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Numerical study on seismic behaviors of steel frame end-plate connections

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ABSTRACT

In order to study the seismic behaviors of steel frame end-plate connections, an efficient and accurate finite element model of ABAQUS was established subjected to cyclic loadings. Element types, material cyclic constitutive models and contact models for bolts, end plate and members were described. Geometry and material nonlinearity were adequately considered. The simulated results of numerical models were verified by typical quasi-static tests of end-plate connections, including both hysteretic curves and failure modes. It provided a strong tool for investigating the performances of this kind of connection. Based on the verified models, connections with different connection methods were established to investigate the effect of connection methods on behaviors of connections, including fully welded connection, extended end-plate connection and flush end-plate connection. The carrying capacity, initial stiffness, hysteretic behaviors, degraded characteristics, fracture tendency index, failure modes and energy dissipation capacity were compared and discussed in depth. The results showed that: If the beam and column are reliably connected, the extended end-plate connection can obtain the same ultimate carrying capacity and initial stiffness (monotonic behaviors) as the welded connection, however, their hysteretic curves, degradation developing curves, and fracture tendency were quite different. It indicated that the connection methods could significantly affect the cyclic behaviors. The stiffeners of end-plate connection could be treated as the first defense of connection, effectively changing the failure mode and avoiding brittle fracture. Therefore, in the high seismic zones, hysteretic behaviors, failure modes and seismic ductility should be taken into account comprehensively to choose the appropriate connection methods.

1. Introduction

The end-plate connection method has obvious economic advantages in the manufacture and installation, which is widely used in a large number of steel frame structures. Because of its flexible connection method, the constrained stiffness of beam to column is effectively reduced and energy dissipation capacity is stronger, which is conducive to seismic. However, the construction forms of the end-plate connections are relatively complex with a large number of variable geometric parameters, such as flush and extended types, column web stiffeners of panel zone, rib stiffeners of extended end plate, end plate thickness, bolt diameter and grade, the arrangement of bolts, cross-sectional dimension of beam and column and friction coefficient of end plate and column flange, etc.

At present, the seismic performances of end-plate beam-to-column connection have been studied in depth by many scholars. A mount of tests were carried out [1–7]. All of them have conducted outstanding works on the behaviors of end-plate connections, however, due to limited numbers of tests, the numerical simulations are widely used currently. The more accurate finite element model for parametric analysis is particularly important.

There were some reports for the numerical analysis on end-plate connections. For example, Ls-Dyna explicit nonlinear solver was used to model a beam to column steel connection with end plate and prestressed bolts by Pacurar et al. [8]. Razavi et al. [9] proposed an algorithm of finite element model, which assigned three degrees-of-freedoms (DOF) to each bolt's end and constraints were introduced for the DOF of the nodes in contact with the bolt head (or nut). The ABAQUS finite-element package was used to simulate four-bolt, tubular moment end-plate connections at the University of Sydney under monotonic loading [10]. Shi et al. [11] developed a finite element numerical model with the ability to simulate and analyze the monotonic mechanical behaviors of different types of beam-to-column end-plate connections based on ANSYS. Diacuteaz et al. [12] presented a full three-dimensional ANSYS finite element model of steel bolted extended end-plate joints to obtain their behaviors. Mohamed Eldemerdash et al. [13] used ANSYS (version 11.0) to create and analyze three finite element models in order to discuss the monotonic behaviors of large capacity end-plate steel connections. Gerami Mohsen et al. [14] reported that finite element simulation was used to study and compare the cyclic

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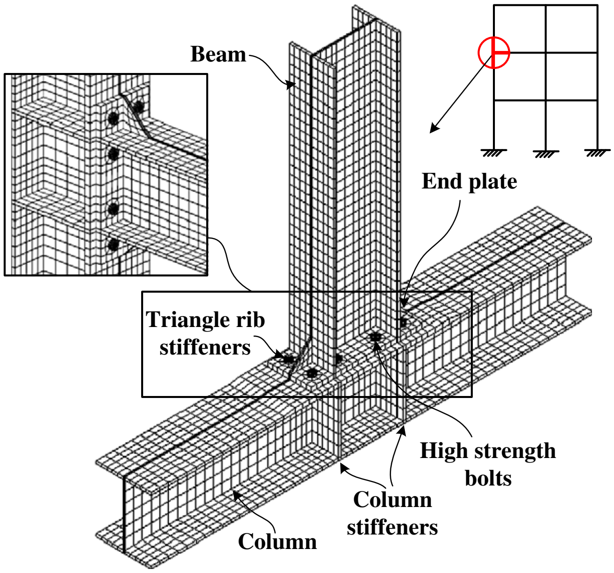

Fig. 1. Typical end-plate connection of steel frame.

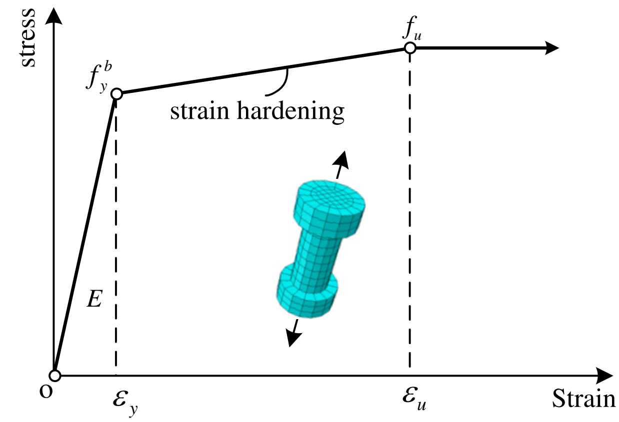

Fig. 3. Constitutive model of high-strength bolts.

behavior of fourteen specimens by changing the horizontal and vertical arrangement of bolts.

However, most of these mentioned numerical simulations focused on monotonic loading situations. Some predictions for cyclic behaviors were not satisfied. Due to complicated contact relations and high nonlinear behaviors, for example, the gap caused by residual deformation of bolts and serious extrusion of end plate and column flange, the numerical simulation of end-plate connection subjected to cyclic loading is difficult to achieve. Furthermore, the responses of steels under cyclic loading and monotonic loading are quite different [16]. The traditional method cannot accurately predict the cyclic behaviors, local buckling phenomenon and pinching phenomenon. Therefore, an efficient and accurate finite element method should be proposed for end-plate connections.

In this paper, firstly, the finite element models of end-plate connections under cyclic loading patterns were established using ABAQUS software. Element types, cyclic material constitutive models and contact models for bolts and end plate were proposed. Geometric nonlinearity and material nonlinearity were adequately considered. The numerical simulation compared well with typical quasi-static tests of end-plate connections, which provided a strong tool for carrying out further analysis. Then, based on the verified finite element method, three connection models were established to investigate the effect of connection methods on behaviors of connections, including fully welded connection, extended end-plate connection and flush end-plate connection, which are most widely used in engineering projects. In the seismic zones, not only carrying capacity, but also cyclic behaviors are important for design, especially strength degradation and fracture tendency. Therefore, the capacity, stiffness, hysteretic behaviors, degraded characteristics, fracture tendency index, failure modes and energy dissipation were compared and discussed comprehensively. Finally, a direct understanding was given for engineers to choose proper connection methods in terms of various situations.

2. Finite element analysis

In order to obtain an efficient and accurate finite element method, the analysis was conducted in ABAQUS/Standard module [15]. Both material and geometry nonlinearities were considered. All parts of models are presented detailedly as follows.

2.1. Element types and meshes

The end-plate connection of steel frame consists of steel beam, column, end plate, rib stiffeners of end plate, column stiffeners and high strength bolts. The typical connection is shown in Fig. 1. Element C3D8I (an 8-node linear brick, incompatible mode) is adopted for H-shaped steel beams, columns and high strength bolts. This element can effectively avoid shear locking phenomenon (comparing with element C3D8R), which will significantly affect the initial stiffness of connection. The boundary conditions are in accordance with typical tests, which are hinged at each end of column.

The structured meshing technique is assigned to have a proper element shape, especially for round bolts and corresponding plates.

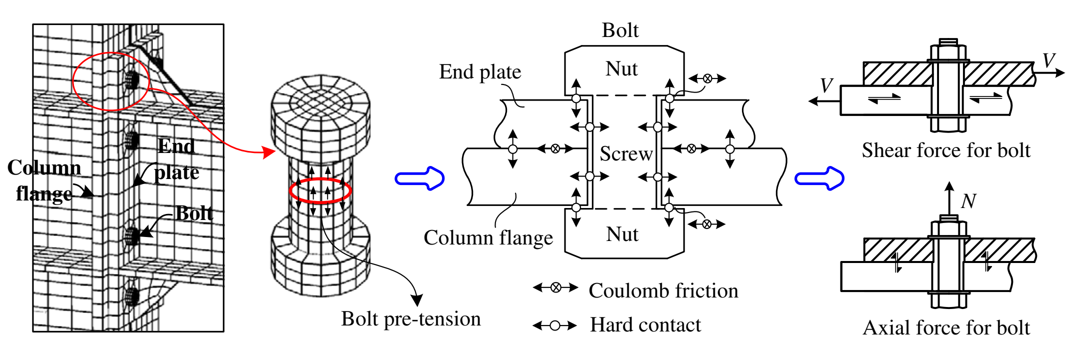

Fig. 2. Contact of high-strength bolt connection.