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An Experimental Study on the Moment-Rotation of Bolted Beam-Column Connections

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Abstract--The behavior of beam-column connections plays an important role in the response of a steel moment resisting and moment stiffness framed structure, especially under statically loaded. In this study, the moment-rotation characteristics of semi-rigid bolted connections using with top and seat angles is discussed based on experimental investigation. The aim was to provide necessary data to improve of the Eurocode 3.The maximum bending moment, the plastic flexural resistance, Mj.Rd and the bending moment capacity, MΘ.Cd increased with the increasing thickness of the top and seat angles joints.

Keywords--top-and-seat angle connections; Experimental testing; beam-column connection; statically load.

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1. Introduction

Structural steel framework with welded joints was considered as one of the best moment resisting and moment stiffness framed structural system till the 1994 Northridge earthquake. In the earthquake, many structural steel frames failed due to the occurrence of brittle reliability at the connections. This caused the loss of reliability on steel welded moment resisting frames. Since then, as an alternative, bolted connections, often called semi-rigid connections, are considered for design of steel moment resisting frames and retrofitting works (Shemy and Sreekumar,2012). It has been done the classification and formed mathematical models by this databank to express the behavior of connection. However, classification is seven types of beam-column connections shown in table 1. However, there are many different types of beam-column connections in steel structures today that aren't defined in data banks. In this research, two full scale beam-to-column minor connections in top and seat angle and web to the beam in two groups were tested in the Laboratory of Ataturk University. The aim is to analyze the influence stiffeners and thickness of top and seat angle joints on the behavior of connections and to provide necessary data for improve of the EN1993-1-8 (2005).

Moment-rotation curves were used to evaluate the main parameters characterizing the behavior of the tested connections, such as the stiffness, the resistance, the failure mode, and the deformation capacity of the joints.

Table 1. 7 Connections Types

Conection types	**Author**	**Experimental number**	**Year**
Double web angle	Davison et al W. C. Bell et al C. W. Lewitt et al W. H. Sommer B. Bose	2 4 6 4 1	1987 1958 1966 1969 1981
Top and seat angle	Davison et al A. Azizinamini et al	4 20	1987 1985
End-plate connection type	Zandonini ve Zanon Moore and P.A. Sims J. R. Bailey J. A. Packer et al S. A. Ioannides R. J. Dews P. Grundy et al	10 2 26 3 6 3 2	1988 1986 1970 1977 1978 1979 1980
Header plate	Davison et al Phillips and Packet J. R. Ostrander	3 5 24	1987 1986 1970
End-plate and single flange angle	Aggarwal	2	1990
single flange angle	Aggarwal	9	1990

2. Test details

Two series of two bolted beam-to-column connections were investigated throughout this study; the experimental program is shown in Fig. 1. The joints were fabricated from a minor axis connection, as shown in Fig. 1 and detailed in Table 3. The stiffeners with a thickness equal to 5 mm were welded to the top-and-seat angle by means of a continuous 45° fillet weld (Maali et al, 2015). The fillet welds were prepared for the workshop in a down-hand position. The manual metal arc welding type of procedure was involved with a consumable electrode. The chosen steel grade for the top-and-seat angle, plate stiffener, and profile section was S235. The column IPE300, the beam IPE120 and hand tightened full-threaded grade 8.8 M8 bolts in 10 mm drilled holes are kept constant for all the tested specimens.

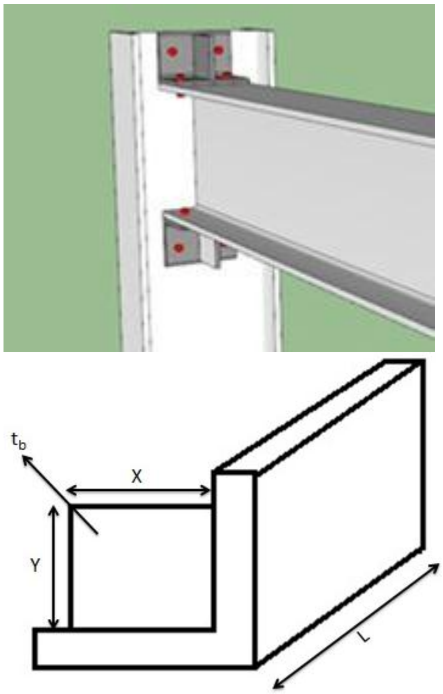

Fig. 1. Top and seat angle geometry and proposed three-dimensional semi-rigid joint

Table 2. Test details

Experiment	**Top And Seat Angle**	**Length Of Angle (L) (mm)**	**Stiffiner Thickness Of Top And Seat Angle (t_P) (mm)**
S60-L73-SA5	L60*60*6	73	5
S50-L73-SA5	L50*50*5	73	5

S= top and seat angle L50x50x5 and L60x60x6, L= Length of top and seat angle, SA= stiffiner of top and seat angle

3. Mechanical properties and test arrangement

The test program included one steel grade for the beam; the column and stiffeners were S235 with nominal values of yield strength f_y, n and ultimate tensile strength f_u, n equal to 235 MPa and 360 MPa, respectively. The coupon tension test on the structural steel material was performed according to the appropriate UNE procedures (UNE-EN 10002-1, 2002). The real mechanical characteristics are obtained using tensile tests on coupons cut from the flange and web of the beam and column and from the top and seat angle 50 and 60. For each component, three tests are performed. The average characteristics are shown in Table 4.

Table 3. Average characteristic values for the structural and bolt

(MPa)	Beam Web	Beam Flange	Column Web	Coloumn Flange	Top And Seat Angle 50	Top And Seat Angle 60	Bolt
f_y	338.1	348.9	341.1	339.6	308.1	311.2	789.9
f_u	446	477.3	445.8	438.1	448.6	450.4	871.6

The specimens were subjected to a static force applied by a 250 kN hydraulic jack with a maximum piston stroke of 200 mm (Aydın et al,2015). Tests were performed under displacement control with a constant speed of 0.016 mm/s up to the collapse of the specimens. The test arrangements are shown in Fig. 2. In order to prevent the lateral torsional buckling of the beam while loading, a two-column guidance device near the beam was provided. In fact, from the experiments, it was observed that lateral torsional buckling of the beam with the course of loading did not occur. The instrumentation plan is described in Fig. 2. The lengths of the beam and column (1500 mm) were chosen to ensure that a realistic stress pattern was developed at the connection, on one hand, and that fracture of the several specimens, i.e., ultimate load, was attained with the specific testing machine.

The results were collected using a data logging device that recorded all measurements and the load cells at one-second intervals. All of the data were recorded for the duration of the test. Displacements were measured using linear variable displacement transducers with a maximum displacement of 100 mm (LVDTs, shown as DT in Fig. 2). The test setup is shown in Fig. 2.

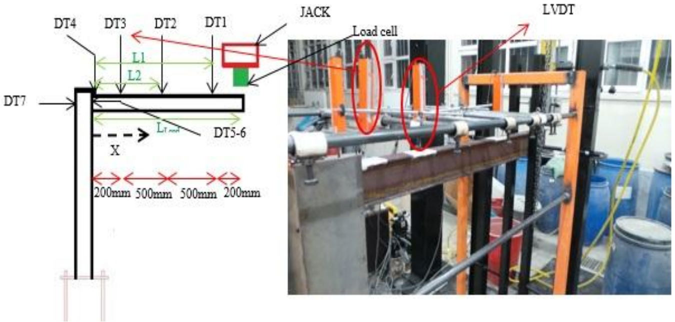

Fig. 2. Location of the displacement transducers (DT=LVDTs)

4. Test results

The moment-rotation curve is the behavior of the moment connections that describe the relationship between the applied moment (M) and the corresponding rotation (ϴ) between the members. The rotation and the bending moment (M) are predicted by using displacements of the beam or top-and-seat angle connection as well as multiplication of the distance between the load application point and beam end, bolted to column (L_{load}), respectively (Aydın et al,2015):

$$M=PL_{load} \quad (1)$$

The rotational deformation of the joint, ϴ, is equal to the connection rotation. The beam rotation is approximately given by (Fig. 2.):

$$\theta_B=\frac{\arctan(\delta_{DT1}-\delta_{DT4}-\delta_{b.el(DT1)})}{L_1}=\frac{\arctan(\delta_{DT2}-\delta_{DT4}-\delta_{b.el(DT2)})}{L_2} \quad (2)$$

where δ_{DTi} and $\delta_{b.el(DTi)}$ are the vertical displacements and the beam elastic deflection, at LVDT DTi, respectively. $\delta_{b.el(DTi)}$ is evaluated as follows:

$$\delta b.el(DTi) = \left(-\frac{P}{EI}\right)\left(\left(\frac{X^3DTi}{6}\right)-\left(\frac{LloadX^2DTi}{2}\right)\right)$$

(3)

Where I is the moment of inertia, E is Young's modulus of beam. The M–ϴ curve of the connection may be characterized by using the aforementioned relationships. The main features of this curve are: moment resistance, rotational stiffness, and rotation capacity. In particular, the following characteristics were assessed for the different experimental tests (European Committee for Standardization, 2005, Bose et all, 1996, Bose et al , 1991), as drawn in Fig. 3.

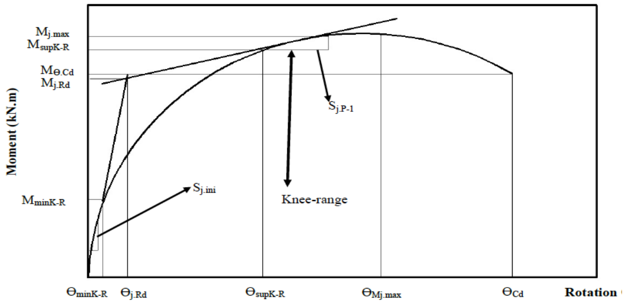

Fig. 3. Moment-rotation curve characteristics

The ductility of a joint (Ψj) is a property that reflects the length of the yield plateau of the moment-rotation response. The proposed definition of the ductility of a joint is the difference between the rotation value corresponding to the joint plastic resistance, Θ_{MRd}, and the total rotation capacity, Θ_{Cd}. Thus, the ductility of a joint relates the maximum rotation of the joint, Θ_{Cd}, to the rotation value corresponding to the joint's plastic flexural resistance, Θ_{MRd} (Coelho, 2004.):

$$\Psi j = \frac{\theta Cd}{\theta MRd}$$

(4)

Also, the rotation values at the maximum load and corresponding ductility levels, Ψj.max load, can be derived from:

$$\Psi j_{\cdot maxload} = \frac{\theta Mj.max}{\theta MRd}$$

(5)

The main features of the two M-ϴ curves are summarized in Table.5. In particular, for the different tests, the following characteristics are assessed in Fig.4. This table shows that: The maximum bending moment, $M_{j.max}$, increased by 9.09% with the increasing thickness of joints. The plastic flexural resistance, $M_{j.Rd}$, increased by 21.49% with the increasing thickness of the joints. The bending moment capacity, $M_{\Theta.Cd}$, increased by 10.74% with the increasing thickness of the joints. the initial stiffness ($S_{j.ini}$) and the post-limit stiffness ($S_{j.p\text{–}l}$) increased with the increasing thickness of the joints of 5mm to 6mm. Incresed were about 0.60% and 13.85%, respectively. The plastic flexural resistance rotation, $\Theta_{M\cdot Rd}$, increased by 53.21% with the increasing thickness of the joints. The maximum rotation, $\Theta_{M\cdot j.max}$ and the rotation capacity, Θ_{cd}. decreased with the increasing thickness of the joints of 5mm to 6mm. decresed were about 16.31% and 14.95%, respectively.

Table.6. evaluates the joint ductility index Ψj and the rotation values at maximum load and the corresponding ductility levels index Ψj.max load. The ductility of joints and the rotation values at the maximum load and corresponding ductility levels of joints decreased about 145.81% and 148.72%, with the increasing thickness of angles, respectively. Also, Table. 5. Shown Energy dissipation capacity increased by 5.353% with the increasing thickness of the joints. Two collapse modes were observed during the tests: (1) the bolt being directly overloaded by the applied forces and (2) excessive bearing stress under the nut face (Fig. 5).Table. 5. Shown the maximum deflection on the web of column. So, will be avoided of deflection by using of stiffener in the web column. also, Figs. 5. shown the collapse of models test are same as each other.

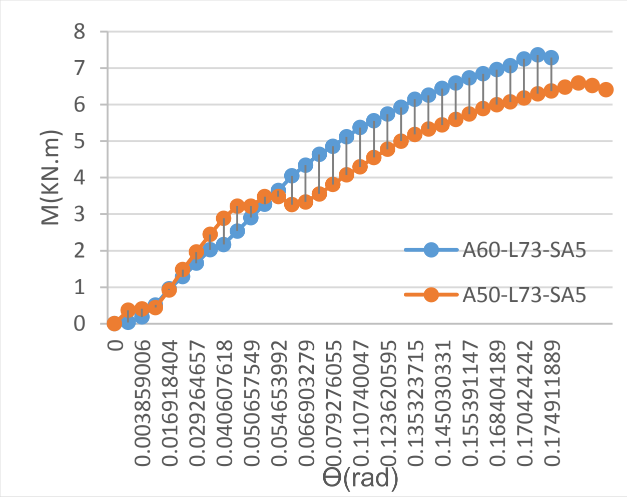

Fig.4. moment- rotaion of speciments

Table. 4. Main characteristics of the moment-rotation curves

Experiment	**A60-L73-SA5**	**A50-L73-SA5**
Resistance (KN.m)		
KR (knee-range)	3.6436-5.3738	1.4811-5.1843
$M_{j.Rd}$	4.8582	3.8141
$M_{j.\ max}$	7.2505	6.5914
$M_{\Theta Cd}$	7.1768	6.4063
Stiffness (KN m/rad)		
$S_{j.ini}$	0.89156	0.88615
$S_{j.p\text{–}l}$	0.4304	0.3708
$S_{j.ini}/S_{j.p\text{–}l}$	2.0716	2.3898
Rotation (rad)		
$\Theta_{M.Rd}$	0.1011	0.0473
$\Theta_{Min.K.R}$	0.0547	0.0100
$\Theta_{Msup.k.R}$	0.1573	0.1849
$\Theta_{Mj.\ max}$	0.1704	0.1982
Θ_{Cd}	0.1739	0.1999

Table. 5. Experimental evaluation of the joint ductility indices Ψj and Ψj.max load and maximum deflection on the web of column

Experiment	**Ψj**	**Ψj.max load**	**Energy Dissipated (kN. m.rad)**	**maximum deflection on the web of column(mm)**
A60-L73-SA5	1.720	1.685	0.770692	23
A50-L73-SA5	4.228	4.191	0.72943	19

Fig. 5. deflection on web of column and collapse models

5. Conclusion

The aim of this study was to analyze the influence stiffeners and thickness of top and seat angle joints on the behavior of connections and to provide necessary data for improve of the EN1993-1-8.The main conclusions that can be drawn from the test program were:

- The maximum bending moment, $M_{j.max}$, The plastic flexural resistance, $M_{j.Rd}$ and The bending moment capacity, $M_{\Theta.Cd}$ increased with the increasing thickness of joints.
- the initial stiffness ($S_{j.ini}$) and the post-limit stiffness ($S_{j.p\text{–}l}$) increased with the increasing thickness of the joints.
- The plastic flexural resistance rotation, $\Theta_{M\cdot Rd}$, increased with the increasing thickness of the joints.
- The maximum rotation, $\Theta_{M\cdot j.max}$ and The rotation capacity, Θ_{cd}. decreased with the increasing thickness of the joints.
- The ductility of joints and the rotation values at the maximum load and corresponding ductility levels of joints

decreased with the increasing thickness of angles

- The energy dissipation capacity increased with the increasing thickness of the joints.
- The observed maximum deflection on the web of the column was prevented by using stiffeners.

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