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Experimental testing and simulation of bolted beam-column connections having thick extended endplates and multiple bolts per row

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ABSTRACT

Retrofit of existing steel buildings often requires strengthening of the connection regions. One common connection, the bolted beam-column connection, is often strengthened in design using stiffened extended endplates, or with continuity plates welded between the column flanges. In a retrofit scenario, adding stiffeners to the endplate is difficult due to the concrete slab and metal deck, and excessive field welding of continuity plates may be uneconomical. Simplifying retrofit efforts, and for economy, connection strength may be improved by simply adding more bolts to the connection. Current code methods, broadly generalized to all connection configurations, are currently based on component experiments having only one bolt on either side of the column web. This study experimentally investigates strengthening of bolted beam-column connections, having no column web stiffeners, using more than one bolt on either side of the column web. Six full-scale bolted beam-column connections are tested, representing exterior beam-column connections (beams attached to only one column flange). Connections with both extended and flush endplates are considered. Two column sections (HE300A and HE300B) are tested along with HE300B beams creating both equal-column-beam, and weak-column strong-beam scenarios. Analytical simulations provide insight into local connection demands, and experimental results are compared with current code methods. The experiments indicate that closer inner-bolt spacing relative to the column web increases connection moment capacity but decreases rotation capacity (connection ductility) due to increased bolt prying forces from column flange distortions. The outer bolt of multiple-bolt-per-row configurations contributes very little to the connection resistance when column web stiffeners are not considered. With the exception of specimen T-3B which failed through bolt-thread shear after 0.02 rad, all connections with multiple bolts per row still achieved rotations greater than 0.06 rad. The Eurocode 3 component method and adapted Eurocode 3 procedures conservatively predicted the connection strength of each test specimen, including weak-column strong-beam assemblies, and accurately identified the initial connection limit states.

1. Introduction

Understanding the strength and rigidity of connection regions is necessary for the efficient design of steel building systems. One common steel building connection, the bolted beam-column connection, is often assumed as either fully pinned or fully rigid; however in reality, the rigidity of such connections is somewhere in-between (a semi-rigid connection). Required strength of beams and columns in a building system depend directly on the considerations made for the connection rigidity [1]. Moreover, in retrofit scenarios where strengthening of connections is needed, accurate understanding of existing and improved connection rigidity is required. To estimate the true behavior of bolted beam-column connections, the Eurocode has adopted the component method [2], which considers individual connection components (bolts, flanges, webs, endplates, etc.) and their interactions.

The component method presented in the Eurocode 3, EN1993 part 1.8 (hereafter referred to as EC3-1.8) is based on research published in the early 1980s by Zoetemeijer [3,4] and can be summarized in five general steps: (1) identification of the load-path through the connection; (2) determination of individual component strength within the load path (for example, the compressive strength of the column web, tensile strength of the beam flange, etc.); (3) determination of individual component stiffness in the load path; (4) assembly of the individual components in series and or parallel (depending on their arrangement); and (5) determi-

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nation of the "weakest link" in the load path based on individual strength and deformation capacity. Fig. 1 shows a typical beam-column connection and the component method representation.

Many analytical and experimental studies have investigated bolted beam column connections [5–12] along with the predictive capabilities of the EC3-1.8 component method. One such study by Abidelah et al. [13] investigated the strengthening of bolted beam-column connections by comparing configurations with and without stiffeners in the extended endplate portion. In [13], results showed that additional endplate stiffeners increase moment capacity but decrease connection ductility. The EC3-1.8 component method accurately predicted the connection failure modes in the strengthened connections; however, connection strength was consistently under-predicted. All connections in [13] had two bolts per row (one bolt on either side of the column web) and column web stiffeners were not used.

Although connection strength may be increased using endplate stiffeners, in a retrofit scenario adding endplate stiffeners is difficult when a concrete slab or metal deck is present. Adding another bolt on either side of the column web may result in similar connection strength gain while simplifying retrofit application. Additionally, it is often more economical to use multiple bolts per row when wide H-sections are used [14]; however, current code methods, broadly generalized to all connection configurations, are currently based on T-stub experiments [3,4] having only one bolt on either side of the column or beam web. While a few analytical studies have investigated connections having four bolts-per-row [14,15], limited experimental data exists in the literature comparing the performance of the EC3-1.8 component method with connection configurations having multiple bolts per row.

This study experimentally investigates the interactive behavior of bolted beam-column connections having thick extended endplates and multiple bolts per row (without column web stiffeners). Weak column strong beam situations are considered. Six beam-column connections having various bolt configurations and section dimensions are tested. Detailed numerical models are also created to determine detailed stress and strain distributions within the connection regions, and to investigate techniques for simulating semi-rigid bolted connections having multiple bolts per row. Both the experimental and numerical tests are compared with the current EC3-1.8 component method. The study begins with an overview of the experimental program, followed by numerical modeling methods and result comparisons. Conclusions on the performance of bolted beam-column connections are provided.

2. Experimental program

An experimental program was developed to determine the static monotonic behavior of bolted beam-column connections having multiple bolt configurations, with the main objectives being: (1) determine the influence of bolt grouping (multiple bolts per row) and thick endplates on connection response; (2) determine the different connection failure modes; and (3) compare experimental performance with code methods. The following sections discuss the experimental program in detail and present results based on the objectives outlined above.

2.1. Test specimens

The experimental specimens consist of a column element and a beam element which is fully welded to an endplate. The beam and column elements are connected using multiple GR10.9 zinc coated M20 bolts with zinc coated GR10.9 HV nuts and standard GR4.6 washers. Note that standard GR4.6 washers were used in place of high-strength GR10.9 washers due to a specimen delivery error; however, additional testing is conducted herein to ensure negligible washer influence on connection response (see later section on T-stub testing). All bolts are pre-tightened with 480 N-m of torque as per [16].

A total of six beam-column connections are considered, representing three different bolt configurations (both extended and non-extended configurations) and two column profiles. The various specimen configurations are chosen to: (1) compare the response of bolt configurations having multiple bolts per row with typical configurations having two bolts per row (using bolt spacing comparable to typical design); (2) determine bolt grouping influence in weak-column strong-beam and equal-column-beam scenarios; and (3) determine the influence of extended endplates on configurations using multiple bolts per row. All beam and column elements are fabricated from S235 steel while the endplates are fabricated from S355 steel following typical practice. Fig. 2 shows the specimen geometry including endplate and bolt group details; Table 1 shows the experimental test matrix; and Table 2 presents the specimen material properties. Shown in Table 1, the column profile tested in group A (specimens 1A, 2A, and 3A) is an HE 300A section having a web thickness of 8.5 mm and a flange thickness of 14 mm; the column profile tested in group B is an HE 300B section having a larger web and flange thickness (11 mm and 19 mm respectively). The beam (HE 300B) is the same for all

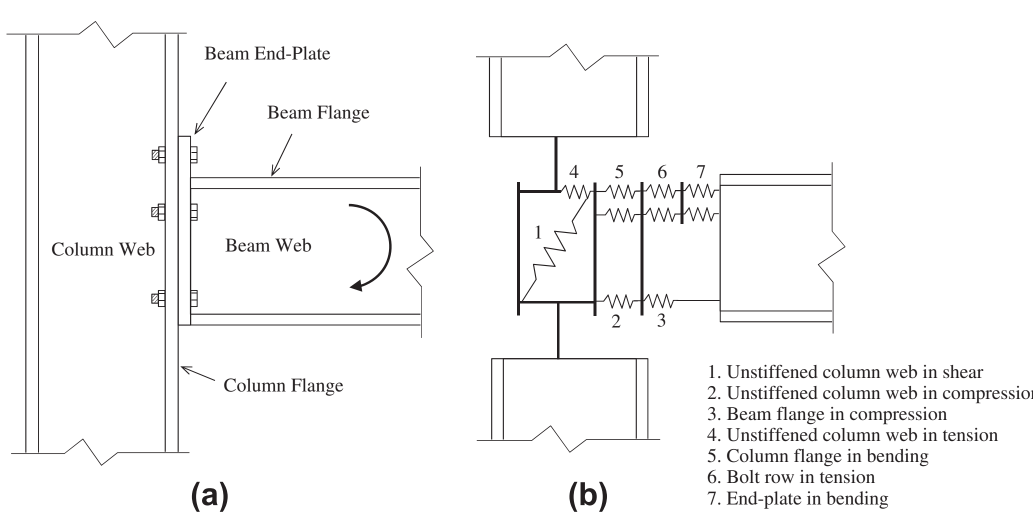

Fig. 1. (a) Typical beam-column bolted connection and (b) component method representation.