB).

I. THE PROBLEM DEFINITION

The connection consists of SHS column of 220x220x6mm of height 1500mm and ISMB200 beam of length 2500mm. The connection is established by welding H- beam to SHS column member with mig weld of size 6mm. An equal angle of IS 80x6 is used as seat and cleat connection, which is welded between H- beam and SHS column with 6mm fillet weld as shown in Fig.1.

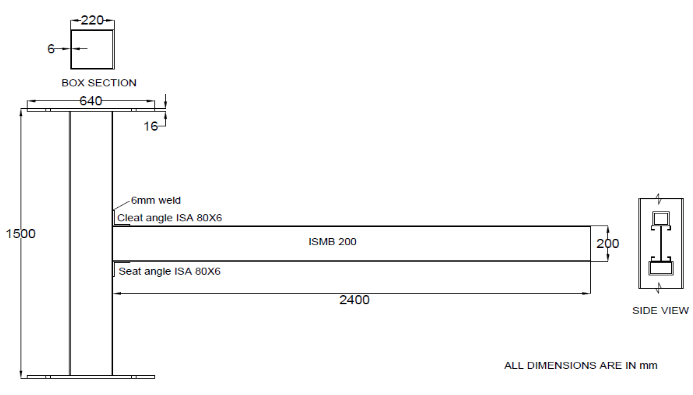

Fig.1 Sketch of beam-to-column connection

II. EXPERIMENTAL STUDIES ON BEAM-TO- COLUMN CONNECTION SUBJECTED TO ELEVATED TEMPERATUR

An experimental set-up to induce elevated temperature effect on the connection from ambient to 600ºC in localized three regions was established. The specially fabricated radiation heaters were wrapped over the region subjected to elevated temperature affect, Cinitha et al [7]. A blanketing material which is cable of preventing dissipation of heat to the atmosphere and to the other regions of the structure is used as insulator. The heats conducted to the other part of the structure are measured with adequate numbers of thermocouples. The experimental set-up to induce elevated temperature on beam-to-column connection as shown in Fig 2. The measured temperature distribution across the joint zone is shown in Fig 3.

Fig.2 Experimental set-up to induce elevated temperature on SHCWHB

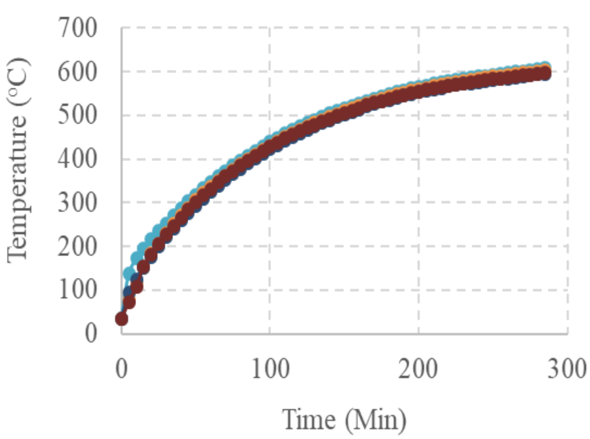

Fig.3 Measured temperature distribution across connection

III. SHCWHB SET-UP FOR MECHANICAL LOADING

To examine the response of temperature on affected steel beam-to-column moment connection, full-size welded flange-web type moment connection commonly used for steel buildings is considered. The column member is axially restrained and axially loaded with a constant load. To understand the P-Δ effect, 0.6Py is applied to column top. The H-beam being subjected to incremental load with 25ton actuator (in monotonic manner) till failure takes place. Linear Variable Differential Transformer (LVDT) and strain gauges were installed to monitor the deformation and strain value of the specimen during the test. The test set-up is shown in Fig.4.

Fig.4 Experimental set-up for SHCWHB

IV. INELASTIC BEHAVIOR OF BEAM-TO-COLUMN CONNECTIONS

The inelastic connection behavior (moment-rotation) is required for the simulation of failure mechanism in steel structures. The moment-resisting frames have a large number of dissipative zones, located near the beam-column connections. Hence, the numerical simulations of connections are equally important. They also play a key role in computation of ultimate load. Since connections frequently are located at points of maximum shear and moment, the details must ensure that the performance that is assumed in design and analysis are one and the same. According to the basic response, they are generally classified as (1) flexible connections (pinned); (2) rigid connections (fixed); and (3) semi-rigid connections. The idealized approximation of the moment-rotation behavior of most realistic connections can be simulated as semi-rigid (Chen and Kishi, 1989; Gioncu and Pectu, 1997; Goto and Miyashita, 1998; Kishi and Chen, 1990). In the present study, an analytical approach is proposed for the inelastic deformations of beam-to column connections as given in Table 1.

Details	Quasi-constant Moment
M_y	$Z_e \frac{f_y}{1.1} \alpha$
θ_y	$\frac{M_y L}{3EI} = \frac{Z_e f_y L}{3.3EI}$
M_p	$Z_p \frac{f_y}{1.1} \alpha$
θ_p	$\frac{M_p L}{3EI} = \frac{Z_p f_y L}{3.3\ EI}$
M_u	$M_p \frac{f_u + f_y}{2f_y} \alpha$
θ_u	$\left\{\frac{M_u}{M_p} + \left[1 - \frac{M_p}{M_u}\right]\left[2\frac{\varepsilon_{hf}}{\varepsilon_{yf}} + \frac{E_f}{E_{hf}}\left(\frac{M_u}{M_p} - 1\right)\right]\right\}\theta_p$

Table 1. Expressions for moment-rotation characteristics of beam-to-column connections

Note: For semi-rigid L=5d, where d is depth of cross section of beam member at that particular joint/connection, and α=0.75 for semi rigid connection

V. Results and Discussion

The temperature distribution across the connection region shows uniform distribution in beam and column members. The deterioration in the strength and stiffness at elevated temperature are important characteristics of steel beam-to-column moment connection. The load vs. deflection behavior of beam-to-column connection subjected to elevated temperature and cooled at room temperature is shown in Fig.5.The beam has undergone a deflection of 80mm at failure. The damage in connection region was less and no cracks were found in welded regions. The beam member has undergone plastic deformation which was evident from the formation of Lüder's lines in top flange. The inelastic connection behaviour in terms of moment-rotation is required for the simulation of failure in steel structures. The moment-resisting frames have large number of dissipative zones, located near the beam-to-column connections and it is complex to compute the ultimate load analytically. The experimentally observed moment vs. rotation behaviour is shown in Fig. 6. The combination of analytical and experimental moment vs. rotation behaviour is shown in Fig. 7.

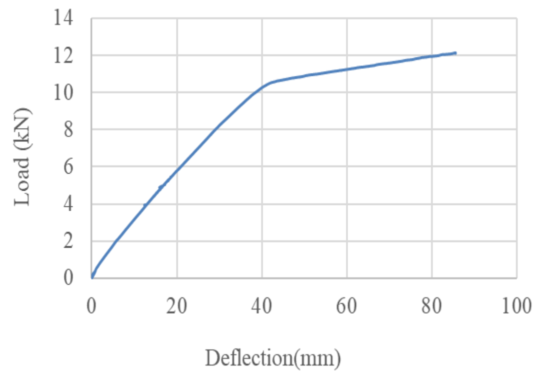

Fig 5. Load vs Deflection behaviour

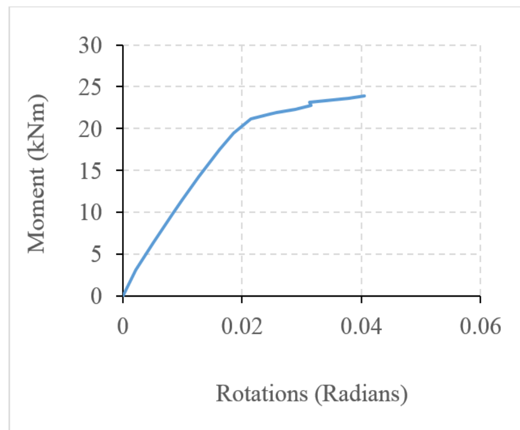

Fig.6 Moment vs. Rotation curve (Experiment)

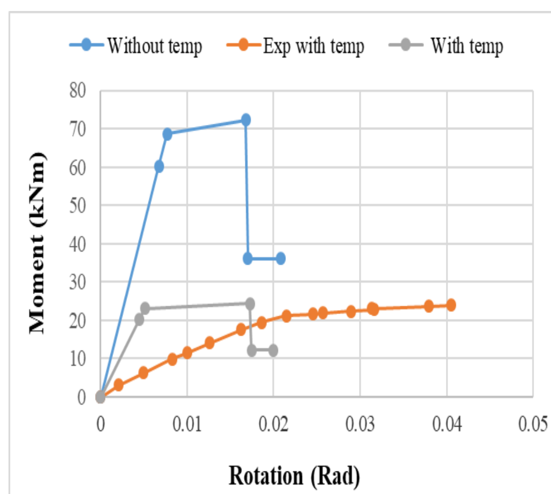

Fig.7 Moment vs. Rotation curve (Combination)

VI. CONCLUSION

The behaviour of SHCWHB type moment connection subjected to elevated temperature was examined. It was found that the connection region had no crack formation or much significant damages. Even though significant loss of its strength and stiffness. The results demonstrate that moment capacity of the connection decreased by exposing to elevated temperature. It is also noticed that axial restraint i.e. (P-Δ effect) force has significant effect on moment capacity of steel beam-column connection i.e. connection failed at lower loads (exact quantification requires further experiments). Based on the analytical studies, the salient plastic hinge locations such as yield, plastic and ultimate are estimated. It is observed that 70% reduction in moment capacity of elevated temperature affected beam-to-column connections compared to ambient conditions. However, the analytical expressions need modifications based on experimental studies at elevated temperature, which is very evident from the present studies.

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