Comparison between "Common Moment Connection" and Moment Connection with Side Plates for Double-I Built-up Columns

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ABSTRACT :

The commonly used rigid moment connections between I-beam and double-I built-up columns cause excessive deformations in column cover plate. To modify the performance of moment connections, we have studied the application of side plate method and method proposed by Specifications. In connection with side plates there is a gap between beam end and face of column. Due to this separation the tensile force is not applied directly to the column cover plate and the moment is transferred from beam to the column through the side plates. Method proposed by the Specifications consists of using a vertical stiffener plate inside the column. In this paper we have compared the behavior of "common moment connection", with these two new systems using finite element method. Results show that "common moment connection" is partially restrained and using a vertical stiffener plate inside the column, reduces the column cover plate deformations, but connection remains partially restrained and high stress levels exist in column cover plate. Moment connection with side plates is a fully restrained connection and due to separation between beam end and face of column there is no stress concentration in column cover plate.

KEYWORDS: Double-I Built-up Column, Side Plate, "Common Moment Connection"

1. INTRODUCTION

Double-I built-up columns are composed of two separated I-shaped sections connected to each other by means of two cover plates. Cover plates are only welded to I-shaped sections along their longitudinal edges. In the case of moment connection, when an I-beam connects to double-I built up column through the cover plate, the connection may impose some problems. The main problems of common moment connections could be divided into two groups:

1- General problems of nearly all welded moment connections, which most significant problem of this group is brittle fracture of full penetration groove welds between beam flanges (or moment transfer plates) and column face. In double-I built-up columns this groove weld is between moment transfer plates, and the column cover plate.
2- Special problem, which is due to existence of column cover plate in moment transfer path. The cover plates are only connected to I-shaped sections of column along their longitudinal edges. They behave very flexible under tensile force of beam flange and undergo large deformations.

In experiments carried out by Mazrooee et al. (1999), the behavior of "common moment connections" of I-beam to double-I built-up column was investigated. They have shown that due to large deformation of the column cover plate; these connections behave as semi-rigid ones. To modify the problem, the latest version of Iranian Specifications for Design and Construction of Steel Buildings, proposes application of a vertical interior stiffener plate inside the column. The vertical stiffener plate connects two column cover plates in the level of beam-column connection. Typical views of "common moment connection" and proposed connection with vertical stiffener plate are shown in Figures 1 and 2 respectively. Box columns without internal stiffeners encounter nearly the same problems. Several researchers have proposed innovative solutions for box columns. Blais (1974), Picard and Giroux (1977), Atsou et al. (1996), have proposed that the best way of moment transfer from beam to the box column is using side plates parallel to the column webs. These plates were in levels of beam flanges and connected the sides of each beam flanges separately to the box column webs.

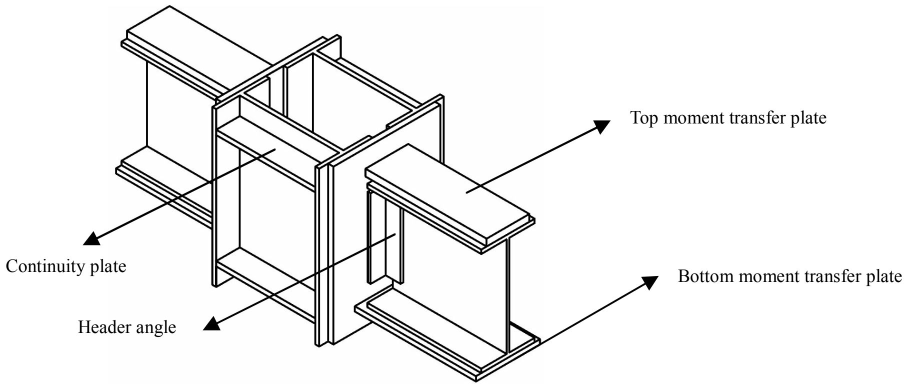

Figure 1 "Common moment connection" with double-I built-up column

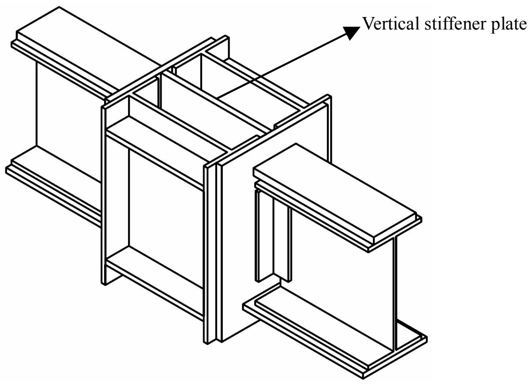

Figure 2 Using vertical stiffener in "common moment connection" with double-I built-up column

The proposed solutions caused modifications in behavior of moment connections of box columns, but all of them have some defects. Houghton (2000) modified and improved the above approach for wide flange and box columns, by using one full depth side plates in each sides of the beam, instead of two separated plates. In all of the explained methods there was a gap between the end of the beam and the face of column. The moments were transferred from the beam ends to column only through the side plates. This new concept was adopted and modified for moment connections of I-beam to double-I built-up column by Deylami and Shiravand (2005) and Deylami and Yakhchalian (2007). Due to the separation between beam end and face of column, the tensile force of the beam flange was not applied to the column cover plate. This method eliminates both general and special problems concerning the welded connections of I-beams to double-I built-up columns. A typical view of moment connection with side plates and double-I built-up column is shown in Figure 3.

2. DIMENSIONS OF MODELS

We have considered five subassemblies. Two subassemblies (model C1 and C2) with "common moment connection", two subassemblies (model C3 and C4) with vertical interior stiffener and one subassembly with moment connection using the side plates (model SP). All the beams were IPE300 and all the columns sections consisted of two IPE300 separated 200 mm (center to center) and cover plates of 300×15 mm. Dimensions of moment connection models C1 to C4 are presented in Table 1. Models C2, C3 and C4 each have two doubler plates of 5 mm thickness welded on two sides of their panel zone. Details of moment connection with side plates are indicated in Figure 3.

Table 1 Dimensions of moment connection models (in mm)

Model	Top moment transfer plate	Bottom moment transfer plate	Header angle	Length of angle	Continuity plate thickness	Doubler plate thickness	Vertical stiffener plate thickness
C1	PL340×120×19	PL340×180×13	2L50×50×8	220	13	------	------
C2	PL340×120×19	PL340×180×13	2L50×50×8	220	13	5	------
C3	PL340×120×19	PL340×180×13	2L50×50×8	220	13	5	7
C4	PL340×120×19	PL340×180×13	2L50×50×8	220	13	5	15

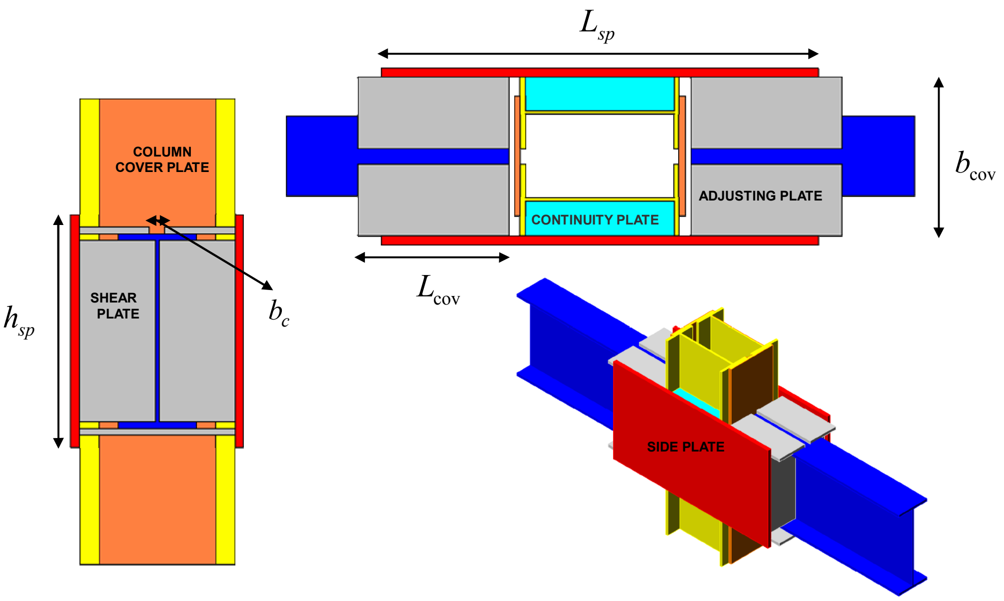

Figure 3 Details of moment connection with side plates and double-I built-up column

Dimensions of connection with side plates are presented in Table 2. t_{sp} , t_{ad} , t_{con} and t_{sh} parameters are the thickness of side plate, adjusting plate, continuity plate and shear plate respectively.

Table 2 Dimensions of model SP (in mm)

Model	t_{sp}	L_{sp}	h_{sp}	t_{ad}	L_{cov}	b_{cov}	b_c	t_{con}	t_{sh}
SP	15	940	370	10	350	350	40	10	10

General configuration of subassemblies is illustrated in Figure 4. Supposing that points of inflection of beams and columns are in the middle of their length, half of beams length and column height were considered for modeling.

3. MODELING

ANSYS finite element software (1997) was applied for three dimensional modeling of all specimens. We have used SOLID45 element. This element has 8 nodes and three degrees of freedom per node. This element has capability of modeling large deformations and local buckling. For modeling of double-I built-up column behavior, we have used contact elements between column cover plate and I-shaped sections. Contact elements were TARGE170 and CONTA173. These elements have the same geometry as the solid elements. TARGE170 elements are situated on the flange surface of I-shaped sections, and CONTA173 elements are situated on the surface of column cover plate. Bilinear model was selected to represent stress-strain behavior of steel. The first line of the model has the slope equal to steel modulus of elasticity, E= 2.1×10^6 kg/cm^2. The yield stress of steel was considered F_y=2400 kg/cm^2. After the yield point the second line continued until ultimate tensile stress F_u of steel (F_u=3700 kg/cm^2). The strain of this point was considered to be equal to 0.2. The Poisson's ratio is considered ν=0.3. Since it was expected that nonlinear deformations mostly occur near the connected parts, more refined mesh and nonlinear material behavior were assigned to these regions. Whereas for portions of models that were far from the connection, the material was assumed to behave elastically. The plasticity model was based on Von Mises yielding criterion, and kinematics hardening was utilized for modeling of steel behavior. Monotonic load is applied to all models up to 0.04 radians interstory drift angle.

Model	H (m)	BL (m)
C1-C4	1.5	3.5
SP	1.5	3.5

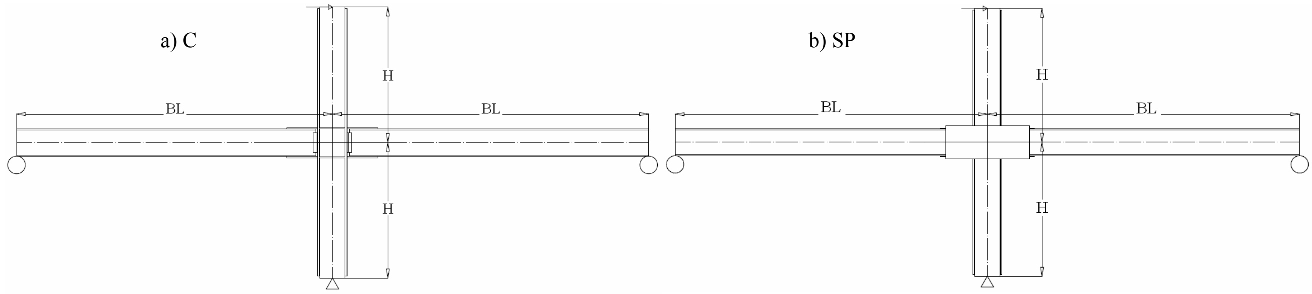

Figure 4 Dimensions of subassemblies

4. FINITE ELEMENT ANALYSIS RESULTS

Von Mises stress distribution for model C1, under monotonic loading of 0.04 radians interstory drift angle, is shown in Figure 5. As it can be seen, due to large deformations of column cover plate under tensile force, (applied by moment transfer plate), the plastic hinge can not be formed in beams. The panel zone has experienced yielding due to shear force, therefore in addition to column cover plate flexibility, the other complication of "common moment connection" of I-beams to double-I built-up columns is the weakness of panel zone under shear forces. Moment-joint rotation curve is plotted in Figure 6 for model C1. The joint rotation is considered as the change of angle between the beam and the column from its original configuration. This rotation includes two parts: a) The shearing rotation contributed by the panel zone of the column and b) The connection rotation, caused by the relative deformation between the beam and the column due to bending deformation of the column cover plate. According to AISC Specifications for Structural Steel Buildings (2005), if secant stiffness of a connection becomes more than $20EI/L$ the connection can be considered as fully restrained and if secant stiffness of connection be less than $2EI/L$ the connection can be considered as simple connection. Connection with secant stiffness between these two limits is considered as a partially restrained connection. Where L and EI are length and bending rigidity of the beam respectively. The value of L is considered equal to length of beam in the frame between two columns which is twice the beam length in each side of column in the selected subassembly.

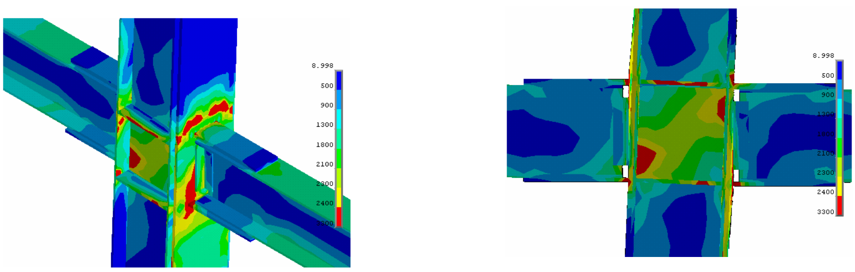

Figure 5 Von Mises stress distribution of model C1 under monotonic loading in 0.04 radians interstory drift

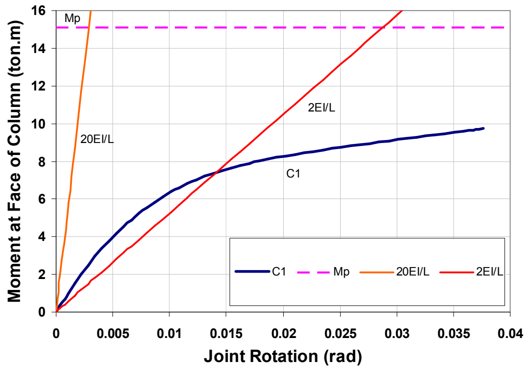

Figure 6 Moment-joint rotation curve for model C1

As shown by Figure 6, the secant stiffness of the connection is situated between two limits proposed by AISC Specifications for Structural Steel Buildings (2005) therefore model C1 is a partially restrained connection.

For prevention of panel zone yielding and increasing the panel zone stiffness, we have used doubler plates with thickness of 5 mm on two sides of panel zone of model C2. Monotonic load up to 0.04 radians interstory drift angle is applied. Von Mises stress distribution for model C2 is shown in Figure 7. It can be seen from Figure 7 that using doubler plates prevents panel zone from yielding but plastic deformations have still occurred on column cover plate. Moment-joint rotation curve for model C2 is plotted in Figure 8. As shown in this figure, adding doubler plates has no tangible effect on the connection stiffness in comparison with model C1, because the contribution of panel zone rotation to joint rotation is very little in comparison with connection rotation. In "common moment connection" of I-beam to double-I built up column the majority of joint rotation is due to column cover plate deformation. In model C2, by adding doubler plates, the panel zone rotation has decreased but existence of doubler plates compels all inelastic deformations in column cover plate which causes increase in connection rotation. Therefore joint rotation that is the sum of panel zone rotation and connection rotation does not have a tangible variation.

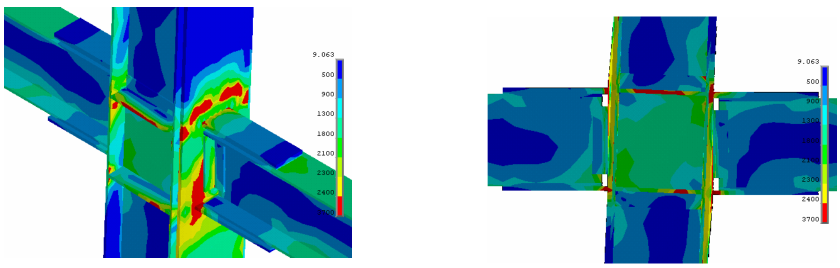

Figure 7 Von Mises stress distribution of model C2 under monotonic loading in 0.04 radians interstory drift

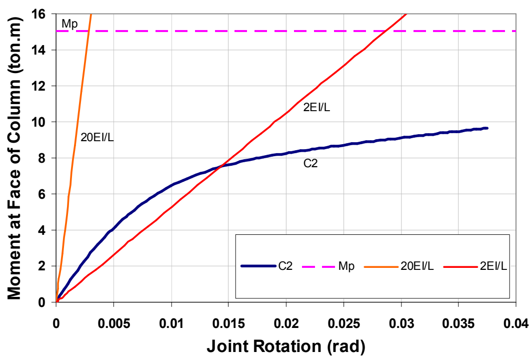

Figure 8 Moment-joint rotation curve for model C2

In order to reduce column cover plate excessive deformations in model C3, we have added a 7 mm thick vertical stiffener plate inside the double-I built-up column. This stiffener connects two column cover plates in the level of beam to column connection. Doubler plates with thickness of 5 mm are also welded on two sides of panel zone for prevention of panel zone shear yielding. Monotonic load was applied to model C3 up to 0.04 radians interstory drift angle. Von Mises stress distribution for this model is shown in Figure 9. It is shown that doubler plates prevent panel zone yielding and the vertical stiffener plate inside column has compelled some inelastic deformation in beams but severe plastic deformations have occurred in column cover plate. Moment-joint rotation curve is plotted in Figure 10 for model C3. As shown in this figure adding vertical stiffener plate has a considerable effect in improving connection stiffness and strength, because this plate is welded to column cover plate and improves moment transfer path but in spite of adding this stiffener plate the connection is still partially restrained.

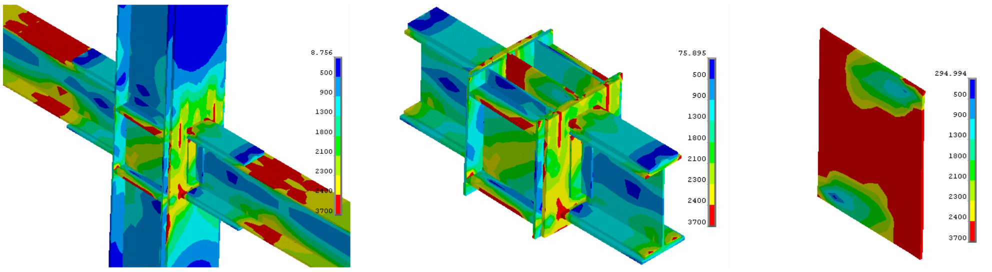

Figure 9 Von Mises stress distribution of model C3 under monotonic loading in 0.04 radians interstory drift

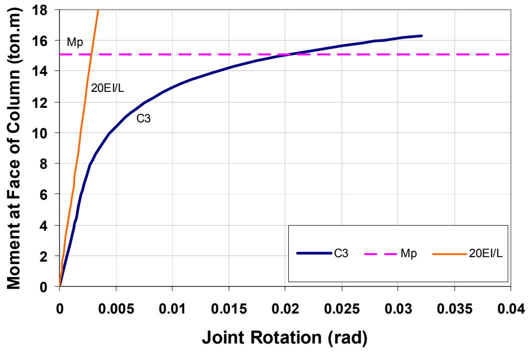

Figure 10 Moment-joint rotation curve for model C3

In model C4, we have increased the thickness of vertical stiffener plate to 15 mm. Doubler plates with thickness of 5 mm were welded to both sides of panel zone to prevent shear yielding. Monotonic load is applied to model C4 up to 0.04 radians interstory drift angle. Von Mises stress distribution for this model is shown in Figure 11. It is shown that the increase of thickness of vertical stiffener plate has compelled more inelastic deformation in beams compared to model C3. But plastic deformations have still occurred in column cover plate and still high stress levels exist in cover plate. Moment-joint rotation curve is plotted in Figure 12 for this model. It can be seen that although the increasing of vertical stiffener plate thickness has increased connection stiffness and strength with respect to model C3, but this connection is still partially restrained.

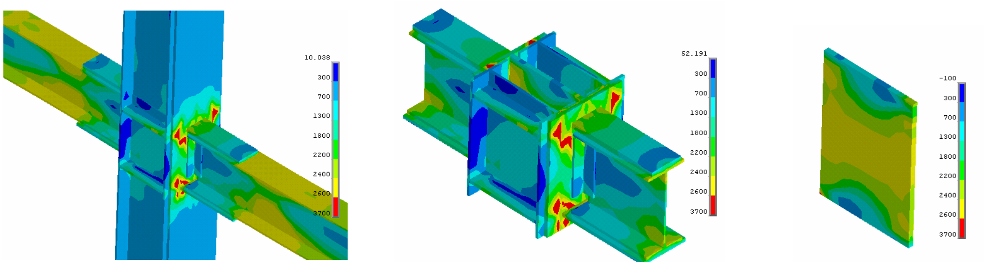

Figure 11 Von Mises stress distribution of model C4 under monotonic loading in 0.04 radians interstory drift

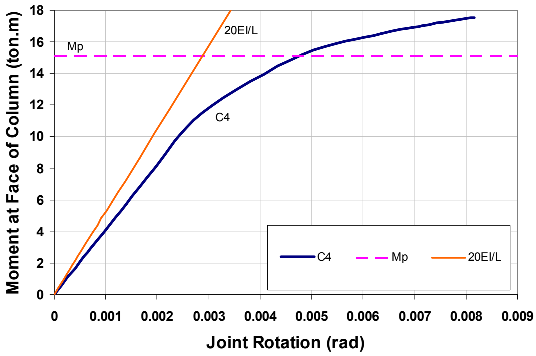

Figure 12 Moment-joint rotation curve for model C4

Monotonic load is also applied to model SP up to 0.04 radians interstory drift angle. Von Mises stress distribution is shown in Figure 13. It can be seen that plastic hinges occur in beams. For observation of stress distribution in interior parts of connection, the front side plate in Figure 13 (right) is virtually removed. In this type of connection, the panel zone remains elastic since it consists of four plates (two full depth side plates + two column panel zones). As it is illustrated by Figure 13, due to separation between beam ends and face of columns, stresses in column cover plate remain in elastic range. Moment-joint rotation curve for model SP is plotted in Figure 14. As it is shown by this figure, the connection can be classified as fully restrained connection.

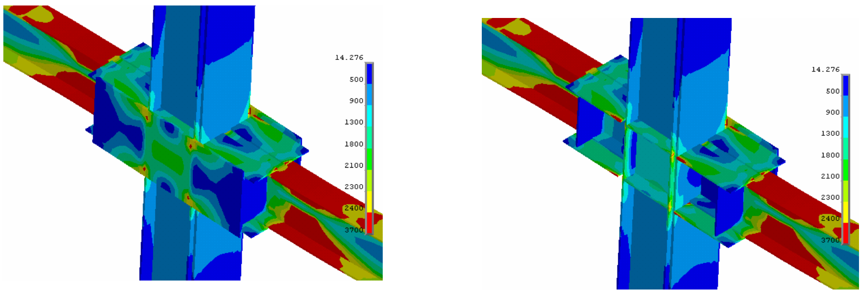

Figure 13 Von Mises stress distribution of model SP under monotonic loading in 0.04 radians interstory drift

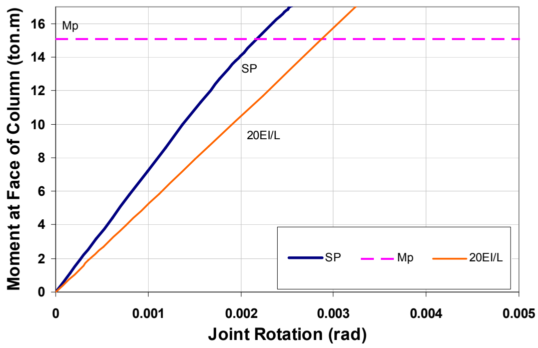

Figure 14 Moment-joint rotation curve for model SP

5. CONCLUSIONS

The main results of this study are:

1- In "common moment connection" of I-beam to double-I built-up column due to flexibility of column cover plate, the plastic hinges can not be formed in beams.

2- "Common moment connection" of I-beam to double-I built-up column is a partially restrained connection.
3- Adding vertical stiffener plate to "common moment connection" reduces column cover plate deformations. It has a considerable effect on improving connection strength, stiffness and compels inelastic deformations in beams. But this connection is partially restrained (with stiffness near to fully restrained requirement) and still there are severe stress concentrations in column cover plate.
4- In the case of moment connections of I-beam to double-I built-up column with side plates, the plastic deformations significantly take place in beams.
5- Moment connection of I-beam to double-I built-up column with side plates can be classified as fully restrained connection.
6- Due to use of two full depth side plates, in moment connection of I-beam to double-I built-up column with side plates, the panel zone remains elastic.

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