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RETROFIT OF SEMI-RIGID KHORJINEE CONNECTIONS WITH HORIZONTAL PLATES

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ABSTRACT

Khorjinee connection has been widely used in the past 50 years by practicing engineers in Iran. In this system, a pair of continuous beams cross several columns and connect to the sides of the columns by means of seat angles. Out of plane position of the beam regarding the longitudinal axis of the column create additional moment in the seat angles and early onset of failure under lateral forces in the connection. Owing to abundant use Khorjinee connections in Iran design of an economical and safe system for retrofitting them seems vital. Utilizing horizontal restrained plates is one of the innovative methods which have been proposed for changing the behavior of Khorjinee connection from semi-rigid to restrained one. This paper studies strength, stiffness and ductility of this new restrained connection, and compares them with AISC2005 specifications. For this purpose four different steel structures with ordinary moment frame were considered and cyclic behaviors of several improved Khorjinee connections of these buildings were evaluated. The results of the computed models have shown good agreement with the results of experiments already carried out by other researches. The results also show that the studied connections have enough strength, stiffness and ductility for being used as an ordinary connection in moment frames.

Introduction

A special type of semi-rigid beam to column connection called "Khorjinee connection" has been developed in the past 50 years by practicing engineers in Iran. Because of its simplicity in fabrication and erection, and its economical advantages this connection is commonly used in Iran. Construction of steel structures with Khorjinee connections decreases not only the erection time but also the labour cost. This type of construction is used all over the urban and in some rural areas of Iran. In Khorjinee system a pair of continuous beams cross over several double-I built-up columns and connected to the lateral sides of the column by means of seat angles (Fig. 1). The seat angles are fillet welded to the beams and columns. The possibility of using two parallel I-beams instead of one deeper one is another advantage of the Khorjinee connections.

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Out of plane position of the beam regarding the longitudinal axis of the column create additional moment in the seat angles. Application of these unexpected bending moments creates important stress concentration in the fillet weld between the seat angles and double-I built-up columns (Hosseini Hashemi et al 2000). Most of the existing steel structures were not designed to resist these kinds of lateral loads. Early onset of failure in the angles is most likely the cause of failure under lateral forces in these types of connections. However, recent earthquakes in Iran, especially the Manjil earthquake of 20 June 1990, Show that the reason for failure of the common steel structures lies mostly on their joints, especially on poor behavior of Khorjinee connections (Tehranizadeh 2000).

Theoretical and experimental researches have been performed to study the static and dynamic behavior of Khorjinee connection as well as its workability, stiffness and strength, using the traditional and some types of different modified models. It was found that the behavior of this widely used connection in its traditional form can not be considered as a classical semi-rigid connection and that some modifications have to be applied to satisfy the dynamic behavior as well (Tehranizadeh and Alavi 1997). Most of researchers have studied the various ways of retrofitting of Khorjinee connections (Mirghaderi et al 2005).
In this paper cyclic behavior of Khorjinee connection with horizontal plates will be presented.

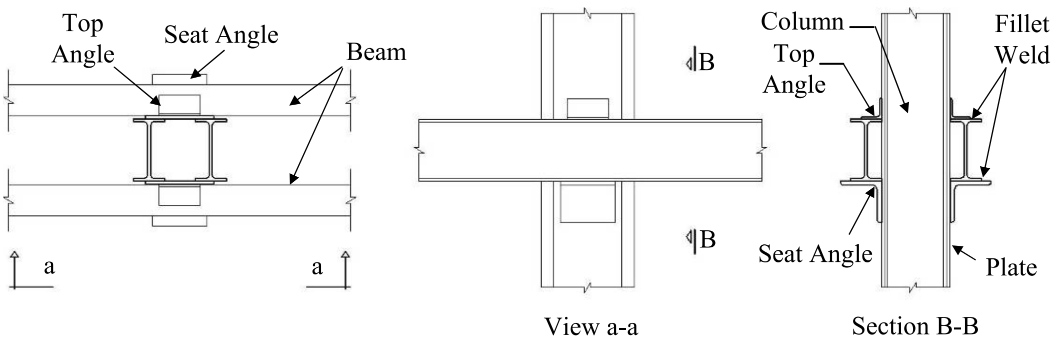

Figure 1. Traditional Khorjinee connection

Experimental Model

The experimental model of a modified Khorjinee connection with horizontal plates was tested at the structural laboratories of the Building and Housing Research Center (BHRC) (Mirghaderi 2000). As illustrated in Fig. 2, the experimental model was a full scale beam-column subassemblage. The column was loaded cyclically with increasing rotation amplitude, θ, of 0.005, 0.01, 0.015, 0.02, 0.025 rad., with one cycle for each increment.

In the experimental model, the double-I built-up column was made of two IPE180 with 180 mm distance between their axis. Two plates, with sections of 200 mm width and 8 mm thicknesses, were welded to the column (Fig. 2). The length of column was 195 cm. The seat plate of beams has the section of 100 mm width, 200 mm length and 10 mm thickness. The length of beam is 160 cm. The horizontal restrained plates are shown in Fig. 2. Thickness of horizontal restrained plates was 15 mm.

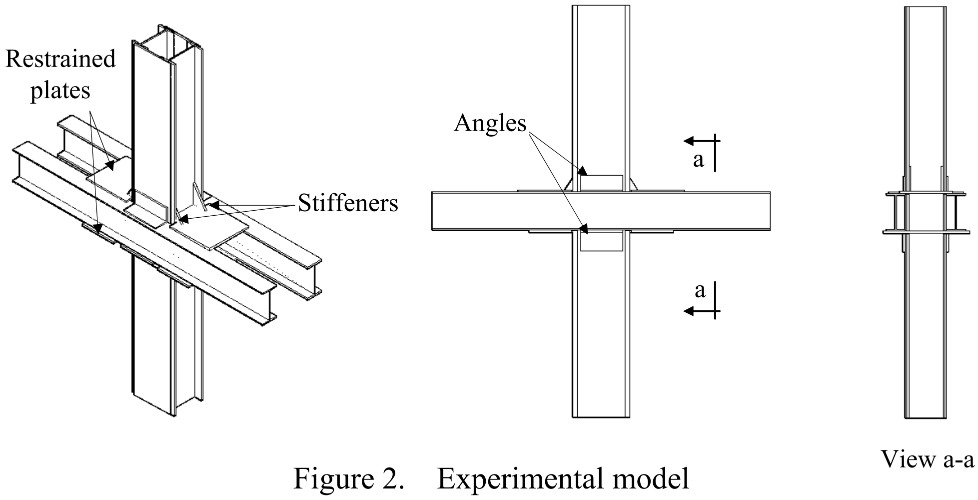

Figure 2. Experimental model

Design of Analytical Specimens

This paper aims to study strength, stiffness and ductility of a modified Khorjinee connection with horizontal plates in accordance with "BHRC. Specification for the Design and Fabrication of Khorjinee Connections in Steel Buildings" (BHRC 2003) and AISC2005 requirements. For this purpose**,** four steel structures of 10, 8, 6 and 4 stories with ordinary moment-resisting frame (OMRF) were considered. Analysis and design of these structures have been done according to AISC2005 requirements. Among studied buildings, 6 connections with maximum stress ratios were selected.

Column and beam characteristics of these structures are shown in table 1. In this table l_{br} and l_{bl} represent the beam length of right side and left side bay of the Khorjinee moment connection respectively. The height of column is equal to 300 cm for all specimens.

Table 1. Specifications of specimens

Specimens	**Khorjinee beams**	**Column**	**Distance between the axis's of column (mm)**	**Column's cover plates (mm^2)**	**The beam perpendicular to the Khorjinee connection**	$l_{br} = l_{bl}$ **(mm)**
KHH01	IPE180	2IPE180	180	200 ×10	IPE140	4200
KHH02	IPE200	2IPE180	180	200 ×10	IPE180	4200
KHH03	IPE220	2IPE200	200	250 ×8	IPE200	4200
KHH04	IPE240	2IPE240	200	250 ×18	IPE220	4500
KHH05	IPE270	2IPE270	250	350 ×20	IPE270	4800
KHH06	IPE300	2IPE270	250	350 ×18	IPE270	5000

Design of Horizontal Plates

The horizontal restrained plates were designed for the derived forces of plastic moments of beams based on AISC 2005 and the recommendations proposed by BHRC Specification. Typical plates' dimensions are shown in Fig.3.

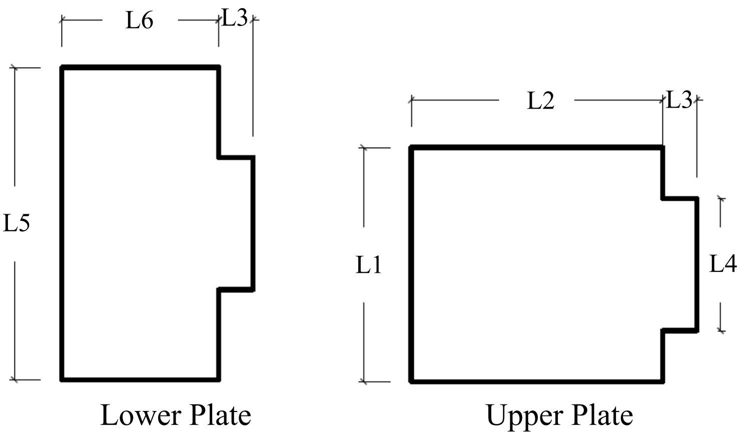

Figure 3. Typical dimension of horizontal restrained plates

For improving the behavior of connection and decreasing the forces which are created during the connection rotation in welds of seat angles, the upper angle was omitted and instead, a stiffener was replaced. In table 2 Dimensions of restrained plates are shown. In this table "t" is thickness of restrained plates and "a" is representative of weld leg size of the restrained plates to the web of column and beam flange.

Table 2. Specifications of horizontal restrained plates

Specimens	Upper Restrained Plates			Lower Restrained Plates			Thickness of Plates	Weld leg size (cm)
	L1	L2	L3	L4	L5	L6	t	a
KHH01	29.63	31.62	4.29	16.4	40.2	20.1	0.97	0.8
KHH02	30.56	34.08	4.285	16.4	42	21	1.1	0.9
KHH03	33.19	36.09	4.72	18.30	45.60	22.8	1.20	0.92
KHH04	40.22	42.34	5.69	22.04	53.6	26.8	1.2	0.98
KHH05	45.16	45.15	6.42	24.96	60.04	30	1.3	1.1
KHH06	49.31	52.83	7.15	27.86	65.74	32.8	1.3	1.1

Finite Element Modeling and Analysis

In order to obtain the reliable finite element models, the models were compared and verified with the results of the experimental model. All the models, including the experimental model, were computed with ANSYS nonlinear software. Further information was reported by Heydari and Deylami (Heydari 2007). The finite element model adopted eight-node solid element (element SOLID45 in ANSYS) with the possibility for employing material nonlinearity. SOLID45 has plasticity, stress stiffening, large deflection, and large strain capabilities. This element is defined by eight nodes having three degrees of freedom at each node, (nodal translations in the x, y, and z directions). 3-D 4-Node Surface-to-Surface Contact elements, CONTA173 and TARGE170 is used to represent contact and sliding between surfaces of seat angles and restrained plates with flanges of beam and also restrained plates with web of columns. Contact elements were located on the surfaces of 3-D solid elements. The plasticity of model was based on the Von Mises yielding criterion and its associated flow rule. Other mechanical characteristics of steel correspond to the mechanical characteristics of experimental model (Heydari 2007). Since brittle fracture is likely to occur within the fillet weld of horizontal plates to the column face and beams, model of these fillet welds was established. The 3D element type SOLID45 was used to create these models. Perfectly elasto-plastic behavior was developed to simulate the weld metal with the yield stress of 350 MPa. The experimental response (solid lines) is compared with the simulated response (dotted lines) in Fig. 4, which is plotting the moment at the column face against the beam rotation angle.

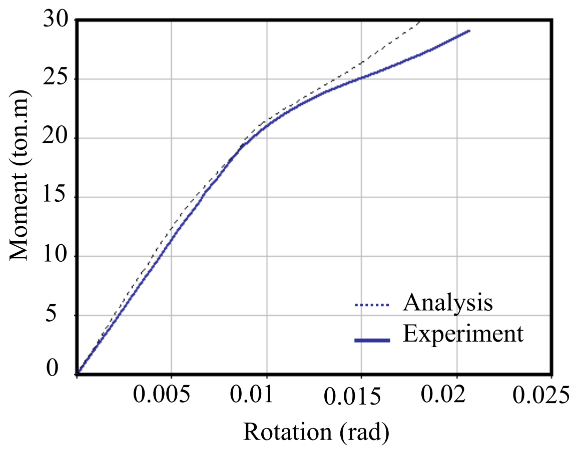

Figure 4. Comparison between test and analysis for full-scale beam-column subassemblage

For new specimens two groups of connections were modeled. In the first ones welds are not considered and all parts were connected to each others directly (segments boundary nodes were merged), and in the second groups welds were completely simulated. The ANSYS finite element software was utilized for large-deformation nonlinear analysis of the specimens. All specimens were modeled symmetrically with respect to strong axis of columns. Fig. 5 shows a typical finite element meshing used in this study. As observed in Fig. 5, a more refined mesh size was applied for the region near to the connection. Nonlinear material was assigned to the elements around the beam–to–column joint, since nonlinear deformations were mostly accommodated within those portions. For the remaining parts of the model the material was assumed to behave elastically.

The plasticity model was based on the Von Mises yielding criterion and its associated flow rule. The steel mechanical properties were considered as: Young’s modulus=2.1×10^5 MPa, Poisson’s ratio = 0.3, yield stress = 250 MPa, ultimate tensile strength = 370 MPa, and tangent modulus = Young's modulus×3/1000. The bilinear Kinematics hardening rule was considered for the stress-strain relation of material. The 3D element SOLID 45 was used to create these models. Perfect elasto-plastic behavior was developed to simulate the weld metal with the yield stress of 350 MPa.

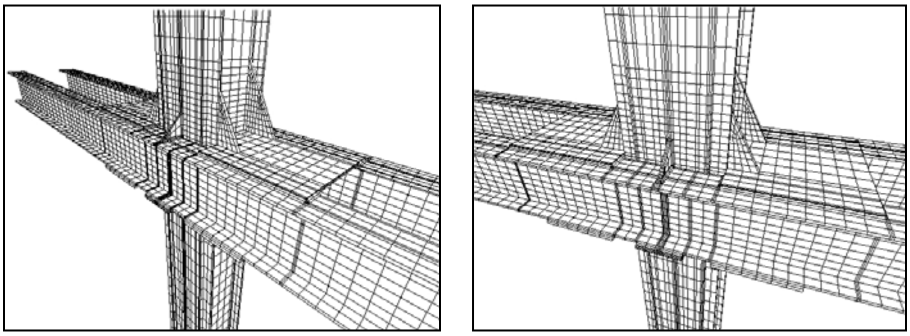

Figure 5. Three-dimensional finite element model

Loading Procedure

Each subassembly was loaded on its column tip by imposing cyclic displacement according to the SAC loading protocol (Clark 1997) (Fig. 6). Cyclic nonlinear analyses of the subassemblies were performed using the Riks method. In this method, buckling mode shapes of the model, computed in a separate buckling analysis, are implemented to perturb the original perfect geometry of the model. Then the imperfect model obtained is analysed to take local and lateral buckling into account (Moslehi Tabar 2005).

Hysteretic Response

Because of special form of this connection, the influence of the beam PZ on the cyclic behavior of the specimens is considered. The beam PZ moment-rotation hysteretic loops are illustrated in Fig.6. The PZ rotation is defined as:

$$\gamma_{pz} = \frac{\sqrt{(a^2+b^2)}}{2ab}(\delta_1-\delta_2) \tag{1}$$

Where a , $b =$ initial dimensions of the PZ, and δ_1 , $\delta_2 =$ changes in length of PZ diagonals (Calado 2000). As shown in the figures' PZ moment-rotation hysteretic loops, beam's PZs have a few rotations and cause that energy dissipation occurs out of the beam PZ, because horizontal restrained plates prevent from the deformation of beam PZ, and rotation is perfectly independent from beam PZ rotation.

Beam moment-rotation hysteretic responses of the subassemblies resulting from the finite element analyses are shown in Fig. 7. The beam moment was measured at the column face. According to AISC2005 seismic provisions for structural steel buildings(AISC 2005b), beam to column moment connections in ordinary moment frames (OMRFs) are required to sustain a total interstory drift angle of ±0.02 rad without significant loss of strength. Significant loss of strength is defined to occur when the flexural resistance of the connection drops below 80% of the nominal plastic moment capacity of the beam.

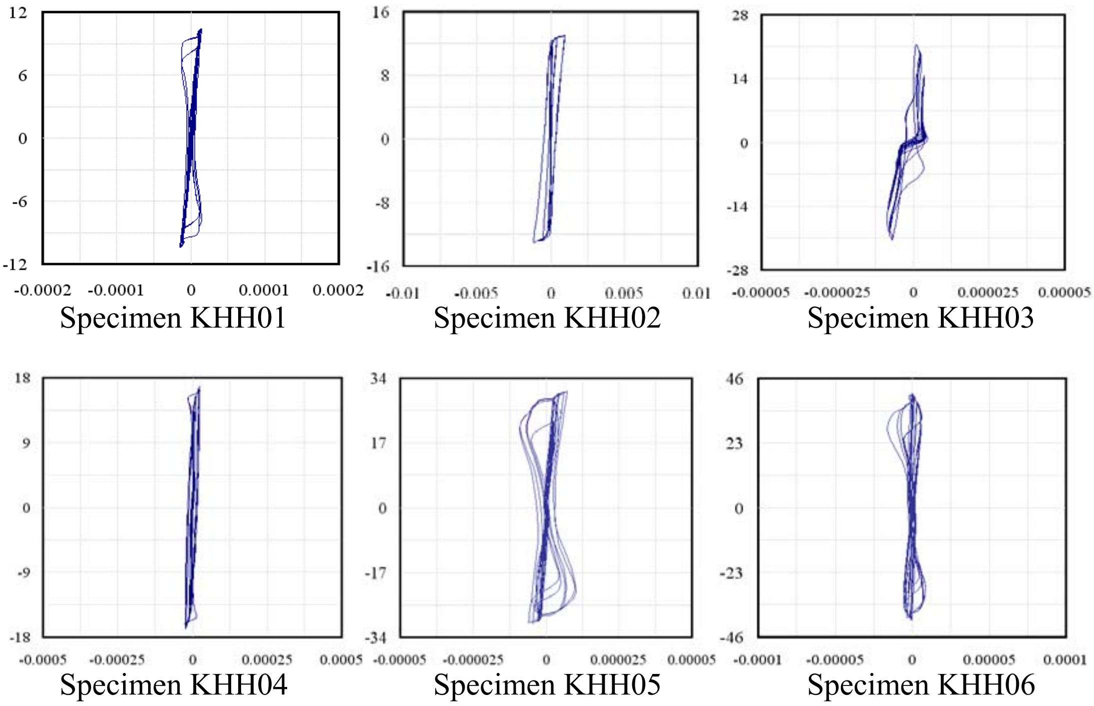

Figure 6. Hysteretic response of beam panel zone, vertical axes represent the moment (ton.m) and the horizontal axes represent PZ rotation (rad)

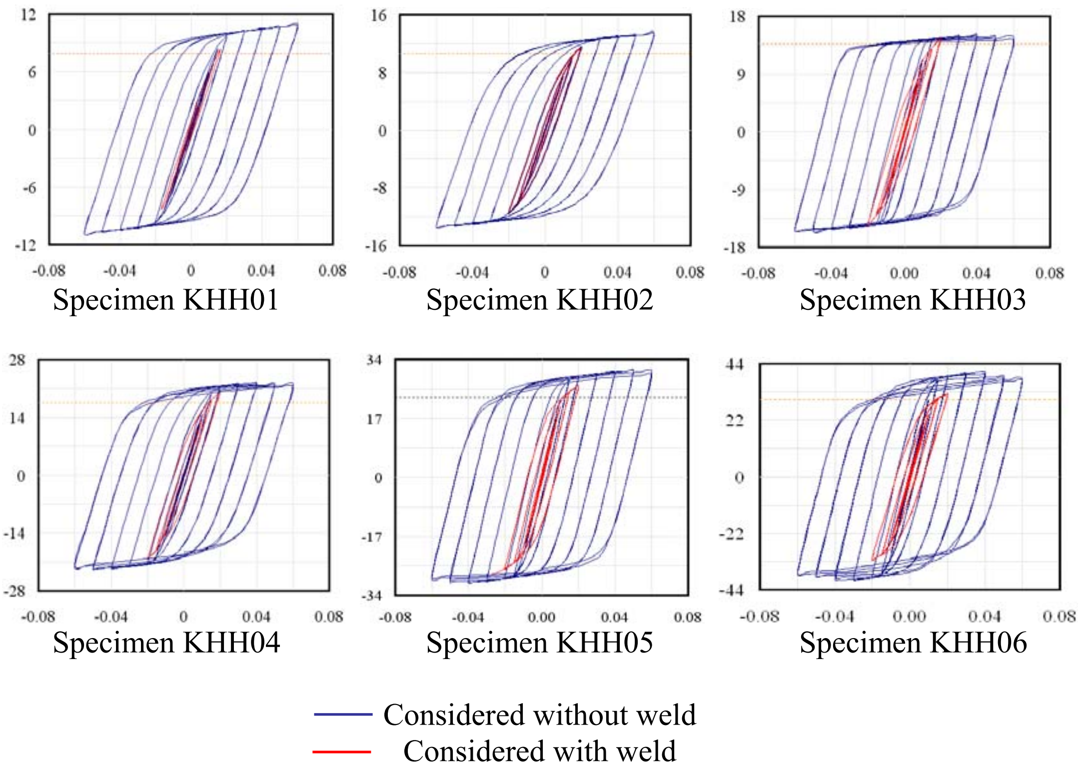

Figure 7. Hysteretic response of specimens, vertical axes represent the moment at the column face (ton.m) and horizontal axes represent the interstory drift angle (rad)

As shown in the Fig. 7 with the exception of specimen KHH01, all other specimens with weld simulation are capable of 0.02 rad. rotation and their strength in this rotation angle are more than plastic moment of beams but in greater rotation angles because of high created strains in welds of connection fracture may be occurred. Therefore, this connection can satisfy the conditions of ordinary moment-resisting frames (OMRFs). In models which the modeling of the weld are not considered; although, in the specimens with deeper beams local buckling in flange and web of beams have caused degradation in moment-rotation hysteretic curves in the latest cycles (Fig. 7), even in every model the amount of moment at the column face is greater than nominal plastic moment capacity of the beam (Mp) in total interstory drift angle of ±0.04 rad.

With considering obtained hysteretic curves of moment- rotation from analysis of F.E models that strength in every model is greater than the nominal plastic moment capacity of the beam (Mp). Therefore Khorjinee connection with horizontal restrained plates is a full-strength connection (According to seismic provisions for structural steel buildings (AISC 2005b)).

Connection Classification

There is a specification for evaluating the connection stiffness in the 2005 AISC commentary on the specification for structural steel building. In this commentary the secant stiffness K_s at service loads is taken as an index property of connection stiffness. Specifically, $K_s=M_s/\theta_s$ where M_s and θs are the moment and rotation, respectively, at service loads. In the discussion below, L and EI are the length and bending rigidity, respectively, of the beam. If $K_S L/EI \geq 20$, then it is acceptable to consider the connection to be fully restrained (in other words, able to maintain the angles between members). If $K_S L/EL \leq 2$, then it is acceptable to consider the connection to be simple (in other words, rotates without developing moment). Connections with stiffness between these two limits are partially restrained and the stiffness, strength and ductility of the connection must be considered in the design.

Secant stiffness Ks is obtained regarding to the loops of moment- rotation of the connections (Heydari 2007). For all specimens Ks is represented in table 3. As shown in this table, Ks for every specimen are greater than 20. Therefore this kind of connection system can be considered as a fully restrained connection.

Table 3. Specifications for evaluating the connection stiffness

Specimens	**Ms (kg-cm)**	**ϴs (rad)**	**Ks (kg-cm)**	**Ix-x (cm^4)**	**L (cm)**	**EI / L (kg-cm)**	**Ks.L/EI**
KHH01	3.50E+05	1.4E-03	2.4E+08	1320	420	6.3E+06	38.9
KHH02	4.66E+05	1.6E-03	2.9E+08	1940	420	9.2E+06	31.7
KHH03	6.05E+05	1.4E-03	4.3E+08	2770	420	1.3E+07	32.8
KHH04	7.78E+05	1.7E-03	4.5E+08	3890	450	1.7E+07	26.3
KHH05	1.03E+06	1.2E-03	8.3E+08	5790	480	2.4E+07	34.4
KHH06	1.34E+06	1.39E-03	9.6E+08	8360	500	3.3E+07	28.8

Conclusions

In order to classification of Khorjinee connection with horizontal restrained plates according to the AISC2005, a numerical study was conducted on a set of subassemblies with various configurations. In the following, the main results are indicated:

1. Khorjinee connection with horizontal restrained plates have much stiffness and accordance to AISC2005, it is acceptable to consider the connection to be fully restrained.

2. The Khorjinee connection with horizontal restrained plates is a full strength connection and it causes that the plastic hinge is created in the beam near the connection, and there is no yielding in the beam PZ.

3. With the exception of specimen KHH01, all other specimens with weld simulation are capable of 0.02 rad rotation and their strength in this rotation angle are even more than plastic moment of beams; therefore, this system can be utilized in the ordinary moment-resisting frames (OMRFs).

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