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STUDY OF CONTINUITY PLATES IN STEEL MOMENT CONNECTIONS

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ABSTRACT

The use of continuity plates has been recommended in all steel moment connections by the AISC-LRFD design codes after the 1994 Northridge earthquake. This is because the preliminary study right after the earthquake showed that continuity plates significantly reduce the high stress concentration in the center of beam flanges. Based on this study; however, it shows that effectiveness in reducing the high stress concentration in the beam flanges of continuity plates rapidly reduces with the increasing of the column flange thickness. The stress concentration in the beam flange did not reduce with the presence of the continuity plates as previous thought with the heavy column size. Therefore this study recommended that continuity plates are not necessary for the column-to-beam thickness ratio (t_{cf}/t_{bf}) over 5.0.

Keywords : Continuity plates, steel moment connection, finite element analysis.

INTRODUCTION

The steel plate stiffeners, which are welded on each side of the column web at the level of both top and bottom flanges of the beam in order to provide a load path from one column flange to the other, and to reduce local bending of the column flange, are commonly known as "continuity plates". Figure 1 shows the location of continuity plate's attachment in a typical exterior steel moment connection. According to AISC-LRFD 1994 (AISC, 1994) Design Specification, continuity plates should be provided when either the column flange is inadequate for local bending or the column web is inadequate with respect to web crippling, local yielding, or compression buckling. Analysis results, after the Northridge earthquake, showed that the use of continuity plates may reduce the high stress concentration in beam flanges and may minimize the cracking potential of the beam flanges. Therefore, the use of continuity plates, whose minimum thickness is equal to the beam flange thickness, is recommended in moment connections (AISC, 1997, and 2000).

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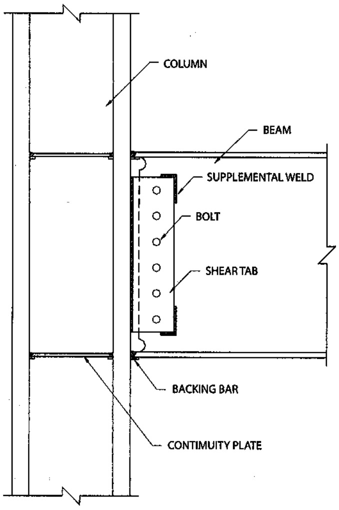

Figure 1. A typical exterior steel moment connection.

FINITE ELEMENT ANALYSIS

The main objectives of the finite element study were to: (1) investigate the flow of forces and stresses in the connection area, and (2) investigate the effects of continuity plates on elastic response of the connections. The finite element analysis presented herein involves: (1) the development of finite element models used in this study, (2) the local behavior of connections, and (3) force and stress distributions in the connection area of Specimens 4.1 and W455 with or without the continuity plates.

DEVELOPMENT OF THE FINITE ELEMENT MODEL

The general-purpose finite element analysis program ABAQUS (ABAQUS, 1997) was used to develop 3-D models of moment connections. The finite element models analyzed in this study represented the exterior moment connection with the connection specimens as shown in Figure 2. The span length between the center of the actuator to the face of the column was 134 inches, and the distance between the column supports was 144 inches. Eight-node brick elements (solid element) with standard integration (C3D8) were used for modeling the connections. To take advantages of the symmetrical and anti-symmetrical properties of the model, and because of the limitation of computer resources such as disk space and memory, the connection subassemblage was modeled only a quarter instead of the entire beam and column sections as shown in Figures 3 to 4. Figure 3 shows the boundary conditions used for this solid element model. The vertical plane presents the symmetrical properties of the left and right sides of the model. On the other hand, the horizontal plane reflects the anti-symmetrical properties of the top and bottom halves of the model. Both symmetric and anti-symmetric boundary conditions were applied together along the intersection lines between the symmetrical and anti-symmetrical planes. Multiple point displacement constrains (MPC) were employed at the interface of the beam webs and flanges, and the column webs and flanges. Moreover, the connections between the beam flanges and column flange, shear tabs and column flanges, shear tabs and the beam webs, continuity plates and column flanges were modeled using MPC.

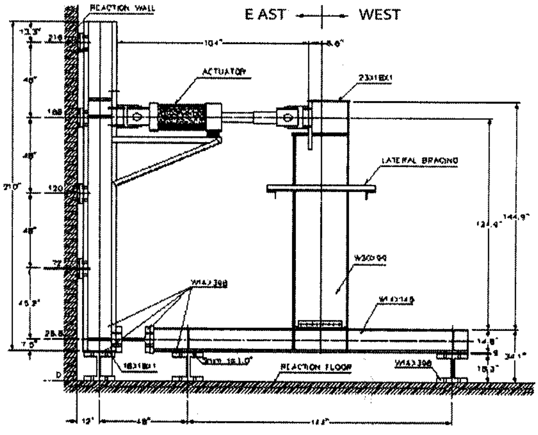

Figure 2. Dimensions of the typical exterior moment connection used by this study.

It should be noted that the welds, bolts, and backing bars were not modeled in these finite element models. The support condition at the column ends was modeled as a pin boundary condition by allowing a free rotation, but restrained the in-plane and out-of-plane displacement. The finite element models were subjected to elastic analysis with a monotonic load of 100 kips.

ANALYTICAL PROGRAM

To study the effects of continuity plates on the behavior of welded exterior connections, the finite element model of specimen 4.1: W14x145 column and W30x99 beam was used. For comparison, continuity plates in the SP4.1 model were removed. The model was named SP4.1W/O. Additionally, two beam-to-column connections with W14x455 column and W30x99 beam were modeled in the same way as SP4.1, and SP4.1W/O. These additional connections were chosen to study whether continuity plates are still effective when a very large column is used. The names for these two large column models were W455 and W455W/O. Obviously, W14x455 column is considered to have a stiff flange associated with deformation caused by the beam flange tension force, whereas the W14x145 is more flexible.

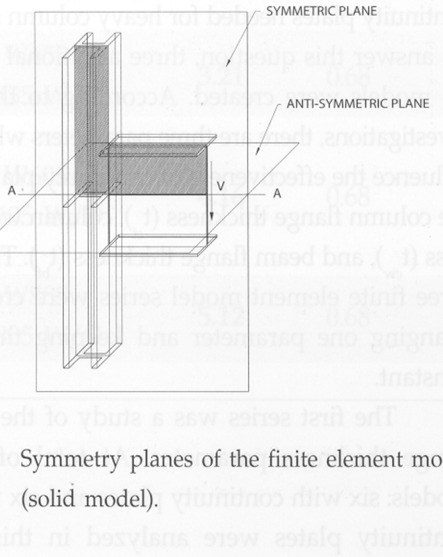

Figure 3. Symmetry planes of the finite element model (solid model).

ANALYTICAL RESULTS

Figure 5 shows tensile (S11) and transverse (S22) stress distributions in SP4.1 and SP41W/O models, in the beam flange 0.5 in. away from the interface line. The same plots for W455 and W455 W/O models are given in Figure 6. Results from the SP4.1 series clearly show that stress distributions along the beam flange are greatly affected by the continuity plates. The stress distributions are somewhat more uniform in the presence of the continuity plates. However, for the W455 series, the distributions of stress are almost unaffected by the use of continuity plates. The deformed shapes of the SP4.1 models are shown in Figure 7. For SP4.1W/O model, the column flange is bent following the deformation of the beam flange in tension. However, such bending could not be noticed in the SP4.1 model, which has the continuity plates.

Based on these elastic analyses, the effects of the presence of continuity plates can be described as follows: (1) continuity plates reduce maximum tensile stress (S11) by 40% in SP4.1 model, (2) continuity plates reduce maximum transverse stress (S22) by 80% in SP4.1 model, (3) continuity plates significantly reduce local bending of the column flange in the SP4.1 model, and (4) small influences of continuity plates in W455 model.

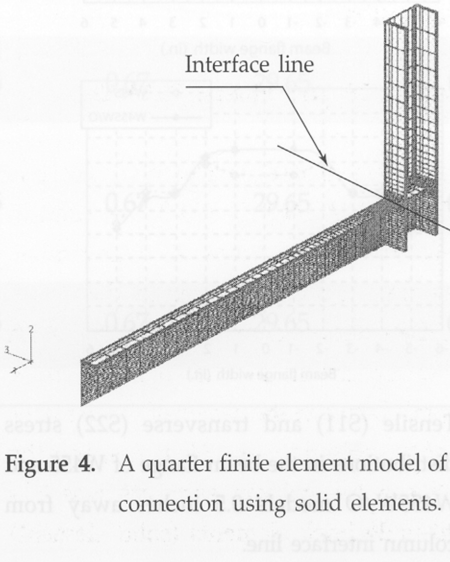

Figure 4. A quarter finite element model of the moment connection using solid elements.

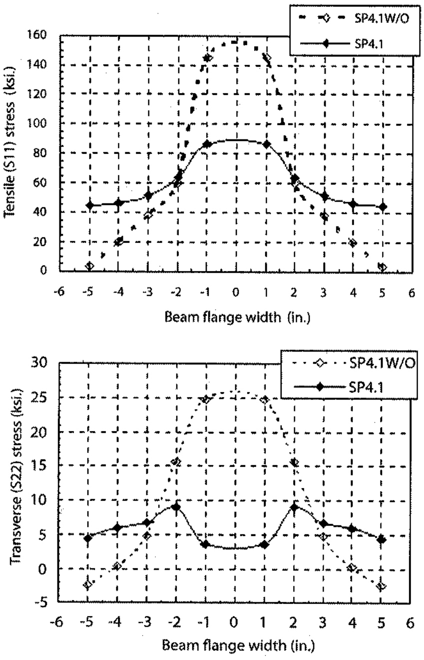

Figure 5. Tensile (S11) and transverse (S22) stress distributions in the beam flange of SP4.1 and SP4.1W/O models 0.5 inches away from column interface line.

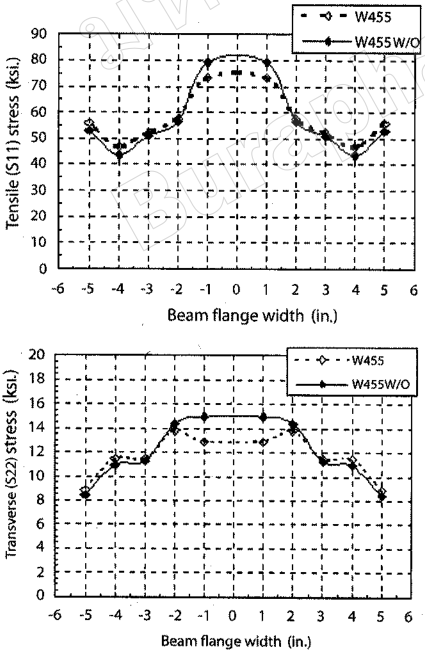

Figure 6. Tensile (S11) and transverse (S22) stress distributions in the beam flange of W455 and W455W/O models 0.5 inches away from column interface line.

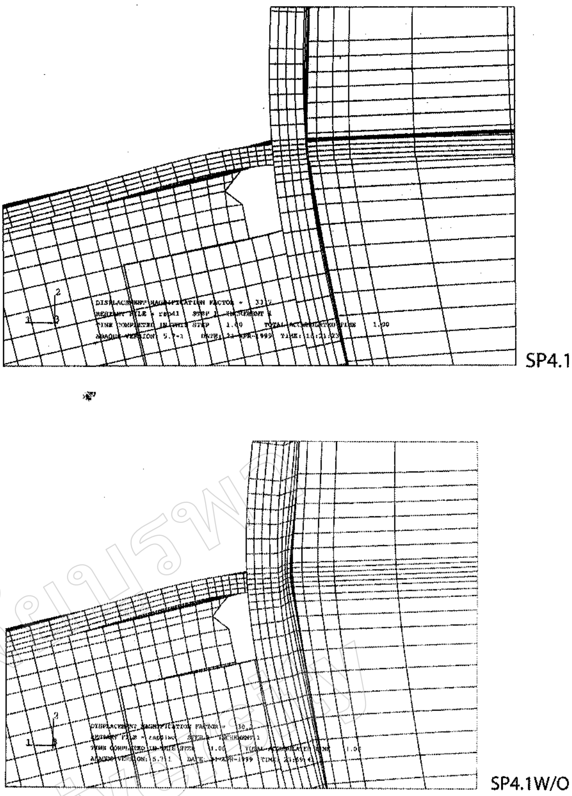

Figure 7. Deformed shapes of SP4.1 and SP4.1W/O models.

PARAMETRIC STUDY OF CONTINUITY PLATES

The above preliminary study of continuity plate effects opens a very interesting question: are continuity plates needed for heavy column sections? To answer this question, three additional series of FE models were created. According to the above investigations, there are three parameters which may influence the effectiveness of continuity plates. They are column flange thickness (t_{cf}), column web thickness (t_{cw}), and beam flange thickness (t_{bf}). Therefore, three finite element model series were created by changing one parameter and keeping the others constant.

The first series was a study of the column flange thickness parameter. At total of twelve models: six with continuity plates and six with out continuity plates were analyzed in this series.

The geometry of Specimen SP4.1 was selected as the primary model. Specimen SP4.1 comprises of W14x145 column and W30x99 beam. Other models were generated by increasing the column flange thickness within the practical range of dimensions for W14 sections, while all other dimensions were kept constant. The models were analyzed with 0.5 inches thickness continuity plates. Table 1 gives details of the models analyzed in this series. All models in this series were subjected to linear analysis under the same loading and boundary conditions as before. The effect of continuity plates on the beam stress distributions was most pronounced at the middle of the beam flange. Thus, the analytical results of these parametric study series were presented only at the middle of the beam flange location. Figure 8 shows comparisons of maximum von Mises stresses between models with and without continuity plates, presented with respect to the flange thickness. The comparison is made at the top, middle and bottom layer of the flange, at a line 0.5 inches away from the interface line. The maximum stresses were computed at the center of the beam flange under tensile loading. The solid lines are for models with continuity plates and the dashed lines are for models without continuity plates.

Table 1. Properties of models in the column flange thickness series.

Name	**Column**			**Beam**		**Continuity plate thickness**
	t_{cf} (in.)	t_{cw} (in.)	d_{c} (in.)	t_{bf} (in.)	d_{b} (in.)	t_{ct} (in.)
SP4.1 SP4.1 W/O	**1.09**	0.68	14.75	0.67	29.65	0.5
SP5 SP5 W/O	**1.31**	0.68	14.75	0.67	29.65	0.5
SP6 SP6 W/O	**1.89**	0.68	14.75	0.67	29.65	0.5
W455 W455 W/O	**3.21**	0.68	14.75	0.67	29.65	0.5
W605 W605 W/O	**4.16**	0.68	14.75	0.67	29.65	0.5
W805 W805 W/O	**5.12**	0.68	14.75	0.67	29.65	0.5

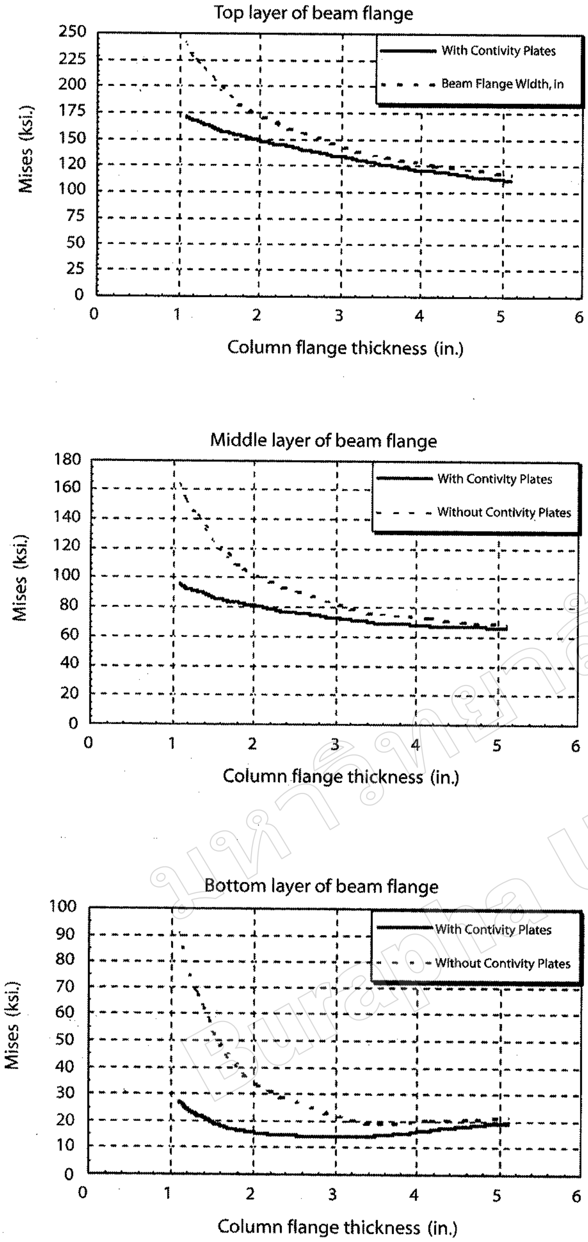

Figure 8. Comparison of von Mises stresses for different column flange thickness.

The results indicate that continuity plates reduce von Mises stresses by as much as 40% at the center of the beam flange, when the column flange thickness is varied from 1 to 3 inches. On the contrary, the maximum reduction of von Mises stress is only 8% with the column flange thickness between 3 to 5 inches. The results imply that continuity plates appear to be less effective in reducing the maximum von Mises stress, when the column flange thickness is increased.

As mentioned earlier, there still are two other parameters, which may determine the need for continuity plates. Although the previous results showed that the maximum von Mises stresses were almost unaffected by the absence of continuity plates with thick column flanges, use of a thicker column web and thicker beam flange may require continuity plates. Therefore, the geometry of W455 model was selected as the base configuration for the other two additional series: column web thickness and beam flange thickness. The details of models can be seen in Tables 2 and 3, respectively.

Analysis results from both series are shown in Figure 9. Only comparisons of the maximum von Mises stresses on the top surface of the beam flange are reported. The increase of von Mises stress was approximately 9 ksi. when continuity plates were removed from the W455 model. The same increment remains constant, even though the column web and the beam flange thickness are significantly increased. Therefore, it can be concluded that increasing the column web and beam flange thickness under a thick column flange model seems to have no effect on the von Mises stress profile. In other words, it can be concluded that the effectiveness of continuity plates depends mainly on the relative stiffness of the column flange to the beam flange. The effectiveness of continuity plates becomes smaller, when the stiffness of the column flange gets larger.

Table 2. Properties of models in the column web thickness series.

Name	Column			Beam		Continuity plate thickness
	t_{cf} (in.)	t_{cw} (in.)	d_c (in.)	t_{bf} (in.)	d_b (in.)	t_{ct} (in.)
W455 W455 W/O	3.21	**0.68**	14.75	0.67	29.65	0.5
W455C1 W455C1 W/O	3.21	**0.83**	14.75	0.67	29.65	0.5
W455C2 W455C2 W/O	3.21	**1.175**	14.75	0.67	29.65	0.5
W455C3 W455C3 W/O	3.21	**2.015**	14.75	0.67	29.65	0.5
W455C4 W455C4 W/O	3.21	**2.6**	14.75	0.67	29.65	0.5
W455C5 W455C5 W/O	3.21	**3.74**	14.75	0.67	29.65	0.5

Table 3. Properties of models in the beam flange thickness series.

Name	Column			Beam		Continuity plate thickness
	t_{cf} (in.)	t_{cw} (in.)	d_c (in.)	t_{bf} (in.)	d_b (in.)	t_{ct} (in.)
W455 W455 W/O	3.21	0.68	14.75	**0.67**	29.65	0.5
W455B1 W455B1 W/O	3.21	0.68	14.75	**0.85**	29.65	0.5
W455B2 W455B2 W/O	3.21	0.68	14.75	**1.18**	29.65	0.5
W455B3 W455B3 W/O	3.21	0.68	14.75	**1.315**	29.65	0.5
W455B4 W455B4 W/O	3.21	0.68	14.75	**2.0**	29.65	0.5

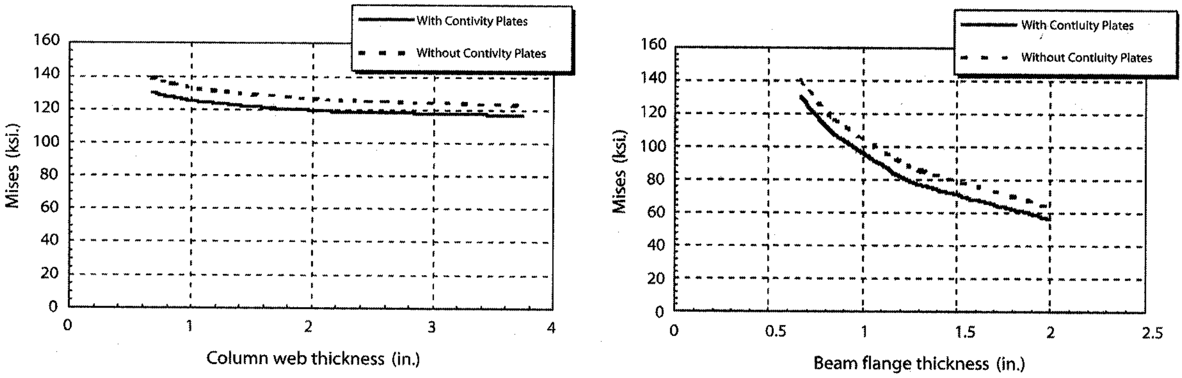

Figure 9. Comparisons of maximum von Mises stresses in the top layer of the beam flange with respect to changing column web thickness and beam flange thickness.

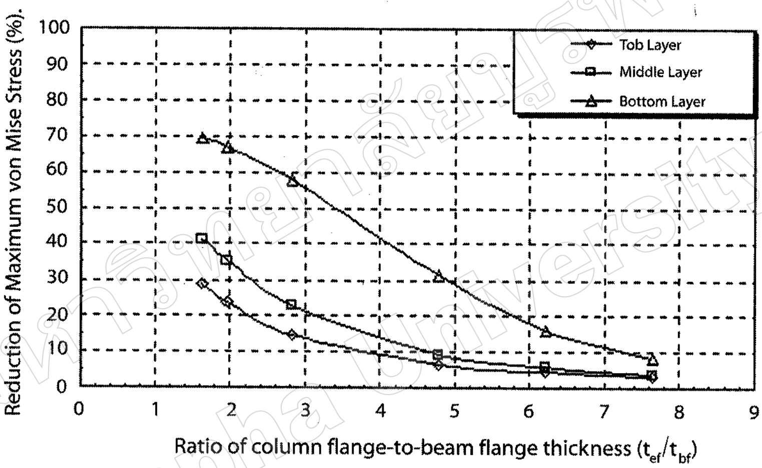

Figure 10. Reductions of maximum von Mises stress at the center of beam flange in percent.

Figure 10 shows the effectiveness of continuity plates in terms of reduction of von Mises stress and ratio of column flange to beam flange thickness. The plot is regenerated from results shown previously in Figure 8. The intent is to demonstrate that the presence of continuity plates on the column section, which has a thickness of at least five times the thickness of the beam flange, is not helpful in reducing stresses. Besides, the use of continuity plates on the stiff column flanges can cause a greater stress gradient between top and bottom surface of the beam flange, which can prevent non-uniform yielding of the beam flange.

CONCLUSION

This study sheds more light on the requirement of continuity plates in beam-to-column connections. It shows that continuity plates are not as beneficial for columns with thick flanges as they are for columns with thin flanges in reducing the beam stresses. The effectiveness of continuity plates solely depends on the column flange thickness. Therefore, the AISC 1997 provision needs to be reviewed regarding continuity plate requirements. Indeed, a thicker column flange implies heavier column sections, which are usually associated with larger beam sections. As specified in the AISC provisions, the continuity plates should have a minimum thickness of the beam flange. This can lead to the use of very thick continuity plates, expensive welding, and high heat input in the sensitive K-line zone, which can increase restraint and residual stresses in the connection area. Based on FE analyses in this study, continuity plates can be omitted when the column flange has thickness at least five time the beam flange thickness ($t_{cf}/t_{bf} > 5.0$).

FUTURE STUDY This topic can further study in terms of the required thickness of continuity plates and welding details of continuity plates to the column flange and web.

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