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Stiffening of bolted end-plate connections with steel member assemblies

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ABSTRACT

This paper presents a new stiffening method for bolted end-plate beam–column connections in which steel member assemblies of steel angles and plates are used as stiffeners. An important benefit of this method is that it can eliminate transverse stiffeners and doubler plates, thereby enabling use of the space between the column-flanges for architectural demands such as ducting. The local tensile strength was first evaluated based on the yield line theory. To examine failure behavior in the tension part of end-plate connections, three local tensile loading tests were conducted for the T-stub connection models. Then the local compressive strength was also evaluated by consideration of previous studies. Subsequently, to ascertain the stiffening method efficiency, one cyclic loading test was conducted for the real-size beam-to-column bolted end-plate connection. Accuracy of the strength formulae was demonstrated by comparing the predictions and the loading test results. The proposed method using the steel member assemblies was revealed to be effective to stiffen bolted end-plate connections.

1. Introduction

Bolted beam-to-column connections are widely used in steel frames. Various connection types have been proposed and developed. Because connection details, materials and loading conditions influence on the connection characteristics including joint rigidity, extensive researches have been conducted for the bolted connections. In recent studies, loading tests [1–4] and numerical analyses [5–8] were conducted for the beam-to-column bolted end-plate connections. The behavior characteristics of T-stub connections were also investigated [9–12]. The bolted moment connections are often stiffened with continuity plates (transverse stiffeners) to protect column flanges from damage. Doubler plates are also used to prevent panel zone shear failure if necessary. Those stiffening plates are welded inside the columns as presented in Fig. 1(a).

Because numerous structures have been damaged in recent natural disasters such as earthquakes, the reinforcement of existing structures has become an important task. For steel structures, spaces between column flanges are sometimes used for some architectural purposes such as ducts and electric cables. In such cases, it is difficult to use transverse stiffeners at the connection of additional reinforcement beams. Furthermore, bolted connection of reinforcement members is sometimes preferred to arc welding because welding processes produce sparks, which necessitates careful protection of existing fixtures including precision equipment.

To eliminate the transverse stiffeners, previous studies [5] have investigated the application of bolted steel channels as stiffeners. The channel stiffeners prevent column-flange deformation, column-web yielding, and column-web panel shear failure. To stiffen the column-flange deformation, bolted backing plates [13,14] and angles [15,16] are also applicable instead of transverse stiffeners. However, their stiffening effects on the column-web yielding and panel-zone shear are not large.

This study investigates bolted beam-to-column connections stiffened with steel member assemblies instead of channel stiffeners. The assemblies are composed of steel angles and plates as presented in Fig. 1(b). The figure shows a duct as an example of using spaces between column flanges. In this paper, the tension zone yield strength is first evaluated using yield line theory. Then tensile loading tests are conducted using T-sub connection models. Subsequently, the strength prediction of the compression zone is formulated in consideration of previous research results. Finally the cyclic loading test for the real-size connection model is conducted to demonstrate the efficacy of the proposed stiffening method for bolted end-plate connections.

2. Local tensile strength

Connection failures in most bolted moment connections are governed by yielding and excessive deformation of the tension zone. This chapter presents a local tensile strength evaluation and tensile test results conducted using T-stub connection models.

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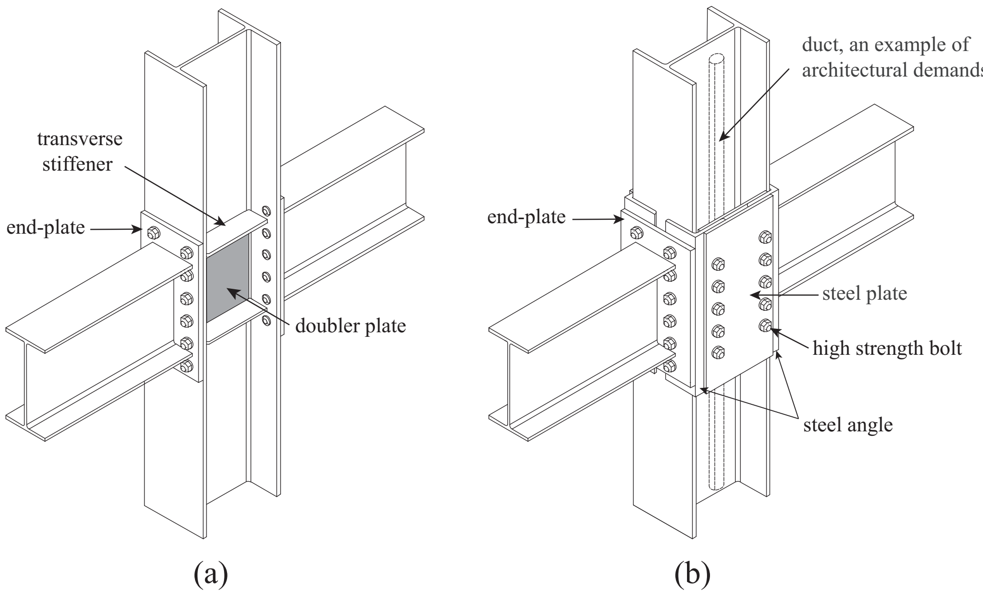

Fig. 1. Beam-to-column connections: (a) typical bolted joint and (b) proposed bolted joint.

2.1. Strength evaluation based on yield line theory

The tension part of end-plate connection is subjected to an axial load from the beam-flange. Idealized T-stub models (Fig. 2) are often used to examine tension part behaviors. In this section, T-stubs and bolts are assumed to have sufficient stiffness rather than the column-flange and angles to highlight the proposed stiffening effect. This assumption leads to failure by yielding of the column-flange and angles. To evaluate the tensile strength based on the yield line theory [17], the failure mechanisms depicted in Fig. 3 were referred from papers of earlier studies [5,18,19]. Mechanism A includes half-circular yield zones around bolt holes and yield lines between bolt holes in the column-flange. Mechanism B includes circular yield zones around the bolt holes in the column-flange. Both mechanisms show identical yield line patterns in the angles.

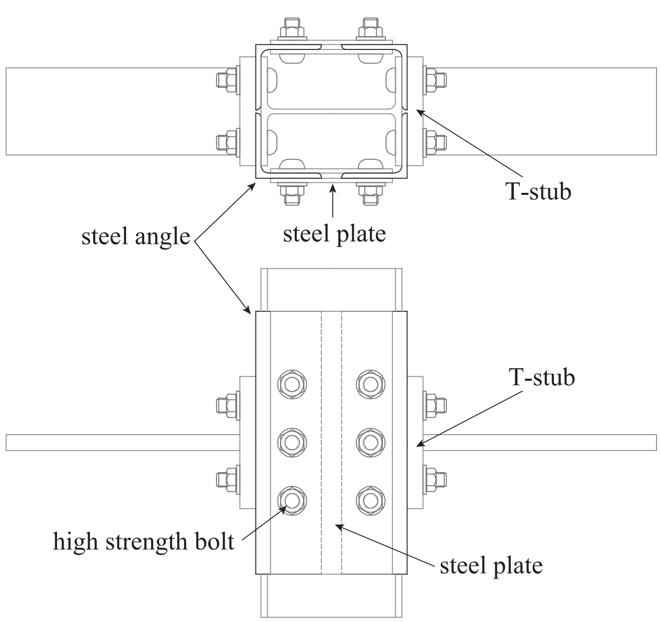

Fig. 2. T-stub idealization of proposed connections.

By applying the yield line theory, the tensile strength for mechanism A is obtained as

$$F_{y\text{-}A} = 2m_p^{cf}\{4\pi + (3c-2D)/m\} + 4m_p^{a}\{\pi + (2k+c-D)/m\}, \quad (1)$$

where variables $m_p^{cf}(=\sigma_{cfy}t_{cf}^2/4)$ and $m_p^{a}(=\sigma_{ay}t_a^2/4)$ respectively stand for the plastic moment capacities per unit length of yield lines in the column-flanges and angles, where t_{cf} and t_a respectively represent the column-flange thicknesses and the steel angle thicknesses. Also, σ_{cfy} and σ_{ay} respectively represent the yield stresses of the column-flange and steel angle.

The yield line theory gives the tensile strength for mechanism B as

$$F_{y\text{-}B} = 16m_p^{cf}\pi + 4m_p^{a}\{\pi + (2k+c-D)/m\}. \quad (2)$$

The yield line theory gives the upper bound of the exact strength. The smaller value of $F_{y\text{-}A}$ and $F_{y\text{-}B}$ is the yield strength prediction.

2.2. Tensile loading tests on T-stub connections

2.2.1. Test specimens

Three test specimens, as portrayed in Fig. 4, were used to examine elastic–plastic behavior of tensile connections with the proposed stiffening. The wide-flange steel section H-194 × 150 × 6 × 9 (H-depth × flange-width × web-thickness × flange-thickness) was adopted for columns. The T-stubs were manufactured using 22-mm-thick plates. In the specimen T-0, T-stubs were connected to a column using no stiffener. In the specimens with stiffeners, T-stubs were connected to a column with 7-mm-thick (specimen T-7) and 10-mm-thick (specimen T-10) steel angles. Both angles have equal width of 90 mm. Stiffening plates were 6-mm-thick for T-7 and 9-mm-thick for T-10. High-strength bolts with 20 mm diameter (F10T M20) were used for all connections. Fig. 4 also shows the location of strain gauges on the column-web. Table 1 presents material properties of components based on the tensile test results of coupons.

2.2.2. Loading conditions and measurements

Using a tensile testing machine, the tension loads were applied incrementally via T-stub webs for each specimen. Relative displacements between two end-plates were measured using two displacement