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Cyclic performance of flange-plate connection to box column with finger shaped plate

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ABSTRACT

The objective of using the flange plate connection as one of the most popular indirect connections to the built-up box column is to avoid using long plates. In deep beams, the need to provide sufficient length to fillet welds necessitates using of long flange plates, which may cause brittle failure due to increasing the bending moments at the face of the column. In the present study, configuring the top flange plate with a finger slot shape type is proposed in order to diminish length of the flange plates. In the proposed configuration, the longitudinal fillet weld was used in flange plates in addition to the transverse fillet and slot weld in the top and bottom flange plates, respectively; in order to provide the required strength for welds. Two full-scale specimens fabricated based on the proposed design methodology were subjected to the cyclic loading. The study results indicated that the flange plate connection with a suggested modified configuration could be prequalified for use in the special moment frames. In a parametric analytical study, the best arrangement of the longitudinal as well as the transverse fillet weld in a top flange plate was proposed for flange plate connections.

1. Introduction

Built-up box columns are more efficient than wide flange columns in areas of high seismic risk because of two principal advantages; large bending and torsional stiffness and strength. The reliable approach to prevent the formation of plastic hinges near the face of I beam to the built-up box column connection is to strengthen the connection zone. This is due to the fact that the force transmitted by the beam flanges on the built-up box column is through the out of plane state; in which the force transfer mechanism in the system contains very low strength and stiffness. Among different methods of strengthening the connection zone [1,2], the indirect connections perform better than direct connections such as WUF-W connection [3] in which the beam section is directly connected to the column face when subjected to reversed cyclic loading. Since the separation between the beam section and the column in indirect connections reduces the stress demand on the CJP groove-welded joints, the indirect connections, function as a structural fuse eliminates weld fractures at the joint [4–8]. The most popular approach of indirect connection for steel moment frames is the flange plate (FP) connection [9] that seems a less complicated and less costly design in comparison with the other different connections.

The design concept of FP connection is based on mitigating excessive force demand overload of beam flanges and local deformation in direct steel moment connections (in which beam connected to the column flange directly) by allowing the flange beam to yield freely; while the connection zone (the flange plates, panel zone and column flanges) remains elastic. In contrast to cover plate (CP) connection in which both cover plates and the beam flanges are welded to the column flange, in FP connection only the flange plates are welded to the column flange. Whereas in this study, the separation between the beam section and column face in the modified FP connection significantly reduces connection deformation constraints and eliminates any uncertainties such as brittle behavior which are intrinsic by the use of complete penetration groove weld in the connection to the box column.

The main point of using the FP connection is the length of the flange plates, which is generally chosen in such a way that it permits the placement of a sufficient length of the fillet weld in order to sustain at least the yield strength of the flange plates. The experimental study revealed that the flange plates cannot be made too long because of the buckling in compression before the beam develops its plastic moment capacity [3]. Moreover, using long flange plates increases the plastic rotation and plastic moments at the face of the column. This can result in a greater potential for fracture at the K-area region of the beam (Fig. 1), which was also proven by the experimental tests [10]. As shown in Fig. 1, plastic rotation in Specimen A with a longer flange plate is more than Specimen B. This increases the prospect of local buckling of the flange and web beam in the plastic hinge location that causes larger plastic strain and eventually it can result in greater potential of the fracture at

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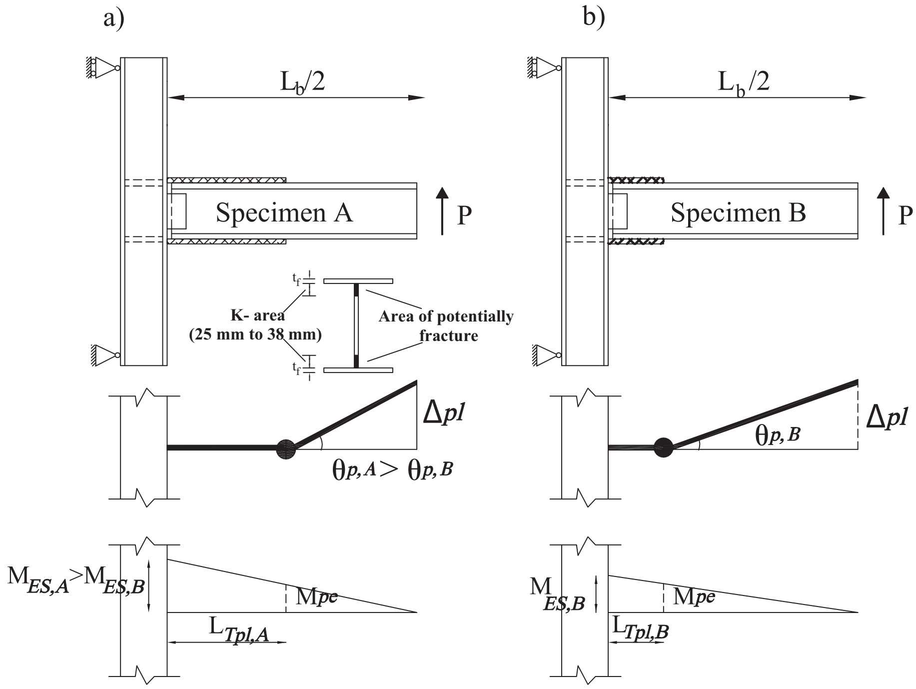

Fig. 1. The plastic hinge rotation and the moment at the face of the column in two FP connections with different flange plate length.

the K-area at the this location. To resolve this problem, the length of the top and the bottom plates was limited to one beam depth (d_b) since based on AISC requirements [11], the plastic hinge location in special moment frame (SMF) should be occurred in a distance of 1.0 d_b to 1.5 d_b away from the face of the column. As illustrated in Fig. 2, in this new connection configuration, the top flange plate has a finger shape, and it is welded to the beam flange by transverse along with longitudinal fillet welds. Moreover, in order to provide the required strength for the welds in the bottom flange plate, longitudinal fillet welds were used along with slot welds to share loads. The strength of all individual welds may be mathematically combined, when all the welds are on a single common plane [12].

In this study, two full-scale modified FP connection specimens were tested to prequalify the modified connection. In order to estimate the appropriate geometry of the finger-shaped top flange plate, an analytical parametric study was employed, and the best ratio of the longitudinal fillet weld to the transverse fillet weld was proposed based on this analytical exploration.

2. Experimental program

In the flange plate connection to the built-up box column, by considering the load path of different components as shown in Fig. 3, it was revealed that the shear force was transferred through the top plate, bottom plate and the shear plates acting as three parallel shear spring due to the same vertical displacement. The shear force distributed among the three connection elements was based on their stiffness ratios as follows:

$$\frac{V_{\mathrm{Tpl}}}{V_{\mathrm{h}}}=\frac{K_{\mathrm{Tpl}}}{K_{\mathrm{Tpl}}+K_{sh.pl}+K_{\mathrm{Bpl}}}=\frac{E\left[\frac{b_{\mathrm{Tpl}}\,t_{\mathrm{Tpl}}^{3}}{L_{\mathrm{Tpl}}^{3}}\right]}{E\left[\frac{b_{\mathrm{Tpl}}\,t_{\mathrm{Tpl}}^{3}}{L_{\mathrm{Tpl}}^{3}}+2\frac{d_{\mathrm{sh.pl}}\,t_{\mathrm{sh.pl}}}{3b_{\mathrm{sh.pl}}}+\frac{b_{\mathrm{Bpl}}\,t_{\mathrm{Bpl}}^{3}}{L_{\mathrm{Bpl}}^{3}}\right]} \tag{1}$$

Since the length of the flange plates considered as the beam depth (d_b), the thickness to length ratios of the flange plates are less than 0.1. According to the following equation, the shear force in flange plates can be neglected and the total force is to be carried out by the shear plates.

$$L_{\mathrm{Tpl}}=L_{\mathrm{Bpl}}=d_{\mathrm{b}} \tag{2}$$

$$\frac{t_{\mathrm{Tpl}}}{d_{\mathrm{b}}}\,\&\,\frac{t_{\mathrm{Bpl}}}{d_{\mathrm{b}}}<\frac{1}{10}\rightarrow\frac{t_{\mathrm{Tpl}}^{3}}{L_{\mathrm{Tpl}}^{3}}=\frac{t_{\mathrm{Bpl}}^{3}}{L_{\mathrm{Bpl}}^{3}}\cong 0.0 \tag{3}$$

$$\frac{V_{\mathrm{Tpl}}}{V_{\mathrm{h}}}=\frac{V_{\mathrm{Bpl}}}{V_{\mathrm{h}}}\approx 0.0\rightarrow\frac{V_{\mathrm{sh.pl}}}{V_{\mathrm{h}}}=1-\frac{\left(V_{\mathrm{Tpl}}+V_{\mathrm{Bpl}}\right)}{V_{\mathrm{h}}}\cong 1.0\rightarrow V_{\mathrm{sh.pl}}=V_{\mathrm{h}} \tag{4}$$

Therefore, it can be concluded that the flange plates can be designed as an axial load element; while the shear plates carry the total shear force. In this study the flexural contribution of the shear plates was not considered and it was assumed that the plastic bending moment was divided between a tension and compression forces in the flange plates.

Given that the beam bending moment mobilizes the axial force in the flange plates, the design procedure can be divided into four parts: 1) calculating the connection design forces, 2) designing the connection in terms of the connection geometry, 3) detailing the top and bottom flange plates and their corresponding welds, and 4) sizing the connection panel zone and continuity plates. The plastic bending moment and the corresponding shear force developed in the beam section are:

$$M_{\mathrm{pr}}=C_{\mathrm{pr}}Z_{\mathrm{b}}\,F_{\mathrm{y}} \tag{5}$$