Experimental research and finite element analysis on Behavior of Steel Frame with Semi-rigid Connections

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Abstract: - Steel frame structure with semi-rigid connections are becoming more and more popular due to their many advantages such as the better satisfaction with the flexible architectural design, low inclusive cost and environmental protect as well. So it is very necessary that studying the behavior of those steel frame under cyclic reversal loading.

The expreiment research on the lateral restistance system of steel frame structure has been completed. Two one-second scale, one-bay, two-story steel frames with semi-rigid connections under cyclic reversal loading. The seismic behavior of the steel frames with semi-rigid connections, including the failure pattern, occurrence order of plastic hinge, hysteretic property and energy dissipation, etc, was investigated in this paper. Some conclusions were obtained that by employing top –seat and two web angles connections, the higher distortion occurred in the frames, and the internal force distributing of beams and columns was changed, and the ductility and the absorbs seismic energy capability of steel frames can be improved effectively.

Key words: semi-rigid connection, cyclic reversal loading, hysteretic property, finite element analysis, steel frame

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 and 1995 Kobe earthquake[1][2]. Since then, a lot of connections have been proposed for the retrofit and the new design of steel moment frames in high seismic areas. One of the proposed connections is top –seat and two web angles connection, many studies show that this connection possess the relative high stiffness, strength and excellent ductility as moment-resisting components in the seismic design of frames[3][4][5].

This paper presents a experiment for steel frames with top-seat and two web angles connections. The aims is studying the failure pattern, occurrence order of plastic hinge, hysteretic property and energy dissipationm of steel frames. In this paper, in terms of the experimental of steel frame structure, the relations of each component of steel frame structure system are discussed. Based on above experimental achievements, the nonlinear finite element computations of one model is carried out here. The load-deflection relation curves, the stress contours under yield load and ultimate load of this model are obtained. It demonstrates that the computing results coincide with the experimental over favorably.

The experimental and finite element computational research shows that this steel frame with top-seat and two web angle connection can improve the ductility of steel frame and possess significant extent lateral resistant rigidity.

2 Experiment Program

2.1 specimens design

Two one-second scale, one-bay, two-story steel frame with semi-rigid connections specimens shown in Fig 1. The material used for two test specimens including beams, columns, continuity flange stiffeners, was in accordance with Q235 steel. Beams and columns were manufactured with rolling H steel. The sizes of beam and column were H200×100×6×8 and H150×150×7×10 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

Components	Section aera □cm^2□	Section Inertia	
		I_x	I_y
column	40.55	1660	564
Beam	25.57	1880	134

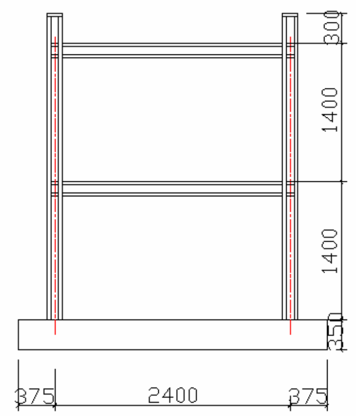
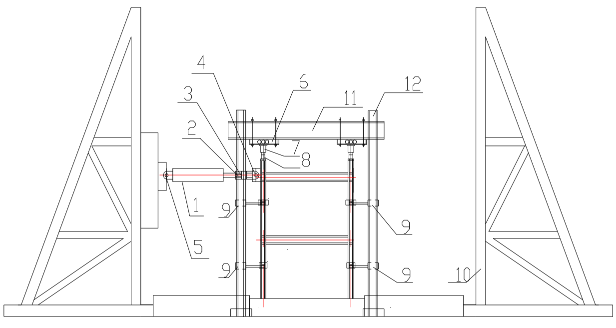


Fig 1 steel frame specimens



1,7 jack 2,4,5 connecting fitting 3,8 transducer
6 axletree bearing loading equipment
9 out-of-plane bracing 10,11,12 Counterforce stand

Fig 2 experimental loading equipment

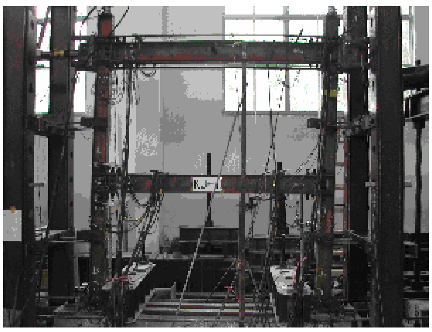


Fig 3 the actual loading equipment

2.2 loading

Fig 2 and Fig 3 show the experimental equipment by which the reciproating horizontal load is applied to the axial line of the beam in upper story of frame. In experiment, the 80KN vertical loads on steel frame are constant throughout the whole loading. The reciprocating horizontal load is applied in several grades. 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 30KN 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.4.

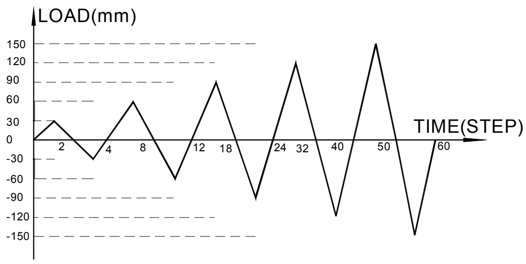
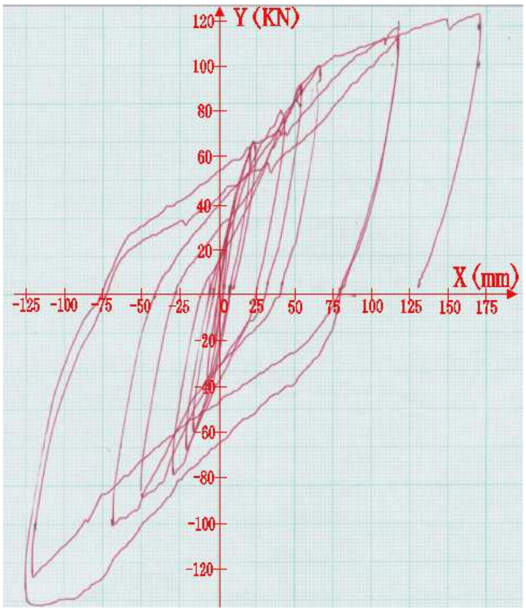


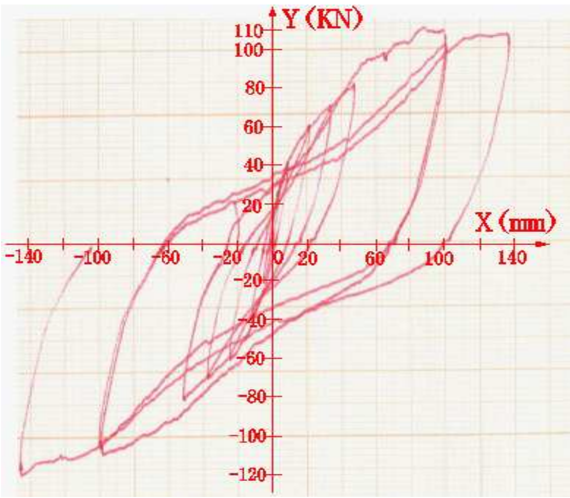
Fig4: actual loading routine of specimens

3 Expereimental results and discussion

The load-displacement hysteresis loops of KJ1 and KJ2 are shown as Fig 5. both of hysteresis loops are plump and behave shuttle shape, which demonstrates steel frame structure possesses good property of energy consumption and favorable ductility. Table 2 shows these parameters for some of the tested specimens.



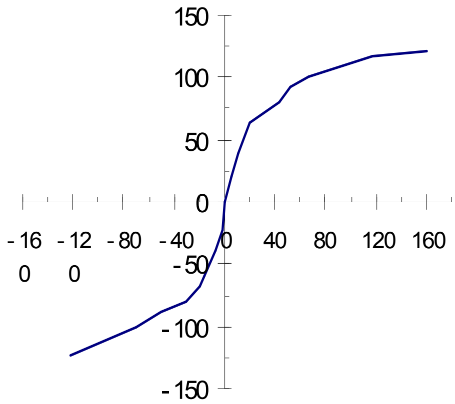
□a□KJ1



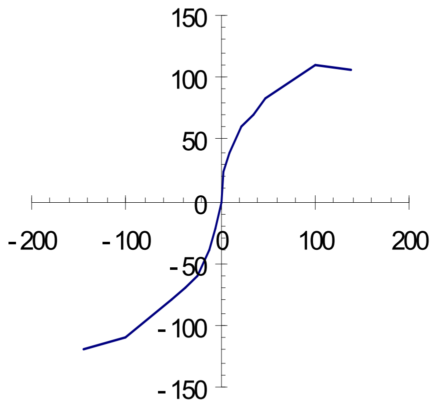
□b□KJ2

Fig 5 load-displacement hysteresis loops of KJ1 and KJ2

bolts lost their pretension forces significantly in the later stage of loading.



□a□KJ1



□b□KJ2

Fig 6 Envelope of the cyclic response of specimens

Table 2 some experimental results

Specimen	Yield load (kN)	Yield displacement (mm)	maximum load (kN)	Maximum load (mm)	the ductility coefficient	the initial stiffness (kN/mm)
KJ1	80/-80	43/-30	122/-135	170/-125	3.95/4.16	6.94
KJ2	70/-70	34/-38	110/-120	110/-146	3.2/3.84	5.0

Fig.6 was the envelop of the cyclic response of KJ1 and KJ2 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 noalinear relations of moment and rotation became very apparent. The fluctuating phenomenon of the relations was revealed. The main reason was that the

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]. 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.

4 Finite element analysis

4.1 establishment of finite element model and matrrial paramenters

The mode of KJ1 is established and analyzed by ANSYS. The finite element model of KJ1 is showed as figure 10 in which steel frame is divided into beam119 elements.

The stress-strain relation curve of steel is decided by actural testing result of matetials. Other material parameters are listed as following: the elastic modulus of steel is 1.9793×105Mpa, and the Poisson's ratio of steel is 0.27.

4.2 computation results

Through the finite element computation, the load-displacement hysteresis loops, the curve of load-angle relation of top-seat and two web angles connections, the skeleton curve of load-displacement relation, the curve of degeneration of rigidity, the equivalent stress contours under yield and ultimate loads and other results of KJ1 are obtained here shown in Fig 7-10.

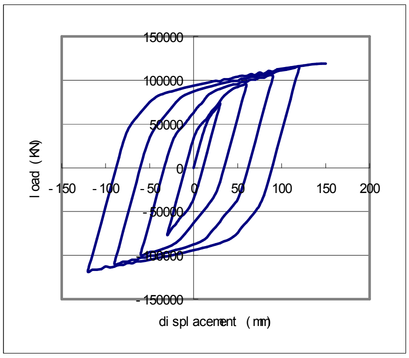


Fig 7 load-displacement hysteresis loops

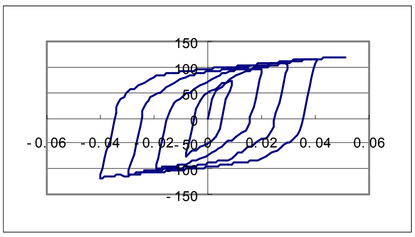


Fig 8 load-angle hysteresis loops

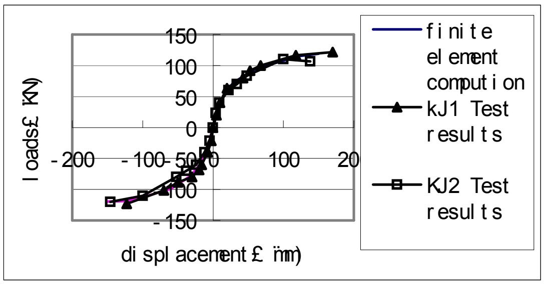


Fig 9 comparison of envelope between finite element and test

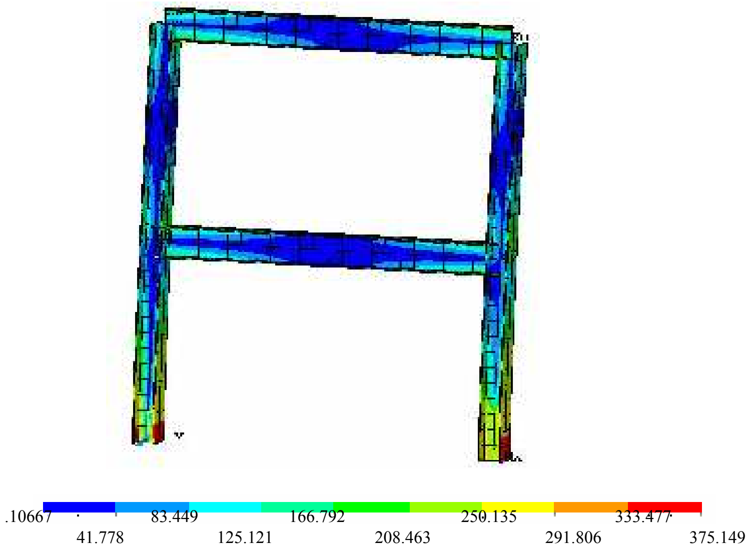


Fig 10 the last deformation figure of steel frame

Fig 7 and Fig 8 demonstrat that the computation results by finite element method accord with the experimental ones well. Because of the limitation of experimental loading equipment, the plastic hinge does not form in frame, so that latter phase of load-displacement curve connot be got, but the front part coincides with the computation curve very well. Fig 8 also indicates that steel frame with semi-rigid connections can possess the relative high stiffness, strength and excellent ductility, because of the better deformation ability of top-seat and two web angles connections.

Fig 9 shows that envelope curves between finite element computation and test are very similar, so the finite element computation results are reliable.

Figure 10 shows the deformation and equivalent stresss contours of frame when horizontal load is increased 115KN. Some results show that the maxium horizontal displacement of beam in upper story of frame is 172.327mm, the maxium stress is 375.149 KN/m^2. With the increase of load, the plastic area extend to bottom of column, and form a plastic hinge in bottom of column. At last when a plastic hinge is formed in every bottom of column in frame, the frame becomes a mechanism so the computation is finished, as showed in Fig11 and Fig 12. This demonstrat that the computation results by finite element method accord with the experimental ones well.

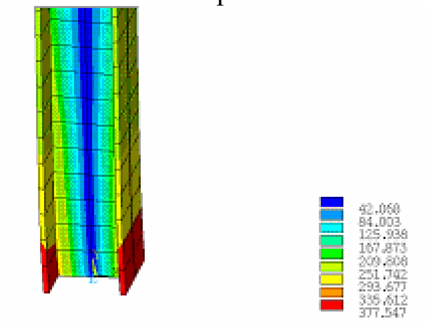


Fig.11 equivalent stress contours of left column botton under ultimate load

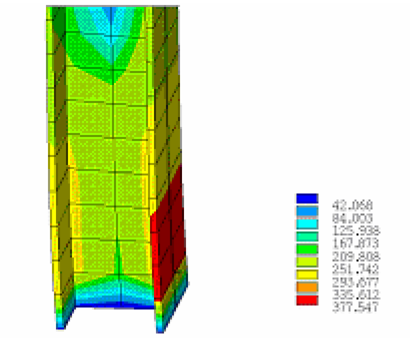


Fig.12 equivalent stress contours of right column botton under ultimate load

5 Conclusions

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 experimental research and finite element analysis on steel frame structure with semi-rigid connections show that a significant extent lateral resistant rigidity, ability of energy consumption and ductility of this structural system are better than common steel rigid frame structural system.

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