Retrofitting of Moment Connection of Double-I Built-Up Columns using Trapezoidal Stiffeners

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Abstract

Double-I built-up columns are used extensively in low and medium rise steel structures. When I beam is connected to double-I built-up columns, through the column cover plate, the load transfer at the joint becomes a disturbing problem. To retrofit the connection, a new geometry is considered. In this method the each flange of the beam is connected to the column by a trapezoidal stiffeners plate. A series of five non-linear three-dimensional finite element models were developed using ABAQUS program to study the behavior of the retrofitted connection under cyclic loadings. The outcomes of numerical investigations indicate that the proposed retrofitting method is a proper choice for "special moment frames (SMF)" and the retrofitted models have sufficient strength and ductility. It reduces also the risk of brittle fracture of the full penetration groove weld.

Keywords: Trapezoidal stiffeners; Moment connection; Retrofitting; Built-up columns.

1. INTRODUCTION

Box, wide flange and double-I built up columns are widely used, in conjunction with I-shaped beams, in steel buildings in which moment resisting frame is chosen as the lateral load carrying system. After the 1994 Northridge earthquake, many researches were conducted on the performance of I-beams to wide-flange and box column connections which shed significant light on the sources of poor behavior in these connections during the event; new methods were also developed, as a result, for retrofit of these connections [1].

According to the results of mentioned investigations, the failures in moment connections were mainly attributed to: improper welding, inappropriate connection detailing, using unsuitable electrodes, and imposition of an unexpected seismic energy to the structures. Nevertheless, few investigations have been performed on the connection of I-beams to compound columns such as double-I built-up columns.
Therefore, this study focuses on assessing a specially detailed connection between I-beams to double-I built-up columns subjected to cyclic loading.

Double-I built-up columns are typically composed of two I-shaped sections, separated by calculated interval, and connected to each other using continuous or discontinuous (laced columns) cover plates. The cover plates are fillet welded along their two longitudinal edges to the I-shape members of the column. Section of double-I built-up column is depicted in Figure 1a.

In the case of conventional moment connection of I-beam to double-I built-up column, the beam moments transfer to the column through the top and bottom flange plates. These plates are fillet welded to the beam flanges. Top and bottom flange plates are connected through complete joint penetration (CJP) groove welds to the column cover plates. A shear tab is fillet welded to the beam’s web and column cover plate. A typical conventional welded moment connection is depicted in Figure 1b.

![Figure 1: Typical conventional moment connection of I-beam to double-I built-up column](image_url)

2. The moment connection of I-beam to double-I built up columns

The failure of the moment connection of I-beam to double-I built-up column connection is mostly governed by the ratio of width of beam flange (or flange cover plates) to column cover plate. In other words, a smaller width of the beam flange (or flange cover plates) compared to the column’s cover plate, will cause significant stress concentration in the full penetration groove weld and reduction in the connection ductility due to the excessive deformation of column cover plate.

The column’s cover plates do not have sufficient stiffness against out of plane deformation and behave in a flexible manner under tensile forces transmitted by the connected beam flanges, (or flange plates). As this deflection takes place during the load-transferring process, it results in significant beam-to-column rotation, and semi-rigid behavior of connection. This phenomenon causes also the important stress concentrations at groove welds between beam flanges and column cover plate and fillet welds between column’s cover plates and I-shapes members of the column. These stress concentrations impose premature brittle fracture in T-joint groove weld between beam flange and column cover plate and failure of fillet weld at the edges of column cover plates.

Brittle behavior is a general problem which concern most of the moment connections in which beam flanges (or beam top and bottom flange plates) are connected to the column using complete joint penetration (CJP) groove weld (FEMA350 [2]). This weld produces three-axial stress concentration in joint area and leads to a brittle failure mode of weld or formation of the plastic hinge in the column face instead of the beam end; they both can result in significant loss of strength and ductility.
Performance of conventional connection of I-beam to double-I column connection under monotonic load was investigated experimentally by Mazrouei et al. in 1995 [3]. The cyclic behavior of this type of connection was studied experimentally by Deylami [4], Shiravand [5] and Deylami and Gholipour [6]. The problem was also studied analytically by Deylami and Yakhchaliyan [7] and Deylami and Shiravand [8].

The different upgrading strategies are based on increasing either the connection stiffness or beam end deformability near to the connection region. In this study, a new practical and efficient method for retrofitting the connection of I-beam to double-I-built-up column is presented. This method eliminates the problems concerning the connection of I-beam to double-I column's cover plates, as well as, improves the connection's ductility under cyclic loading.


In order to retrofit the existing conventional moment connection of I-beams to double-I built-up columns, a new method was proposed by Deylami and Nazok-kar [10] in Amirkabir University of Technology of Iran. The proposed method consists of welding the trapezoidal vertical stiffeners to the beam and column flanges at the connection. The retrofitted connection is illustrated in Figure 2. The bottom and top connection cover plates are fillet welded along their length to the beam flanges (or flange plates) and the trapezoidal stiffeners. For the construction reason, the top connection cover plates are made of two pieces. The connection cover plates fill the gap between the beam flanges (or flange plates) and the trapezoidal stiffeners. The vertical trapezoidal stiffeners are, connected to the column members by complete penetration groove welds. To maintain the continuity and rigidity of the column flanges and panel zone, continuity plates were welded to the column members just in the level of each flange of the beams. Regarding the behavior and stress distribution of models presented by Deylami and Nazok-kar [10], we have used two continuity plates behind each vertical stiffener instead of one.

The load transfer mechanism from beam to column is significantly improved because of the new detailing. That is, due to the higher stiffness provided by vertical stiffeners. The major part of the compressive and tensile forces acting on the connection is transferred by these vertical stiffeners directly to the column members instead of groove weld between the beam flange and the column cover plate. Hence the stress on the groove weld decreases and the risk of brittle fracture of this weld is eliminated. On the other hand, decreasing the tensile stress applied to the column cover plate reduce the out of plane deformation of this plate which results in a more rigid connection. Therefore, the drawbacks of the conventional connection are improved and the rigidity and ductility of the connection are enhanced.

![Figure 2: Moment Connection of double-I built-up column using trapezoidal vertical Stiffener](image)
4. Modeling the behavior of connection

Finite element method, as a numerical tool, provides a powerful mean for precise analytical prediction of many structural systems. This technique is used in this study for assessing the behavior of connection under study. ABAQUS software is selected for this purpose according to its special capability in analysis of large deformation problems.

4.1. Model Geometry

One-sided (interstory), simplified subassembly models, representing the exterior columns, according to AISC 2005 [11] and FEMA-350 [2] were considered. Two types of models were considered according to the height of the connected beams. Mode type A for beam’s height up to 40 cm. and model type B for beam’s height of 50 and 60 cm. selected for the beams studied here. As depicted in Figure 3, the beam lengths were selected as 5.0 and 7.54 meters, and columns were 3 and 3.5 meters long, for models A and B correspondingly.

![Figure 3: Models of moment connection of double-I built-up column using trapezoidal stiffeners (all dimensions in cm)](image)

The distance from beam's lateral support to the column axis was 222 and 150 cm. for model types A and B, respectively. These distances were chosen according to AISC [11] provisions so as to prevent the lateral-torsional buckling of beam and the beams could develop the full range of their plastic capacity.

4.2. Dimensions of connection components

Component dimensions and characteristics of models are presented in Tables 1 and 2 respectively.

<table>
<thead>
<tr>
<th>Models</th>
<th>Beam</th>
<th>Column</th>
<th>Center to Center of I-shapes</th>
<th>Column Cover Plate</th>
<th>Type of model</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>IPE300</td>
<td>2IPE300</td>
<td>200</td>
<td>PL300*15</td>
<td>B</td>
</tr>
<tr>
<td>02</td>
<td>IPE330</td>
<td>2IPE270</td>
<td>175</td>
<td>PL270*15</td>
<td>B</td>
</tr>
<tr>
<td>03</td>
<td>IPE400</td>
<td>2IPE300</td>
<td>200</td>
<td>PL300*15</td>
<td>B</td>
</tr>
<tr>
<td>04</td>
<td>IPE500</td>
<td>2IPE300</td>
<td>200</td>
<td>PL300*15</td>
<td>A</td>
</tr>
<tr>
<td>05</td>
<td>IPE600</td>
<td>2IPE400</td>
<td>220</td>
<td>PL300*15</td>
<td>A</td>
</tr>
</tbody>
</table>
Table 2: Characteristics of models using trapezoidal vertical stiffeners (all dimensions in mm)

<table>
<thead>
<tr>
<th>Models</th>
<th>Doubler Plate thickness</th>
<th>Cover Plate thickness</th>
<th>Trapezoidal Stiffener a</th>
<th>b</th>
<th>c</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPT-01</td>
<td>7</td>
<td>12</td>
<td>345</td>
<td>100</td>
<td>200</td>
<td>15</td>
</tr>
<tr>
<td>SPT-02</td>
<td>7</td>
<td>12</td>
<td>345</td>
<td>110</td>
<td>220</td>
<td>15</td>
</tr>
<tr>
<td>SPT-03</td>
<td>10</td>
<td>12</td>
<td>435</td>
<td>120</td>
<td>240</td>
<td>20</td>
</tr>
<tr>
<td>SPT-04</td>
<td>12</td>
<td>15</td>
<td>495</td>
<td>120</td>
<td>280</td>
<td>25</td>
</tr>
<tr>
<td>SPT-05</td>
<td>12</td>
<td>20</td>
<td>555</td>
<td>160</td>
<td>330</td>
<td>25</td>
</tr>
</tbody>
</table>

ST-37 steel with yield strength of 2400 and ultimate strength of 3700 kg/cm² was considered for all elements of the connections.

All the models were loaded on their beam tips according to the cyclic loading pattern recommended by AISC [11] for moment connections (Figure 4).

Three dimensional finite elements modeling has been performed using 8-node C3D8R and 6-node C3D6 elements available in ABAQUS program. Each node of this element possesses 3 degrees of freedom in principal X, Y, and Z directions with no rotational freedom.

Regarding the fact that stresses are more likely to change in the vicinity of the connection than distant portions, a finer mesh has been generated around the connection region. Mesh dimension is determined according to the required preciseness. The meshing of model SPT-01 is depicted in Figure 5 as an example.

Figure 4: Loading history; Figure 5: Meshing of model SPT-01

4.3. Boundary conditions

The boundary conditions of models are applied in accordance with AISC [11] and FEMA 350 [2]. The translation of the nodes at the column base is restrained in all three directions. These restraints are also applied to column's upper end nodes except that these nodes are left free to translate in vertical direction. For modeling the restraints provided by the beam lateral supports, the beam's top and bottom flanges are restrained from out-of-plane movement at these supports.
Figure 6: Stress and strain distribution and Moment-rotation hysteretic curves
5. Results

5.1. Stress and strain distribution and Moment-rotation hysteresis curves

Figure 6 represent the distribution of Von-Misses stress (Figure 6- a) and equivalent plastic strain (Figure 6- c). According to distribution of stresses and equivalent plastic strains, the formation of plastic hinge is seen to fall out of the connection region and at the beam end region. Models with deeper beam sections show the buckling of beam occurred at the plastic hinge region. This local buckling includes both the flanges and the web of the beam section. The hysteretic moment-rotation curves for all models are presented in part (b) of Figure 6. The moment depicted in these curves is measured at the column center line. The plastic strength moment of beam connected to assemblies (M_p) are shown with a horizontal dashed line in each figure. According to AISC [11], the moment developed at column face at the 0.04 radian story drift shall exceed 80% of the beam's plastic moment strength (M_p). As can be seen, this condition is hold for all models analyzed in this study. Therefore, it can be concluded that this connection detailing can be used in special moment frames (SMF's).

5.2. Hysteretic moment-rotations envelops

To compare the cyclic performances of models, the envelop of all moment-rotation hysteretic curves are illustrated simultaneously in Figure 7.

The degradation in the curves, as noted earlier, are due to the occurrence of local buckling in beam sections. With increase of beam height, both the strength and the rate of degradation increase in hysteretic curves.
6. Conclusions

1. Investigations performed on the hysteresis moment-rotation curves demonstrate that in all models, the moment developed at column center at 0.04 radian drift angle exceeds the plastic moment strength ($M_p$) of connected beam, and hence the 0.8$M_p$ limit which is set by AISC2005 [11] for qualifying the connection for use in special moment frames (SMF's). As a result, all models revealed the eligibility for been used in SMF's.

2. The retrofitted connection was able of transfer the full beam's plastic moment. The plastic hinge and causes the plastic hinge to form, out of connection, in the beam end region. The connection can be categorized as a full-strength connection.

3. The existence of the vertical trapezoidal stiffeners decrease the rate of stress concentration on the groove weld between beam flange plate and column cover plate, which reduce in turn the risk of brittle fracture of the weld.

REFERENCES


