Experimental Research on Hysteretic Behavior of top-seat and web Angles Connections

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Abstract: -In the current practice of analysis and design of steel-frame building structure, the actual behaviour of beam-column connection is generally simplified to the two idealized extremes of either fully regid behaviour or ideally pinned behaviour. However, most connections used in current practice actually exhibit semi-rigid deformation behaviour that can contribute substantially to overall displacements of the structure and to the distribution of member forces. So it is very necessary that studying the behavior of these semi-rigid connections under cyclic reversal loading. Three full-scale specimens of angles steel using H-section members had been conducted. The specimens were subjected to cyclic reversal loading simulating earthquake effects on a steel moment-resisting force. The objective of the work is to determine the behavior of these connections under cyclic reversal loading well into the inelastic range and to ascertain the effect of design parameters such as column flange stiffener, pre-tension of bolts and the angles flange thickness on the overall behavior. Observations were made concerning the response of the connections and its elements in terms of strength, stiffness and energy dissipation. Information on the design of these connections is presented. The hysteretic behavior of angles beam-column connections under cyclic loading is presented in this paper. Rotational stiffness, the carrying capacity and ductility of top-seat and web angles connections are analyzed. It is concluded that angles connections can possess the relative high stiffness, strength and excellent ductility as moment-resisting components in the seismic design of frames. Most of the input energy was dissipated in the flange of angles while the column participated a little in the energy dissipation process in the test.

Key words: semi-rigid steel joint, hysteresis cycles, top-seat and web angles, energy dissipation, rotational stiffness, moment-resisting force.

1 Introduction

Beam-to-column connections are integral element of a steel frame, and their behavior affects its overall performance under loading. Vulnerability of welded moment connections in steel moment-resisting frames subject to severe cyclic loading was demonstrated during the 1994 Northridge Earthquake. Since then, a lot of connections have been proposed for the retrofit and the new design of steel moment frames in high seismicity areas. Among the proposed connections are those with high strength bolts[1][2]. Top-seat and web angles connections is regarded as one of the most typical semi-rigid connections. This connection type offers several advantages such as low cost, simple and convenient erection procedures, and good quality control since field-welding in adverse environment is undesirable in the best of connections.

However, from an analysis and design point of view, sufficient in formation about the distribution of stresses and forces in top-seat and web angles connection is very lacking. The state of stress in such a connection depends not only on the bolt's arrangement, the numbers of line of bolts, but also on the relative deformation of the connecting elements, such as top-seat angles and web angles. Tests conducted on such top-seat and web angles connection configurations under monotonic loading have revealed that this type of connection can indeed provide reasonable strength, stiffness and adequate ductility. However, there seems to be a lack of knowledge about the response of such connections to cyclic loading. To obtain the data about the response of top-seat and web angles connection under cyclic loading, this study will be conducted. Special attention is paid to the behavior of the individual components comprising the connection and to their effect on the response. The important factors that influence the behavior of the connection, such as angle thickness, bolts' pre-tension forces, column flange thickness and column flange stiffeners, are examined. Recommendations for designing the connection's components to achieve good performance during severe earthquakes are provided. The performance of the connections under conditions of cyclic loading in terms of stiffness, ductility, strength and energy dissipation, are investigated. It is planned to assess the following:

(1) The behavior of column flange stiffeners;

(2) The behavior of top-seat angles and web angles connections;

(3)The failure models of top-seat and web angles connections;

(4) The energy dissipation systems and capability of top-seat and web angles connections.

2 Experiment Program

2.1 specimens design

In the design of moment-resisting frames under severe lateral loads, it is reasonable to assume that the points of inflection are located at the mid-span of the beams and the mid-height of the columns. A simple cantilever type beam-column connection, such as the one shown in Fig.1, was chosen as the specimen for this study. The cantilever length represents approximately one-half the length of typical beams in a moment-resisting frame. For simplicity of testing, no attempts were made to simulate axial force in the column. Attention was mainly concentrated on the study of the behavior of the connection itself.

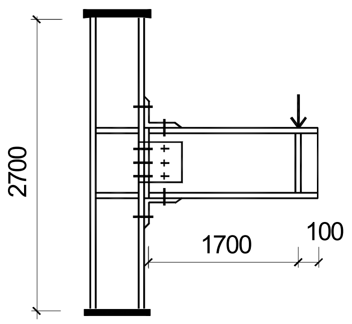


Fig:1 Typical top-seat and web angles connection

The material used for three test specimens including beams, columns, continuity flange stiffeners, top-seat and web angles was in accordance with Q235 steel. Beams and columns were manufactured with rolling H steel. The sizes of beam and column were H300×200×8×12 and H200×200×12×12 respectively. The high tensile bolts used are specified as 20mm diameter, grade 10.9. They were full preloaded according to the China Code. The contacting surfaces between connections components were treated according to China steel design code (GB50017). An average value of the cyclic friction coefficients measured from the cyclic tested was about 0.40.

The main geometrical dimensions are indicated in the table 1.

Table1

Details of the test connection

Specimen	Top-seat angles Size(mm)	Column flange stiffener
JD1	110×12×12	yes
JD2	140×16×14	yes
JD3	140×16×14	yes

2.2 testing apparatus and the measurement setup

All specimens attached through the connection to be test to a “rigid” counter-beam, as shown in Fig.2. The loads are applied to the free end of the specimen by means of a device that transfers horizontal forces only. Testing conditions hence approximate quite closely the case of beam-column joints with negligible column deformability.

Fig2: general view of test arrangement

For monitoring the actuator load, load transducers was loaded in the front of jack. The load transducer was calibrated after each test on a multipurpose test machine. For measuring the connections rotation, electron centigrade instrument was used. The curves of connections rotation and the load were drawn by X-Y function enregistering instrument. Strain gauges were used to monitor the onset of beam flange local bucking and to determine initial yielding of the beams.

All date from strain gauges and transducers were scanned by a multi-channel DH3815 scanner system. The readings were recorded using a microcomputer system.

2.3 loading sequence

To simulate seismic forces the test specimens were subject to a quasi-static cyclic loading. The loading history may be considered one of the most important factors affecting the significant of cyclic tests.

Before reaching the yield point, an individual specimen was first subjected to two load cycles of 20% the expected yield value, then the load was increased 20% the expected yield value and the two load cycles was also adopted. The load was then increased until the initial beam yielding was recorded by the strain gauges or the apparent turning point was turned out in the curve of connection M-φ. Then for subsequent loading cycles, the rotation of connection was incrementally increased by the yield rotation up to the failure of connections. The models of the failure of connections included top and seat angles fracturing, local flections of column flange and the looseness of bolts. In reaching either of failure modes, the test would be terminated. A typical loading routine is presented in Fig.3.

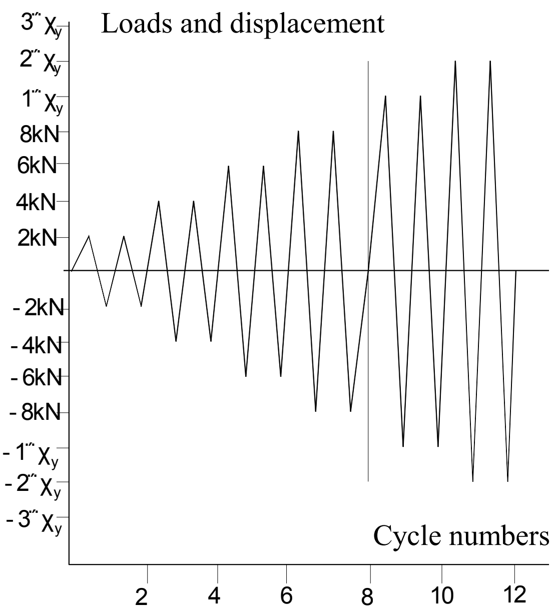
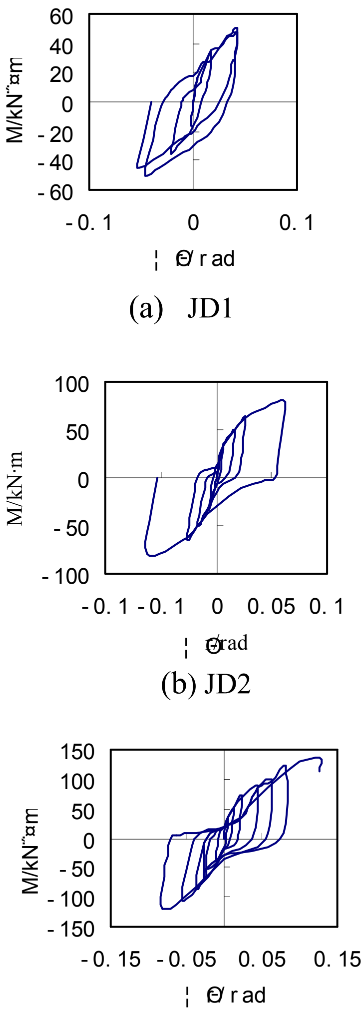


Fig3: actual loading routine of specimens

3 Experimental Results and Disucssion

The connection's rotation was the result of top-seat and web angles and column flange deformation and bolt extension. No panel zone deformation was observed, since the column flange stiffeners were designed. Fig.4 showed the moment-rotation hysteretic curves for connection JD1, JD2 and JD3 respectively. As can be observed, all the connections showed stable hysteretic behavior up to the fracture of the connections. In the latter cases, significant degradation occurred in the connection strength after severe distortion and/or crack initiation developed. During latter cycles of the test severe distortion to the column flange was observed. It was evident that column distress could have been avoided with the use of column stiffeners. Failure of the specimen was attributed to severe distortion of the flange of top-seat angles.



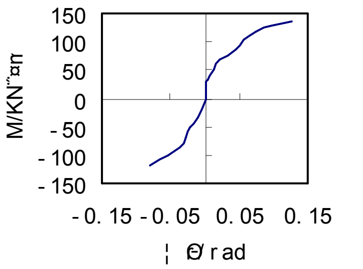
(a) JD1

(b) JD2

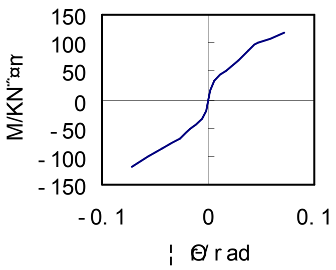
(c) JD3

Fig4:hysteresis curves for specimens

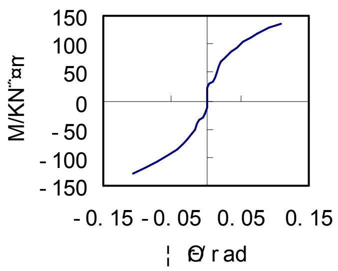
Fig.5 were the envelop of the cyclic response of JD1, JD2 and JD3 respectively. The relations of moment and rotation were outlined. The line relations of moment and rotation were showed in the initial phase and the phase was very short. With increasing the load, the non-line relations of moment and rotation became very apparent. The fluctuating phenomenon of the relations was revealed. The main reason was that the bolts lost their pretension forces significantly in the later stage of loading.



□a□JD1



□b□JD2



□c□JD3

Fig5: Envelope of the cyclic response of specimens

In seismic design, cyclic energy dissipation is of great important, since it expresses the ability of the members and their connections to dissipate earthquake input energy. Generally, sufficient energy dissipation without substantial loss of strength and stiffness constitutes desirable behavior for beam-column subassemblages[3][4][5]. It was confirmed that most of the energy was dissipated in the flange of top-seat angles while the column and web angles participated a little in the energy dissipation process in this test.

The main parameters that describe a connection's behavior are (1) the connection yield moment, M_y, (2) the initial stiffness of the connection, R_0, (3) the connection strength, M_u and (4) the connection rotation capacity (i.e.ductility), θ_u. Table 2 shows these parameters for some of the tested specimens. As expected, the initial stiffness of a connection increases as the top-seat angles flange thicknesses increase. This is evident when connections JD1 and JD2 are compared where the column flange thickness differ, while the stiffness of JD2 is greater than that of JD1 because of the former's greater top and seat angles thickness.

Table2

Joint capacity and ductility

Specimen	R_0	M_u	θ_u	μ_φ
JD1	0.71	124.67	0.0788	5.5
JD2	1.03	136.01	0.1097	5.0
	1.16	136.51	0.1265	5.6

R_0 the initial stiffness of connections, $10^4 KN\cdot mrad^{-1}$

M_u maximum moment of connections, $KN{\cdot}m$

θ_u maximum rotation of connections, *rad*

μ_φ the ductility coefficient of connections $\mu_\varphi=\theta_u/\theta_y$

4 Conclusions

Based on the experiment work, the following preliminary conclusions and design code implications can be made about beam-column top-seat angles connections.

(1) All two tested connections showed degradation in stiffness with load cycles due to diminished bolt pre-tension forces and inelastic deformations. Pre-tension forces in all the bolts showed degradation with repeated load cycle. The drop in the pre-tension force continues with increasing the load. To ensure that the bolts do not fail and do not lose their pre-tension forces significantly even during moderate earthquake excitation, it is suggested that the bolts be designed to sustain a force corresponding to beam moment of 1.3Mp.

(2) In all the tests, the connections were not able to sustain moment higher than the beam's nominal plastic moment capacity. The main reason was that the stiffness of top-seat angles was too weak.

(3) If the stiffeners of the column flange were designed, the most possible failure mode is the fracture of top or seat angles.

(4) because of web angles, these connection's yield moment were higher than top-seat angles connection's yield moment, the main reason was that the web angles restrict the deformation of connections.

(5) Most of the energy was dissipated in the flange of top and seat angles while the column participated a little in the energy dissipation process.

(6) When properly designed and detailed, the top-seat and web angles connection, which can provide reasonable strength, stiffness and adequate ductility, can be considered suitable for moment-resisting frames in areas of high seismicity.

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