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Research Article

Finite Element Investigation of a Bolted Extended End-Plate Moment Connection Subjected to Variation of Temperature

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Abstract

Although beam to beam joints are a critical part of steel structures and connection strength varies with temperature considerably, regrettably very few works have been conducted under elevated temperature conditions on end plate moment connection. The strength and stiffness properties degrade with increase of temperature. This paper presents an investigation of a bolted extended end-plate beam to beam joint subjected to variation of temperature. 20°C, 204°C, 316°C, 427°C, 649°C temperatures were considered for finite element analysis and their effects on end-plate moment connection were discussed. It has been found that with the increase of temperature, end plate thickness does not vary but stiffness of end plate reduces considerably. Finally, the effects of the changes of different beam parameters on the end-plate moment connection were discussed.

Keywords: Bolted joint; End-Plate moment connection; Finite element model; Temperature

Introduction

An extended end-plate connection is one in which the endplate protrudes beyond the flanges of the beam section to allow for the placement of exterior bolts. Moment connections are usually designed to transfer bending moments, shear forces and sometimes normal force. The strength of end plate will change with temperature which will cause reduction of strength of connection. When the steel elements and structures are subjected to high temperatures (fire) they progressively lose their stiffness and carrying capacity because Young's modulus and yield strength are decreasing. The ability of connections to withstand force during a fire weakens as a result of strength and stiffness reduction [1]. Connections play a very important role to survive extreme fires without progressively collapsing [2]. Lawson [3] first examined the fire resistance of beam-to-column connection experimentally. Al-Jabri [4] conducted a series of fire tests to establish the moment- rotation temperature relationships for semi-rigid joints. When temperature exceeds 100°C, the stress-strain curve begins to become nonlinear, gradually eliminating well-defined yield point. The modulus of elasticity, yield strength and tensile strength all reduce as temperature increases. After 500°C, the rate of decrease is maximum [5].

Stress and strain values of a mild steel (Yield strength 275 MPa) were obtained from tension test performed in Structural Mechanics Laboratory of Bangladesh University of Engineering and Technology, Dhaka, Bangladesh. Then using the guidelines proposed by NIST [5], corresponding yield strength, ultimate strength, elastic modulus, stress and strain values were calculated at 20°C, 204°C, 316°C, 427°C, 649°C. Finally in order to investigate adequate end plate thickness and corresponding end plate reaction with change of temperature, finite element software ANSYS 11.0 was used.

Methodology

Finite element model

A finite element model was developed to describe the behavior of the joint in a beam-to-beam extended end-plate moment connection at elevated temperatures. Among different finite element analysis packages, ANSYS 11.0 was chosen for modeling and analysis. In order to analyze the bolted extended end-plate moment connection, large deflection and plastic material properties (material nonlinearity) were used. A typical situation where end-plate type beam splice is used is shown in Figure 1. For finite element analysis of the moment capacity, a part of the beam on one side of the joint was modeled with appropriate load and boundary connections. A 3-D sketch of the problem is shown in Figures 2 and 3.

Separate elements had been used for the modeling of the beam flange, beam web, end-plate, load plate, bolts and contact surface. SHELL181 had been used for the beam flange, beam web, end-plate and load plate. COMBIN39 was used for the contact surface and the bolts. A load plate had been used in order to avoid the local yielding of the beam, at the point of the application of load. The behavior of the bolts and the contact surface was described by COMBIN39 spring element. The behavior of nonlinear stress-strain materials can be simulated accurately in ANSYS.

Multilinear isotropic hardening is one such option to describe such material behaviors. W12x58 section and A325 bolt having yield strength 90ksi (620 MPa) and ultimate strength 120 ksi (827 MPa) were used in the analysis. When the beam is subjected to external load then a reaction is created in end-plate to resist corresponding enddisplacement which is termed end-plate reaction and that displacement is termed as end-displacement.

Meshing

SHELL181 was used to model the entire beam. The meshing was done in such a way that more intense meshing reamained near the endplate. This is because the effect of bending is greater in that region.

Meshing of the end-plate

SHELL181 was used to model the end-plate. BKIN option was used in order to describe the behavior of the bilinear isotropic steel. The meshing was done in such a way to ensure that nodes exist at the desired locations of the bolts, as shown in Figure 4.

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more intense meshing near end-plate Beam Flange Figure 3: The finite element mesh has more intense meshing near the end-plate.

Here, $a1 + a2 = 1.5 \times \boldsymbol{b}_d$ here \boldsymbol{b}_d = Bolt dia

$$a1 = \frac{a1+a2}{2}$$
 and $a2 = \frac{a1+a2}{2}$
 $a3 = \frac{beam \, width}{4}$ and $a4 = a3$

 $b1 = 1.5 \times b_d$ and $b2 = 3 \times b_d + weld$ where weld = min (flange thickness, endplate thickness)

$$b3 = \frac{beam \, depth}{4}$$
 and $b4 = \frac{beam \, depth}{2} - b3$

The meshing of the load plate is identical to the meshing of the end-plate.

Properties of the bolt

COMBIN39 link element was used to simulate the behavior of

bolts. Figure 5 shows the force-deflection behavior of bolts. The values of both K_c and K_t are equal here. K_c and K_t represent the stiffness of the bolt and were calculated as follows:

$$K_c = K_t = \frac{A_b}{L} \times E$$

Where,

 A_{b} = bolt cross-sectional are

E = Young's modulus of elasticity

L =length of bolt

Properties of the contact element

Contact element was used to describe the behavior of two end-plates in contact with each other. The same COMBIN39 spring element was used for this purpose. The nodes of the end-plate are extruded along the axis of the beam, in the opposite direction of the beam, to generate the COMBIN39 contact elements. The stress-strain relationship for the

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Figure 5: Force-deflection behavior of the bolts.

element was described so that it can resist compression but remains very weak in tension. Figure 6 shows the force-deflection behavior of contact springs. The value of K_{a} is large while that of K_{a} is very small.

Boundary conditions

The free ends of the COMBIN39 link elements, which simulate the contact surface, were restrained in all directions. To protect against sliding, one node of the end-plate was restrained in the vertical direction and two nodes were restrained in the horizontal direction. It would help the COMBIN39 elements to resist the displacement both in horizontal and vertical direction or to give stability to the end-plate. A point load is applied at the load plate end of the beam. The point load is applied at the intersection of the top flange of the beam with the web as shown in Figure 7. The magnitude of the load is such that it ensures that yielding of steel occurs. This is of importance for determining the corresponding thickness of end-plate for a particular dimension of beam.

Stress-strain data input

Stress and strain values of a mild steel (Yield strength 275 MPa) were obtained from tension test performed in Structural Mechanics Laboratory of Bangladesh University of Engineering and Technology, Dhaka, Bangladesh. The stress-strain curves were prepared and used for finite element analysis (Figures 8-10).

Convergence of the solution

The objective of the finite element study is to determine the endplate thickness for W12x58 section considering temperature effects. The required end-plate thickness is that thickness for which the failure is just initiated by the yielding of the beam. This thickness can be determined by a trial and error solution involving the force-deflection relationship of the structure. From the Figure 11 given below it was found that after increasing end-plate thickness to 50 mm, end-plate reaction does not change which indicates that at this thickness failure will be just initiated by the yielding of the beam.

Results

Temperature effect on end plate reaction

Using the Table 1 proposed by NIST [5], corresponding yield







strength, ultimate strength, elastic modulus, stress and strain values were calculated at 20°C, 204°C, 316°C, 427°C, 649°C. The end-plate reaction vs. end displacement curve at 20°C, 204°C, 316°C, 427°C, 649°C are shown below. From the values obtained from finite element analysis, it had been found that end-plate thickness does not change with the increase of temperature but stiffness of plate had been found to decrease considerably. Here the value just after which nonlinearity









Temperature (°C)	$k_E = E(T)/E$	$k_p = F_p(T)/F_y$	$k_y = F_y(T)/F_y$	$k_u = F_u(T)/F_y$
20	1.00	1.00	1.00	1.00
93	1.00	1.00	1.00	1.00
204	0.90	0.80	1.00	1.00
316	0.78	0.58	1.00	1.00
399	0.70	0.42	1.00	1.00
427	0.67	0.40	0.94	0.94
538	0.49	0.29	0.66	0.66
649	0.22	0.13	0.35	0.35
760	0.11	0.06	0.16	0.16
871	0.07	0.04	0.07	0.07
982	0.05	0.03	0.04	0.04
1093	0.02	0.01	0.02	0.02
1204	0.00	0.00	0.00	0.00

Table 1: AISC, NIST proposed table showing changes of reduction factors of material strength with change of temperatures.

begins was taken as end-plate reaction. Stiffness is termed as resisting force per unit deflection. Stiffness of end-plate at 20°C was taken as 1.0 and stiffness of end-plate at other temperatures were compared with it and a relative stiffness curve had been drawn.

Effects on end-plate reaction with the change of beam parameters

The effects of the changes of different beam parameters on the end plate reactions are shown in the curves in Figures 12a-12d. It had been found that end-plate reaction increases with increase of beam height, flange thickness, web thickness, and beam width. This is because increasing any one of these parameters results in an increased moment capacity of the beam. Thus to counter the increase in moment, a greater end-plate thickness is required and as a result end-plate reaction also increases.

Conclusion

This study originated with the aim to provide an idea about temperature effects on end-plate connection. How end-plate reaction varies with temperature was the problem. The conclusions are mentioned below,

- The end-plate reaction at 204°C is found very close to reaction found at 20°C.
- At temperature 316°C, end-plate reaction is found 61% of reaction found at temperature 20°C.



Figure 12: Parametric studies on end-plate reaction: (a) end-reaction vs. beam height; (b) end-reaction vs. flange thickness; (c) end-reaction vs. web thickness; (d) end-reaction vs. flange width.

At temperature 427°C, this variation is much. End-plate reaction is found as much as 60% less than reaction at 20°C.

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- At temperature 649°C, only 5% of strength is found at end plate . than that was for 20°C.
- The beam height, flange thickness, web thickness and beam . width were the studied parameters to have a significant effect on the end-plate reaction. End-plate reaction tends to increase with the increase of any of the four parameters.

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