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Numerical evaluation of the effects of fire on steel connections; Part 1: Simulation techniques

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ABSTRACT

Steel connections are used to connect between beam and column in steel moment frame structures. As of present time, there is a huge lack of understanding of the performance of steel connections and their response to fire especially the uncontrolled fires. Therefore, in this paper, by using a finite element program ABAQUS and with the static analysis of coupled temperature-displacement and to fully understand the behavior of such connection under the fire scenario, developed a temperature-dependent models for different types of steel connections are implemented. Finite Element Analyses (FEA) of selected experimental models are performed to verify the implementation of these models. Fully detailed, field-variable-dependent conductivity element models of the connections are developed, and analyses are performed to determine the effects of heat on the behavior of the materials in the elastic and plastic areas are considered. Moreover, severe deformation in the nonlinear region was investigated.

1. Introduction

Steel connections between beams, girders, and columns are an integral and critical part of the design of steel structures. Standard design practices for steel connections may not consider temperatures outside the normal ambient temperature range. It is critical to consider the effects of thermal loading on steel connections, otherwise the structure may suffer severe damage or destruction in a fire scenario. This was observed in the September 11, 2001 attack on the World Trade Center. The steel structure provided resistance for the service loads and withstood the aircraft impact. However, the resulting thermal loading from explosion and fire resulted in the complete collapse of both structures. Many researchers have studied the effects of fire and heat on steel structures, but relatively few have employed numerical methods for comparison with experimental results [1].

One possible explanation for such a gap in this area is the lack of laboratory equipment due to the huge cost associated with conducting these studies. Saedi Darian et al. (2009–2012) conducted a study on simple connections with seat angles, in welded and bolted states [2,3]. Lawson (1990) investigated the effect of fire on the rigid connection of steel. He found that the behavior of joints and concrete cover over the connection regions improves when they are exposed to fire [4]. Rahnavard et al. (2014) studied the rigid connection of steel on end plate connection proposed thermal modeling using the finite element program ABAQUS [5–7]. Selamet and Garlock (2010) numerically studied the behavior of simple steel connections. They found that the durability hole's diameter of bolts is crucial in predicting the simple behavior of connections [8]. Suleiman et al. (2017) used 3-D finite element modeling of extended single plate shear connections to examine whether at the unfactored loads, the lateral displacement of beams or extended plate connections are mainly associated with the torsional moment at the connection regions [9]. Kalogeropoulos et al. (2012)

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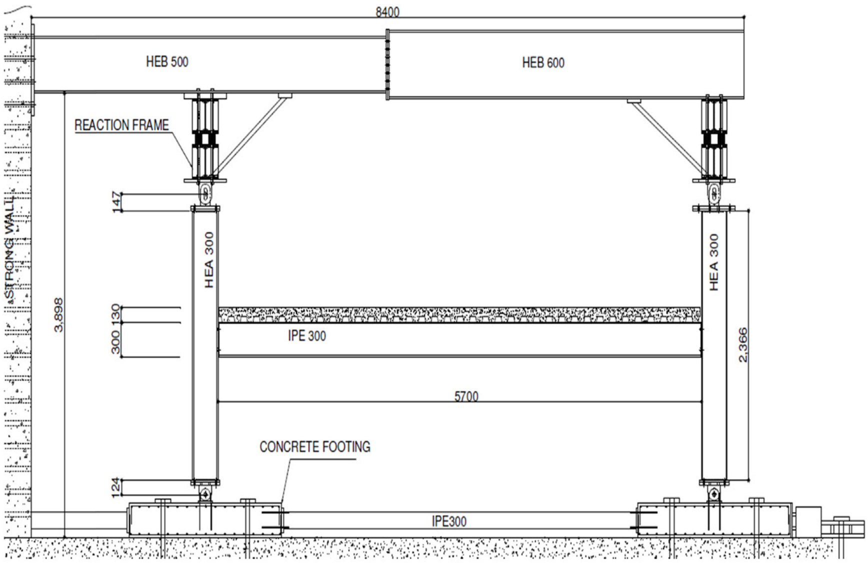
modeled bolted rigid connection plates with end plates via ABAQUS finite element software and evaluated the influence of parameters such as mechanical loads, the yield and ultimate stress of bolts and the holes of bolts [10]. Wald et al. (2006) proposed experimental models for rigid end plate connections and compared the failure mode and shift of the beam centers in these models [11]. Kruppa (1976), in his research investigated how some types of steel joints will behave at high temperatures. He found that failure of steel members occurred prior to the failure of high strength bolts [12]. Burgess (2008) studied an explicit dynamic solver [13]. Other studies focused on the cooling phase of fire and used an artificial neural network to describe the stress-strain relations of steel connections exposed to fire [14]. Qiang et al. (2014) studied the post-fire behavior of high strength steel end plate connections. The results of their experimental study showed that the use of a high-strength thin steel plate, compared with a thick steel plate with less yield stress, does not present an appropriate performance in the end plate connection and even higher rotation capacity after fire [15]. The 14th edition of the AISC *Steel Construction Manual* (2010) and Eurocode 3 provides equations to evaluate the need for stiffeners; these equations were developed based on the fundamental concepts of structural mechanics [16-19]. An analytical method to calculate temperatures of components of reverse channel connection to concrete filled steel section under fire conditions evaluated by Jana et al. (2016). Temperature analysis of partially heated steel members in fire conducted by Wong (2017) [20]. Other research projects involve the study of the cooling phase of a fire, as well as implementation of an artificial neural network for the description of the stress–strain relations of steel under fire [23,24]. Huang et al. using a component-based method evaluated the behavior and effects of beam-end buckling in fire [25–30]. The current study evaluates the effect of heat on common rigid connections of steel using computer program ABAQUS [18] and compares these connections in terms of deformation, rotation, and moment- capacity.



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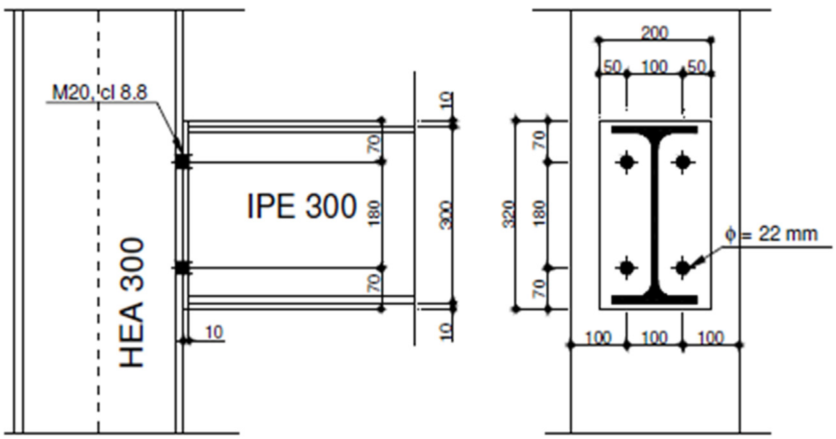

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Fig. 1. (a) Laboratory test geometry [11]; (b) details of the rigid end plate connection.