VERTICAL BRACING CONNECTIONS IN THE SEISMIC REGIME

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ABSTRACT

The effect of frame distortions have been routinely neglected in the design of bracing connections. It is coming to be realized that, because of the large story drifts that occur during seismic events, that this practice may not be adequate to provide a structure that can survive an earthquake without collapse. This paper is abstracted from a forthcoming AISC design guide on vertical bracing connections.

INTRODUCTION

It is coming to be realized for high seismic applications where story drifts of 2-2½% must be accommodated, frame distortion cannot be ignored. These story drifts of 2-2½ % are on the order of ten times the drifts that are expected for wind and low seismic ($R \leq 3$) design. They occur in part because the actual maximum considered earthquake ("MCE") forces are reduced to about $^1/_9$ of the forces the MCE could produce. This is done by first using $^2/_3$ of the MCE forces and then dividing them by an "R" factor on the order of 6, so the MCE load reduction factor is $6 \text{x} ^3/_2 = 9$.

The rationale for this reduction factor is twofold: (1) the forces are of short duration and are reversing, so the response to them does not necessarily achieve the maximum values, and (2) to allow economical designs to be achieved. The price paid for this MCE force reduction is the high drift, and the requirement for ductile response that allows large distortions without fracture and resulting building collapse. If one used an *R* of 1, or even $^2/_3$, the drift under even the MCE forces would be no greater (and probably less because of the duration factor) than traditional wind design. Some designers of hospitals (Walters et al, 2004) and nuclear power plants do just this.

The current AISC Seismic Provisions (2005) have no requirement to consider frame distortions and the resulting distortional forces.

DISTORTIONAL FORCES

These forces exist because a braced frame, although considered a pinned structure, is in reality a braced rigid frame. They would be reduced to essentially zero by the use of an actual pin as shown in Fig. 1, or they can be controlled by the use of a designed hinge in the beam as shown in Fig. 2. If no pin or hinge is used, the maximum distortional forces can be derived from the maximum distortional moment,

$$M_D = \min\{2M_{P_{column}}, M_{P_{beam}}\}$$

In this formula, the column is considered continuous above and below the location being considered. Fig. 3 shows a statically admissible distortional forces distribution. These forces are to be added algebraically to those resulting from the Uniform Force Method (AISC 2005) of bracing connection analysis.

Note that, when the brace force is tension, the distortional forces F_D are compression. These forces tend to "pinch" the gusset and can cause the gusset to buckle even when the brace is in tension. This gusset pinching has been observed in physical tests (Lopez et al, 2004).

AN EXAMPLE

Figure 4 shows a connection designed to satisfy the current Seismic Provisions (AISC, 2005). This design, which does not consider distortional forces, is given in the Design Guide (AISC, 2008). The statically admissible interface forces for the connection of Fig. 4 are given in Fig. 5. These forces would be correct if a beam hinge such as shown in Figs. 1 or 2, were used. However, with no hinge as shown in Fig. 4, the maximum possible (demand) distortional moment is

$$M_D = \min\{R_y M_{p_{beam}}, 2R_y M_{p_{column}}\}$$

$$= \min\{1.1(826), 2(1.1)2260\}$$

$$= 909 kip - ft$$

From the geometry of Figs. 3 and 4,

$$F_D = \frac{M_D}{\bar{\beta} + e_b}\left(\frac{\bar{\beta}}{\bar{\alpha}}\right)^2 = \frac{909}{14.5 + 8.5}\left(\frac{14.5}{18}\right)^2 = 609 kips$$

where e_b is the half depth of the beam.

The horizontal component of F_D is

$$H_D = \frac{\bar{\alpha}}{\sqrt{\bar{\alpha}^2 + \bar{\beta}^2}} x609 = 474 kips$$

This value, which is compression when the brace force is tension, can be compared to the 176 kip horizontal force of Fig. 5 between the gusset and the column, which is tension when the brace force is tension. It can be seen that it is not reasonable to neglect the distortional forces.

Note that the large distortional forces may not be able to be achieved because of column and beam web yielding and crippling, and gusset pinching (buckling when the brace is in tension). The Design Guide (AISC, 2008) proposes using the plate buckling theory given in the Manual pages 9-8 and 9-9 (AISC, 2005) to control gusset pinching. The Manual formulations can be written as

$$F_{cr} = QF_y$$

$Q = 1.0$ for $\lambda \le 0.7$ (yielding)

$Q = 1.34 - 0.486\lambda$ for $0.7 < \lambda \le 1.41$ (inelastic buckling)

$Q = \frac{1.30}{\lambda^2}$ for $\lambda > 1.41$ (elastic buckling)

$$\lambda = \frac{\left(\frac{b}{t}\right)\sqrt{F_y}}{5\sqrt{475 + \frac{1120}{\left(\frac{a}{b}\right)^2}}}$$

where

a = length of “free” edge–distance between points A and B of Fig. 4.

b = the perpendicular distance from the “free” edge to the gusset junction point at the beam and column, point C of Fig. 4.

From the geometry of Fig. 4,

a = 44.3 in. b = 21.2 in., $t = \frac{3}{4}$ in.

$\frac{a}{b}$ = 2.09, $\frac{b}{t}$ = 28.3

$$\lambda = \frac{28.3\sqrt{50}}{5\sqrt{475 + \frac{1120}{2.09^2}}} = 1.48$$

$$Q = \frac{1.30}{1.48^2} = 0.594$$

$$\phi F_{cr} = 0.9x0.594x50 = 26.7ksi$$

The actual stress is

$$f_a = \frac{609}{0.75x21.2} = 38.3ksi$$

Since $38.3ksi > 26.5ksi$, the gusset will buckle in the pinching mode when the brace is in tension. This buckling will prevent the distortional moment $M_b = 909k - ft$ from being achieved, but this out-of-plane buckling is undesirable because it could cause low cycle fatigue cracks to form in the gusset and its connections.

CONTROL OF DISTORTIONAL FORCES WITH A BEAM HINGE

The idea is shown in Figs. 1 and 2, and has been tested in the context of buckling restrained braced frames (Fahnestock et al, 2006). A completely designed example with a beam hinge is shown in Fig. 6. The loads and geometry are the same as the example of Fig. 4. The Design Guide (AISC, 2008) gives complete calculations for this example. Because of the beam hinge, the distortional force F_D is reduced to 204 kips. The design shown in Fig. 6 satisfies all the usual limit states, plus gusset pinching, with the original $\frac{3}{4}$ in. gusset plate.

SUMMARY

A forthcoming AISC Design Guide (AISC, 2008) on Vertical Bracing Connections treats many types of bracing connections and loadings. This paper, which is abstracted from the Design Guide, presents a rational state of the art treatment of the distortional forces induced by large seismic drifts.

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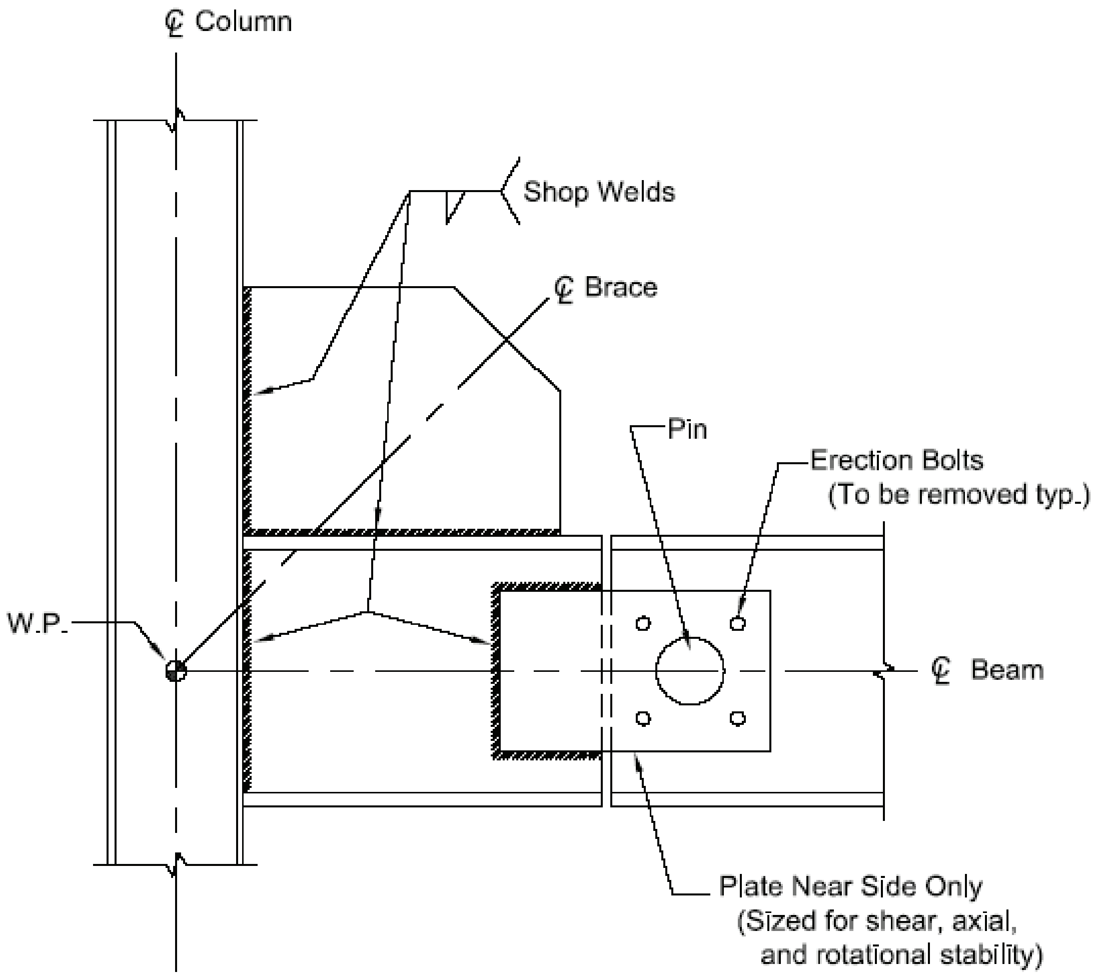

Figure 1. Connection to Minimize Distortional Forces

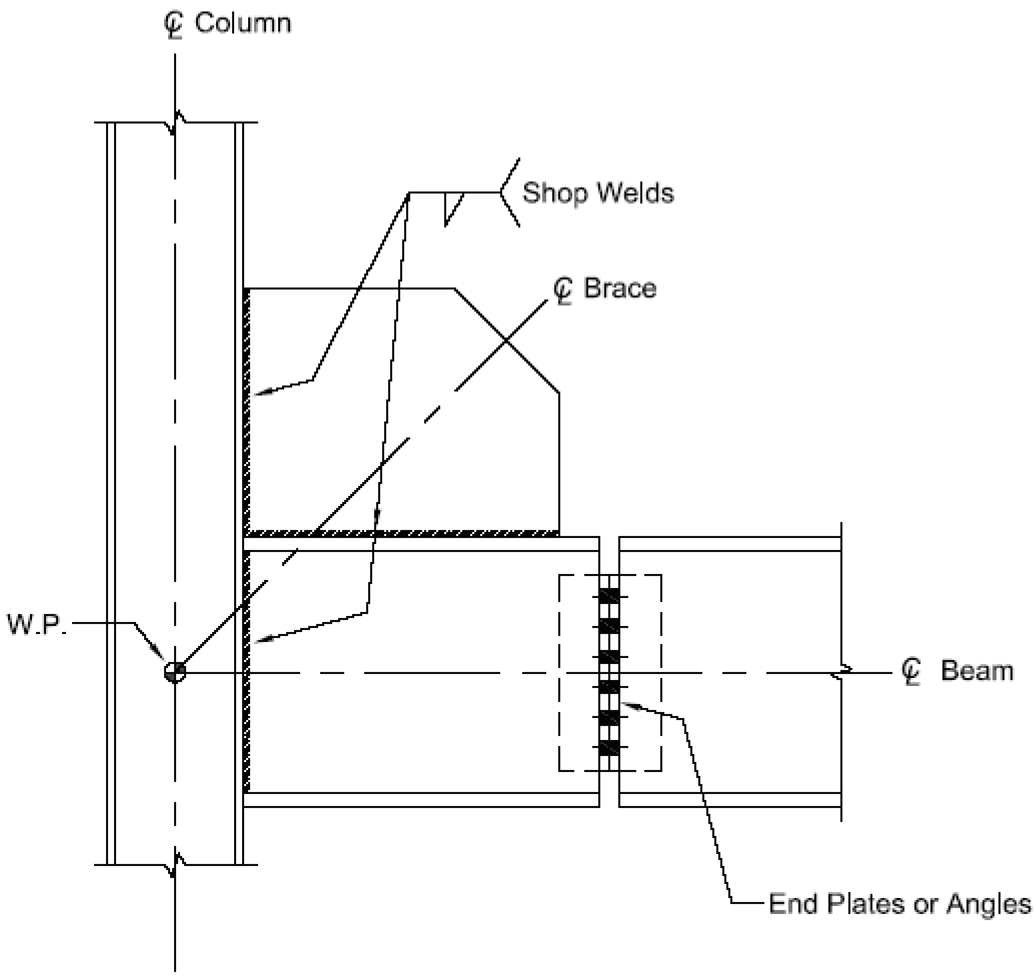

Figure 2. Shear Splice to Control Distortional Forces

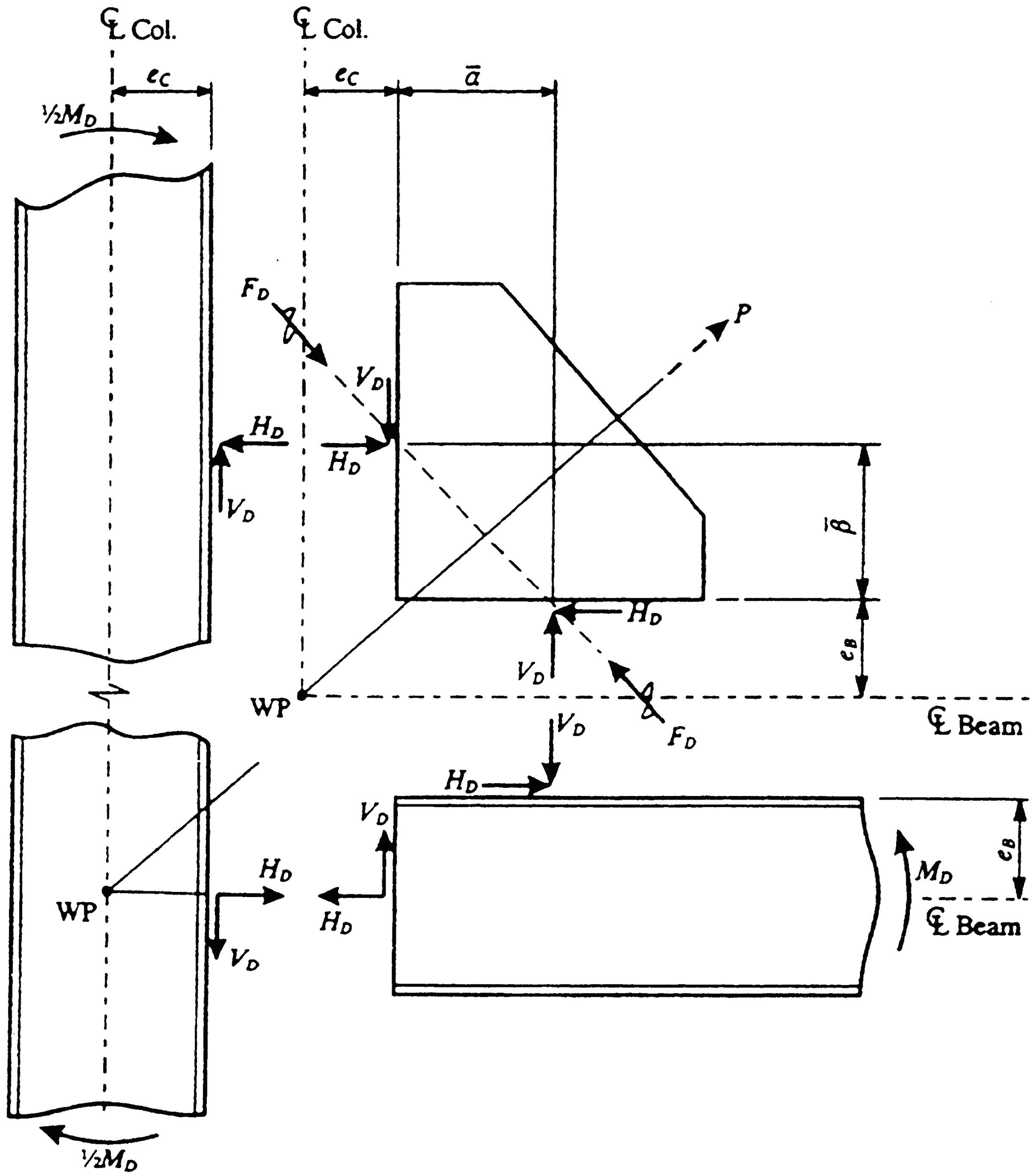

Figure 3. Admissible Distribution of Distortional Forces

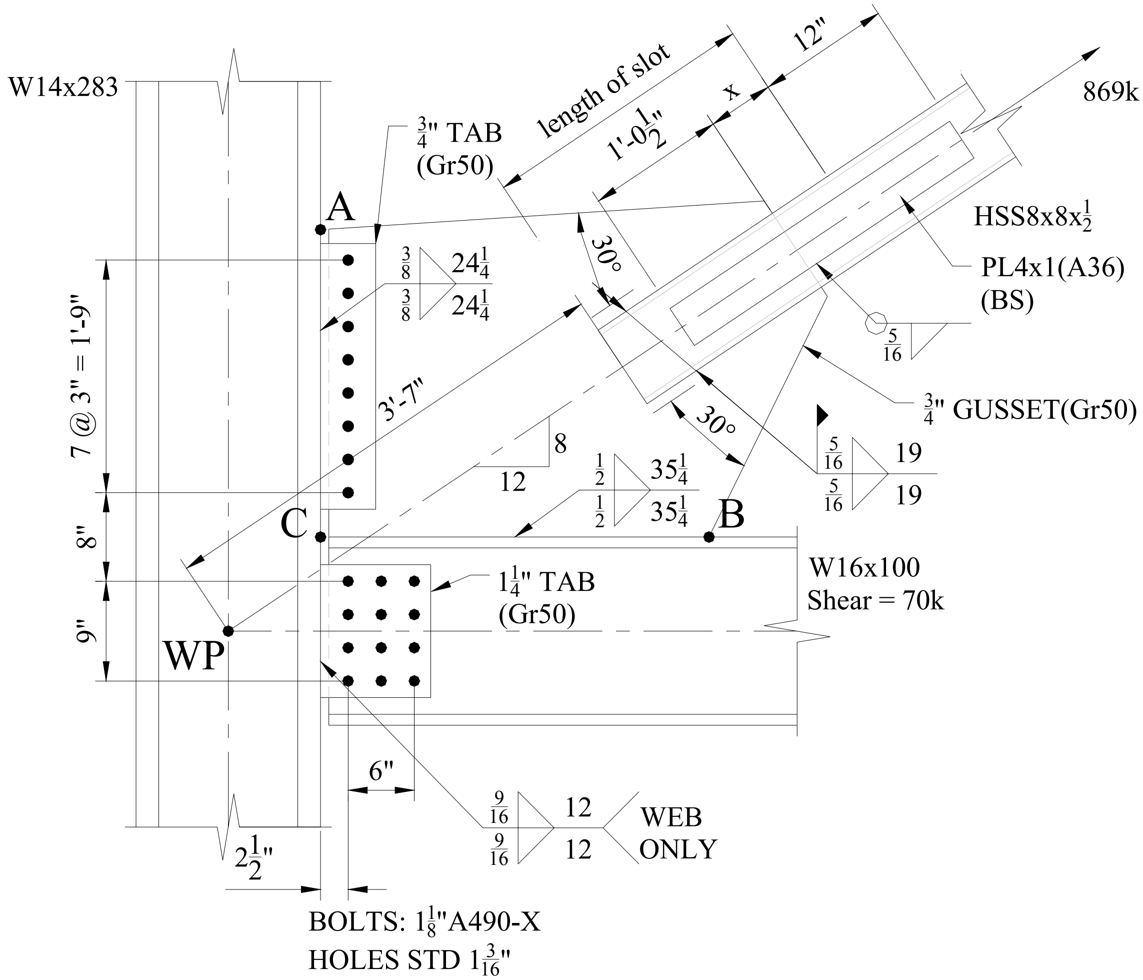

Figure 4. SCBF Connection

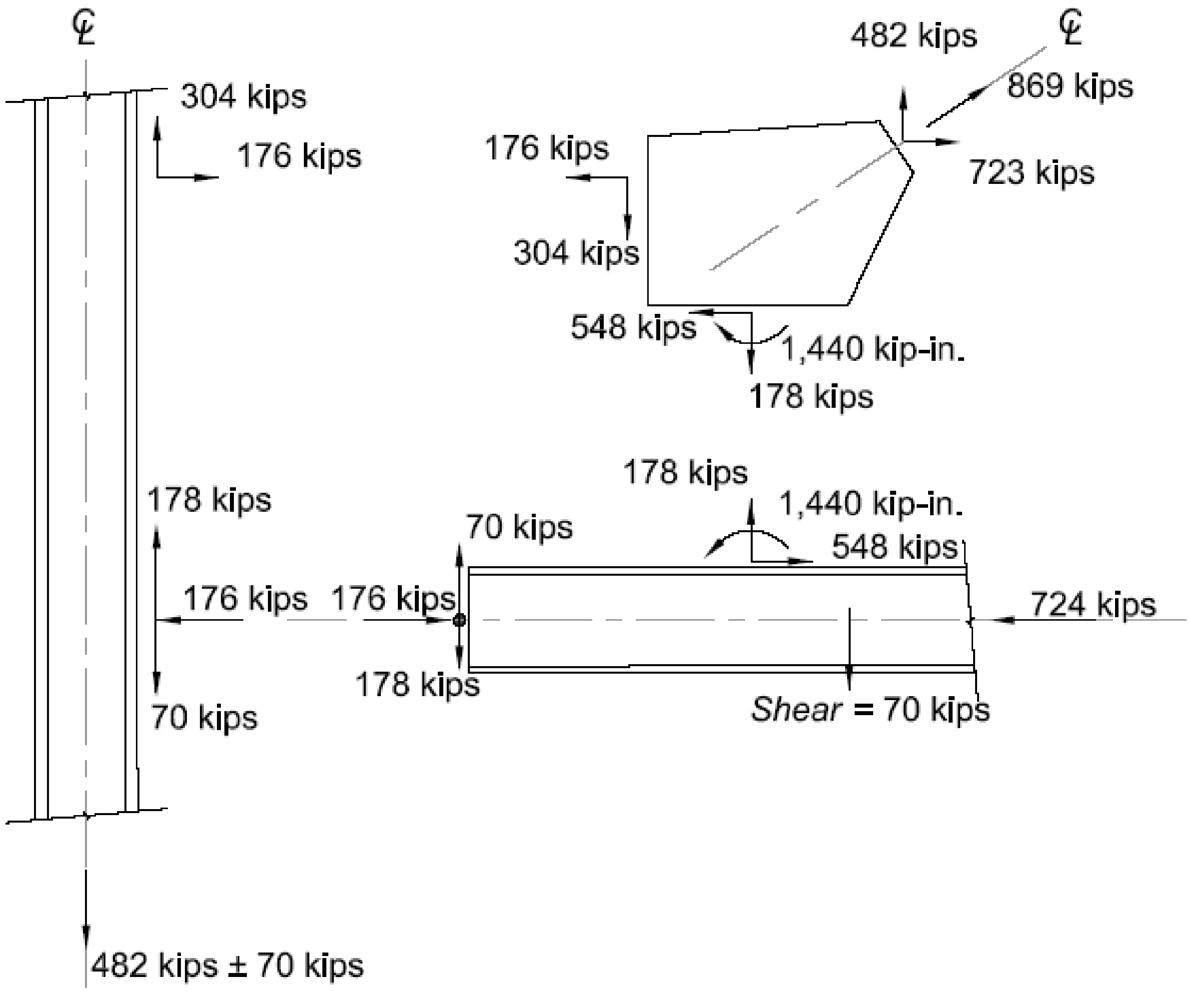

Figure 5. Admissible Force Field for Connection of Figure 4

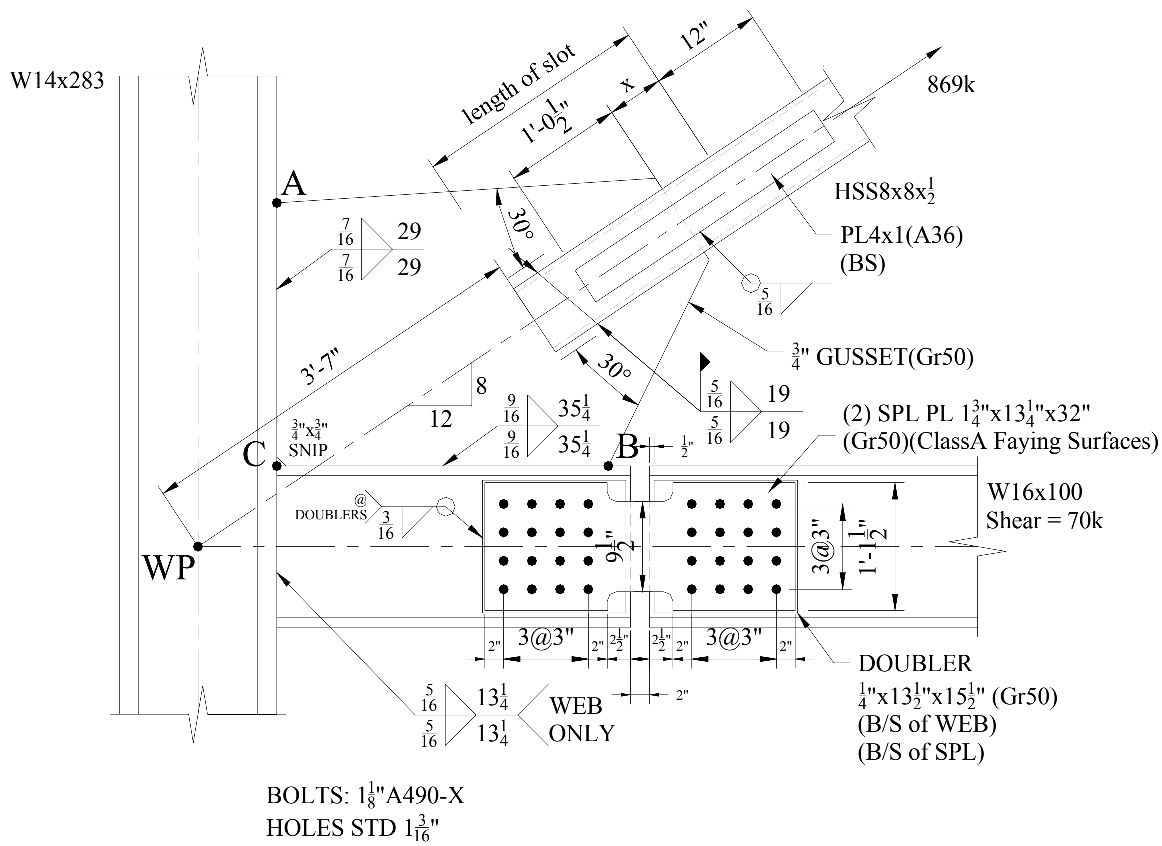

Figure 6. High Seismic Design Including Distortional Forces