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Thermal creep effect on the behavior of shear tab connections due to fire temperatures

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ABSTRACT

This study investigates the effect of thermal creep of steel on the behavior of shear tab beam-column connections due to fire temperatures. FE simulations are first developed under *fast* steady-state temperature conditions to study the behavior of the shear tab connections at different temperatures and validated against experimental data available in the literature. Parametric studies are performed to investigate the impact of major geometric parameters on the behavior of the shear tab connections during fire temperatures with and without creep effect. Then, creep effect is explicitly included in the FE models under steady-state temperature conditions to study the time-dependent deformations of shear tab connections when applied forces and temperatures are kept constant. Also, isochronous force-rotation curves are developed to better understand the time effect on the strength and rotational capacity. Results from the simulations and parametric studies show that the connection experiences additional rotation/displacement and a change in failure mode is observed when the effect of thermal creep is included in predicting the response of the shear tab connections. These results clearly indicate the importance of including creep in predicting the response of shear tab connections subjected to fire temperatures and its effect on the behavior.

1. Introduction

Shear tab connections are considered simple shear connections, designed to transfer gravity loads. However during a fire, these connections are subjected to additional thermal induced forces. Therefore, it is important to understand the behavior of the connection at fire temperatures, during which the strength and deformation capacities are reduced. Experiments were conducted in order to understand and predict the overall behavior of shear tab connections, under the effect of combined axial-shear forces [1] and under the effect of pure tension [2,3] at elevated temperatures. In these studies, isolated shear tab connections were assembled and tested under steady-state temperature conditions. In addition to the isolated connections, full scale beam-column shear tab connections were also tested under transient-state temperature conditions to study their behavior when the beam is axially restrained [4]. Parameters, such as shear-to-axial load ratio, bolt size and grade, that impact the flexibility, strength, rotational ductility, and failure modes were examined [1,3]. Also, experimental investigations and analytical studies show that the thermal induced axial forces, rotations and displacements may cause the connection to fail during the heating phase or even during the cooling phase of the fire [4].

During a fire, the behavior of steel becomes time-dependent and this might impact the response of shear tab connections at elevated temperatures which is known as thermal creep [5,6]. Thermal creep is defined as the time and rate-dependent deformation under applied load at elevated temperatures. The effect of thermal creep becomes significant when the temperature reaches above one-third of the melting point of steel, which is around 400 °C for structural carbon steel [7]. The creep of steel is affected by the material type, applied stress, temperature and duration. The thermal creep curve represents the rate of deformation of a material, which is known as time versus strain curve. The creep curve is divided into three stages as presented in Fig. 1. In the primary creep stage, the curve experiences a decrease in the creep strain rate as time increases. The secondary creep stage starts when the creep strain rate is relatively uniform with respect to time. The final stage is known as tertiary stage, during which the creep rate accelerates until the

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material deteriorates and fractures. For the steel material, the shape of the curve, the magnitude of the creep strain, and the time scale are highly dependent on temperature and stress levels [5,6]. Morovat et al. [5] studied the time-dependent behavior of steel columns under the effect of thermal creep at fire temperatures. Furthermore, it is indicated that not only slenderness and fire temperature affect the buckling capacity of steel columns but the duration of the applied stress as well, under the influence of thermal creep [5]. Kodur and Dwaikat [8] studied the effect of thermal creep on the fire response of restrained steel beams under transient state. When including the effect of thermal creep in FE, the FE results predicted well the experimental tests. Therefore, ignoring the effect of thermal creep at high temperatures may lead to inaccurate predictions in the behavior of restrained beams. Also, limited research was performed in observing the behavior of the ASTM A325 bolts under the effect of thermal creep at fire temperatures [9]. A methodology was developed to study the time-dependent behavior of the flush-end plate connections subjected to fire temperatures. This methodology is based on isochronous curves that predict the response of flush-end plate connections under the effect of thermal creep [10].

This research presents an approach to investigate the time-dependent behavior of shear tab connections when subjected to fire temperatures. The strength and deformation capacities of shear tab connections are explicitly expressed as a function of time. In order to study the effect of applied load and temperature separately, steady-state thermal creep analysis is performed where a fraction of the peak load is applied and held constant for two hours at the desired temperature. The peak load is defined as the ultimate applied load at which the specimen has failed during the steady-state experiment. The creep-free temperature-stress-strain curves proposed by Refs. [11,12] are used in the analysis, where the effect of creep is not taken into consideration. To account for thermal creep explicitly, Fields and Fields [13] equations are incorporated in these creep-free temperature-stress-strain curves to study the effect of applied stress and temperature separately. A methodology is proposed to account for the fire duration exposure on shear tab connections and its creep effect on the response. Finally, a parametric study is performed to study the impact of each parameter on the behavior of the connection with and without the effect of thermal creep. These parameters include shear tab location, beam setback, applied load angle, and shear tab thickness.

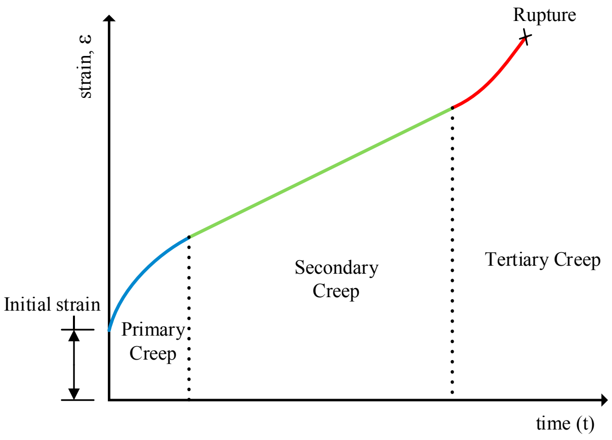

Fig. 1. Typical creep curve of structural steel [8].

2. FE modeling of shear tab connections

Two connection prototypes selected for analysis were tested experimentally at the University of Sheffield [1,14] and the University of Texas at Austin [2,3]. The shear tab connection specimen conducted experimentally at the University of Sheffield [1,14] consisted of FP 200 × 100 × 8 mm shear tab (fin plate), a UB 305 × 165 × 40 mm beam, and a UC 254 × 254 × 89 mm column was selected for analysis as shown in Fig. 2(a). Three grade 8.8 M20 bolts were used to connect the shear tab to the beam, having a standard bolt holes of diameter 22 mm (7/8 in.) [1,14]. The second shear tab connection selected for analysis followed the experimental results conducted at the University of Texas at Austin and the details are available in Ref. [3]. The shear tab connection specimen used in Ref. [3] consisted of FP 222 × 115 × 10 mm (8.75 × 4.5 × 0.375 in.), a UB 305 × 165 × 40 mm (W12 × 26) beam as shown in Fig. 2(b). Each of the beam and the shear tab are connected to thick base plates by welds, and the beam is connected to the shear tab by three M24 (1 in.) bolts of grade 8.8 (A325). The bolt holes are of standard type having a diameter of 27 mm (1-1/16 in.). Further geometric details of both connection configurations can be found in Refs. [1,3].

Finite element (FE) models of shear tab connections are developed in Abaqus to predict the rotation/displacement-force response and to validate the experimental work at ambient and fire temperatures. The details of the models are described below.

2.1. Model discretization and boundary conditions

Eight-node brick element with reduced integration (C3D8-R) was used to mesh the connection components. The size of the mesh is chosen based on its accuracy in predicting the behavior of the connections. The final mesh size is determined based on the accuracy of the validation of the FE models against the experimental tests. The mesh configuration is shown in Fig. 3(a) and (b). Note that, the mesh used in the connection region is relatively finer than that of the rest of the connection, where failure is expected to occur, and at regions where stresses are concentrated (around bolt holes), a mapped mesh is used in order to achieve a higher accuracy of interpolations. A square mesh size of 2 mm is used for the bolts and bolt holes, while a size of 12.5 mm is used in the connection area, and the rest of the model has a mesh size of 25 mm.

A surface-to-surface contact with finite sliding coefficient is assigned to the surfaces of shear tab, beam, bolt shanks, and bolt heads. The finite sliding is used to permit separation, sliding, and rotation of the contact surfaces. A friction coefficient of 0.25 is used to model friction between contact surfaces. A surface based tie constraint is used to define the contact between the shear tab and the column, and between shear tab/beam and thick plates as shown in Fig. 3(a) and (b).

Throughout the analysis, boundary conditions are applied on different components of the connection. The bolts in both experiments were hand tightened. To account for this type of pretensioning in the FE models, compressive stresses are applied at bolt head and nut. During the pretensioning step, the shear bolts are restrained against any translation to make sure that contact occurs between the bolt head, nut and steel elements. During the loading step, this boundary condition is deactivated. The column is fully restrained against any translation and rotation throughout the analysis as shown in Fig. 3(a).

2.2. Material properties

An idealized bilinear stress-strain relationship is used for all steel