Engineering Structures 75 (2014) 11–26

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

A phenomenological component-based model to simulate seismic behavior of bolted extended end-plate connections

Pu Yang [a], Matthew R. Eatherton [b,*]

[a] College of Civil Engineering, Chongqing University, Chongqing 400045, PR China
[b] Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg 24060, VA, USA

ARTICLE INFO

Article history:
Received 5 August 2013
Revised 16 May 2014
Accepted 17 May 2014
Available online 13 June 2014

Keywords:
Component-based model
Phenomenological model
End-plate connections
Seismic behavior
Moment-resisting connections
Computational simulation

ABSTRACT

In order to investigate seismic behavior of bolted extended end-plate connections, a phenomenological component-based model with several separated springs is presented where the constitutive relationships for individual components are determined using material and geometric properties. Analytical results using the developed model were compared with experimental data from full-scale moment connection tests including global load versus displacement and local response of beam hinge, panel zone and other components. The effectiveness of the model was demonstrated by these comparisons. The model is then leveraged to study the influence of design decisions such as weak columns and bolt pretension. The analytical results indicate that bolt pretension and related connection slip can significantly affect the seismic behavior of the end-plate and column flange and thus their inclusion in the proposed model is validated.

1. Introduction

Steel end-plate moment connections are an important connection type used in many buildings in seismic regions. There have been numerous previous experimental programs investigating the behavior of end-plate moment connections subjected to monotonic and cyclic loading and similarly, a range of computational models and analytical expressions have been developed to simulate their behavior. High fidelity three dimensional finite element (FE) models are presented in the literature that can capture monotonic and cyclic response of end plate connections in small subassemblages such as those tested in the lab. On the other hand, analytical expressions and simplified component models have been developed to model the behavior of end plate connections subjected to monotonically increasing moment. Although these models allow computationally efficient analysis of end plate moment frames, they are typically not capable of capturing the seismic response of a frame subjected to inelastic cycles.

In the context of modern earthquake engineering which focuses on probabilistic evaluation of seismic performance, computationally efficient numerical models of seismic resisting systems are critical. For example, evaluating the suitability of seismic performance factors such as the response modification factor, R, used in current United States building codes, often requires thousands of response history analyses on archetype buildings [1]. Similarly, performance based earthquake engineering design of new buildings [2] and retrofit of existing buildings [3] requires numerous response history analyses to verify seismic performance and in some cases iterate on the structural configuration and details. Conducting these types of studies using three dimensional FE models is not feasible making cyclic component models necessary.

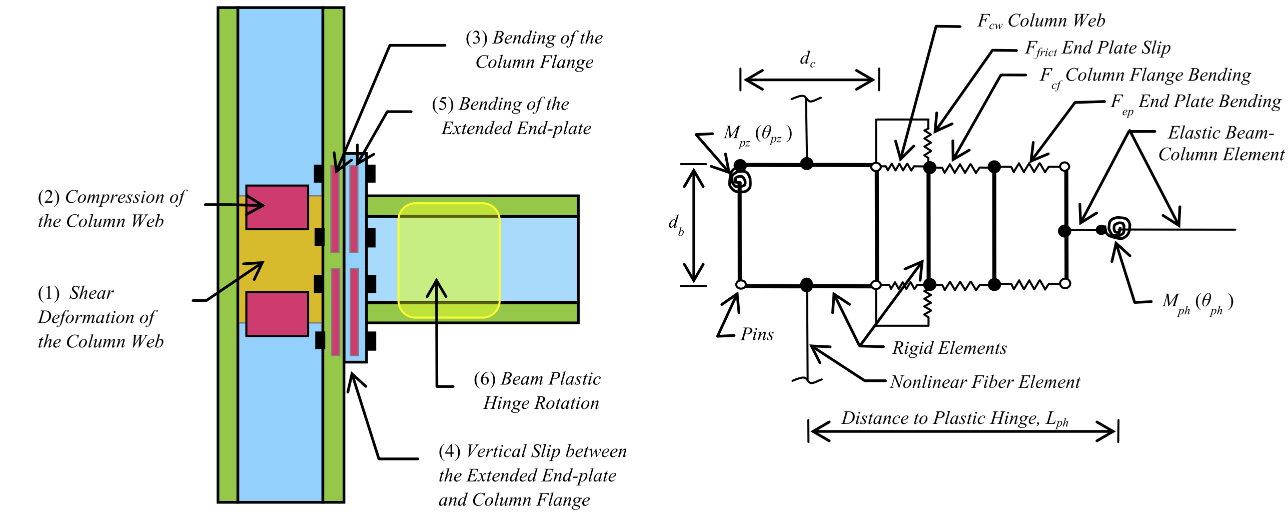
A brief overview of the types of models available in the literature is provided here although more thorough background on end plate modeling is provided elsewhere [4]. A number of the models developed in the literature are constructed and calibrated for flush end plates or end plates that are extended only on one side that do not conform to prequalified seismic extended end plate connections in the United States [5]. Furthermore, as noted below, the studies are almost exclusively developed for monotonic loading only.

There have been a number of previous studies that created detailed three dimensional finite element (FE) models of end plate connections with continuum elements, contact, bolt pretension, and more [6–10]. These models have been shown to accurately capture the behavior of a wide range of end plate moment connections to different loading scenarios.

In an effort to create simplified models, researchers have developed analytical equations to model moment rotation behavior of flush end plate connections [11,12], and extended

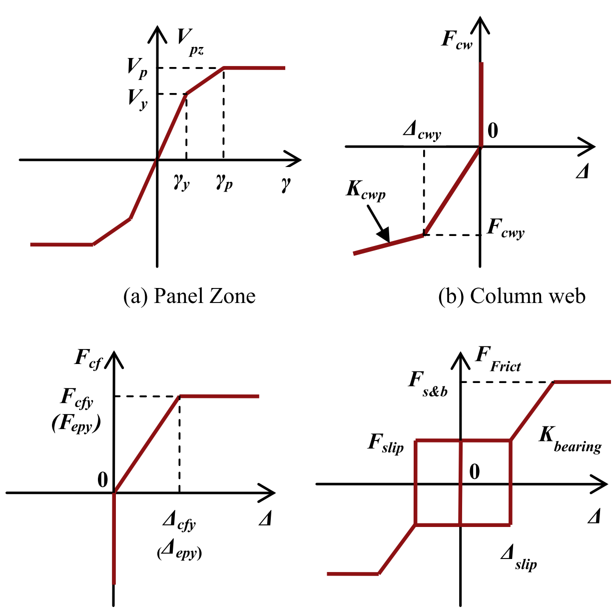
* Corresponding author. Tel./fax: +1 540 231 4559.
E-mail address: meather@vt.edu (M.R. Eatherton).

http://dx.doi.org/10.1016/j.engstruct.2014.05.023
0141-0296/© 2014 Elsevier Ltd. All rights reserved.



(a) Deformation sources of a specimen. (b) Phenomenological component-based model.

Fig. 1. An extended end-plate connection and analytical model.



(a) Panel Zone (b) Column web (c) Column flange (end-plate) (d) Slip model

Fig. 2. Constitutive relationship of components.

end plate connections [7,12,13–16]. Several of these models analytically decompose the connection into components and then sum up their moment-rotation behavior. In effect, these models can be considered as a component model with a single rotational spring at the intersection of the beam and columns. Some researchers have even extended the analytical equations to work for cyclic loading [17,18].

Another approach is to explicitly model each component of the end-plate connection as a discrete spring. Anderson and Najafi [19] developed a simplified component model to capture monotonic behavior of extended end plate connections with a composite slab. Assemblies included a few springs that lumped end plate behavior in with beam flange and column behavior. More recently, component models have been developed for flush end plates with composite slabs [20], extended end plate connections [21], extended end plate models capable of capturing ultimate rotation and ductility [22], and end plate connection models capable of capturing flexure-axial interaction [4]. However, all of these component models were constructed and calibrated to work for monotonic loading only.

There has also been substantial work on component modeling of end plate connections subjected to elevated temperature. These vary in complexity and can capture behavior of short end plates [23], and full depth end plates [24–26], but similarly are calibrated for monotonic behavior and do not capture cyclic behavior.

Considerably fewer examples of component models exist capable of modeling cyclic behavior of semi-rigid steel connections. Rassati et al. [27] developed a component model for a partially restrained composite connection with bottom seat angles and composite concrete slab. Kim et al. [28] developed a component model to capture the behavior of top and seat angle connections with double angle web connection to column.

In this paper, a phenomenological component-based model is developed to simulate cyclic behavior of bolted extended end-plate connections. Bilinear or tri-linear constitutive relationships based on material and geometric properties of the connection are used to represent the behavior of connection components. The connection is decomposed into components related to the deformation of the column flange, column web, end-plate, panel zone, and a slip model is used to simulate the relative slippage between end-plate and column flange. The model is built based on connection geometry and material properties and thus does not require calibration. The proposed model is developed and then applied to specific connection configurations, subjected to cyclic loading, and evaluated against experimental results.

2. Phenomenological component-based model

2.1. Identification of key deformation sources and model description

The key components which contribute to the deformation of steel bolted extended end-plate connections are shown in Fig. 1 and include, going from left to right: (1) shear deformation of column web including consideration of continuity and doubler plates; (2) compression of the column web; (3) bending of the column flange; (4) vertical slip between the end-plate and column flange; (5) bending of the extended end-plate in association with elongation of the bolts in tension; and (6) inelastic deformations of the beam in the plastic hinge region. These deformation sources and the proposed phenomenological component-based model are shown in Fig. 1.