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Seismic Performance Evaluation of Weak Axis Connections Steel Moment Frames

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Abstract—**In this paper, weak axis connections with steel moment frames were evaluated seismic performance. Weak axis connections with proposed prequalified connections in US and weak axis column-tree type connections were tested. As a results, weak axis prequalified connections were evaluated lower ductile than weak axis column-tree type. Prequalified connections satisfied ordinary moment frame, while column-tree type connections met the special moment frame condition.**

***Keywords* — steel moment frame, weak axis connections, cyclic loadong, story drift ratio**

I. Introduction

Moment resisting frames have been considered one of the best seismic load resisting frames. However , brittle fractures occurred at the beam-to-column connections in the steel moment resisting frames at the time of 1994 Northridge earthquake. So various researches on seismic performance of beam-to-column connections have been conducted. As a results, prequalified connections were suggested through many researchers. For example, the Federal Emergency Management Agency (FEMA) suggested six typically prequalified beam-to-column connections.

Unlike the United State and Europe, weak axis connections have frequently been used to steel moment frames in Korea. The biggest difference is when weak axis connections were needed, the moment connections were used. The weak axis connections with moment joint are disadvantageous because deflection occurs the largest when wide shape steels were used. However, there have been no studies about weak axis connections in Korea.

The column –tree connection is one type of beam-to-column connection frequently used in moment resisting frames in Korea and Japan. In column-tree connection, short stub beams are welded in the shop, and then the middle portion of the beams are bolted to the stub beam in the field. Like the preceding, column-tree type connections were also used weak axis connection.

In this paper, prequalified connections proposed by FEMA and column-tree type with weak axis moment connections were evaluated seismic performance. Of the prequalified connections, welded free flange type, welded flange plate, bolted flange plate type, and double split tee type were selected, and compared with pre-Northridge connection details. And, column-tree type with reduced beam section and inducing yield at the flange plate type were fabricated, and compared with typical column-tree type connections. The cyclic testing of ten full-scale weak axis connection specimens were tested.

II. Experimental Program

A. *Design of specimens*

As mentioned earlier, group A is the weak axis prequalified connection types and pre-Northridge connections type. Prequalified connections types included weak axis welded free flange (FF) type, welded flange plate (WFP) type, bolted flange plate (BFP) type, and double split tee (DST) type. Connections details of these were followed FEMA350/351.

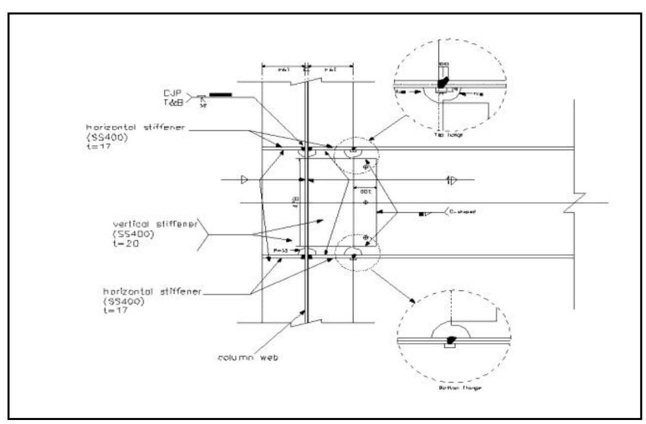

Figure 1. Detail of pre-Northridge connection.

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Group B is the weak axis column-tree type specimens. Group B is composed of two column-tree type connections with reduced beam section, those with inducing flange plates and basic column-tree type connections. Two column-tree type connection with reduced beam section were expected to form plastic hinge at the RBS. Two specimens with inducing flange plate were predicted to occur plastic hinge at the stub beam over yielding flange plate. The basic weak axis column-tree type connections with a moment resisting frame that are generally used in Korea were investigated for comparison of four specimens. The size and details of the basic column-tree specimen was shown in Fig. 2, Table 1 summarizes the properties of each specimens.

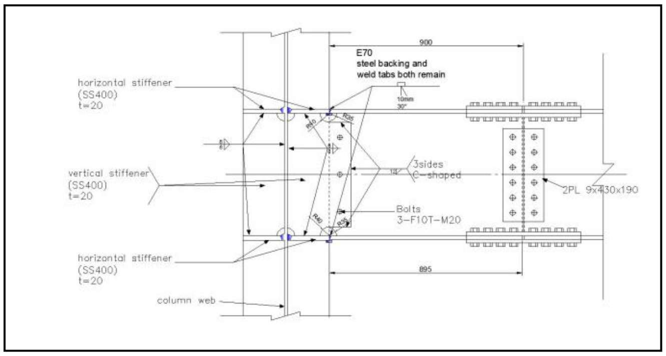

Figure 2. Detail of weak axis basic column-tree type.

TABLE I. SUMMARIZES OF EACH SPCIMENS

Group	Characteristic	
	Specimen	*Type*
A	PN-W	Weak axis pre-Northridge connection
	FF-W	Weak axis welded free flange connection
	WFP-W	Weak axis welded flange plate connection
	BFP-W	Weak axis bolted flange plate connection
	DST-W	Weak axis double split tee connection
B	CT-BASE	Weak axis basic column-tree connection
	CT-RBS	Weak axis column-tree with RBS
	CT-DRBS	Weak axis column-tree with deformed RBS
	CTY600	Weak axis column-tree with inducing plastic hinge 600mm from the column face
	CTY900	Weak axis column-tree with inducing plastic hinge 900mm from the column face

B. *Test Specimens*

The beam and column of each specimen were made with SS400 steel (similar to that of ASTM A36) (nominal yield strength = 235Mpa, nominal tensile strength 400Mpa) and SM490 steel (nominal yield strength = 325MPa, nominal tensile strength 4o0MPa).

The test set-up is shown in Fig. 3. The column of each specimen was fixed to the strong floor, and the free end of the beam was connected to the 500kN actuator . Also, guide frames were installed to prevent out-of-plane instability and twisting of the beam.

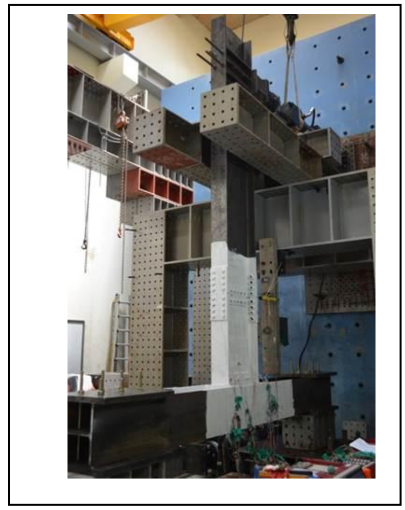

Figure 3. Real veiw of test set-up.

The specimens were tested by application of a prescribed quasi-static cyclic story drift history based on the loading protocol defined in the AISC Seismic Provision. Two cycles of 5% story drift ratio were added to the existing loading protocol. The loading protocol is shown in Fig. 4.

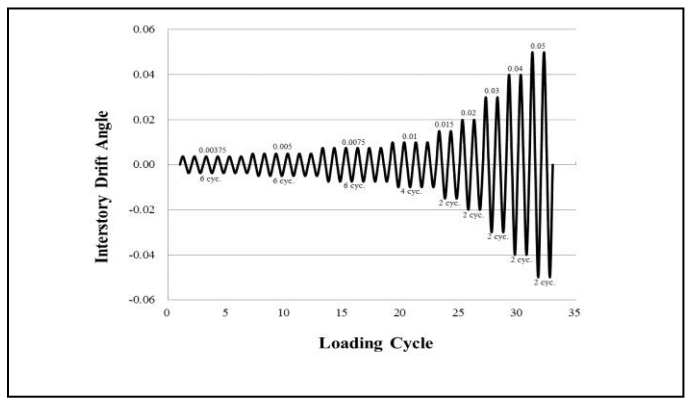

Figure 4. Loading protocol

Linear varying displacement transducers (LVDTs) were installed on the specimens to measure their displacement. Also, strain gauges were attached to the beam and column. After attachment of the strain gauges, the specimens were painted with whitewash to reveal yielding and deflection during test.

III. Experimental Results

The tests were conducted until 5% story drift ratio because of the limit of the actuator stroke. Group A was mostly fractured beam-to-column connection before 5% story drift ratio, while Group B was reached 5% story drift ration without brittle fracture. Typically, the normalized moment versus the story drift ration relationship of PN-W specimen and CT-

BASE specimen were shown in Fig. 5 and Fig. 6, respectively. Also, a summary of the response of each specimen is given in Table. 2.

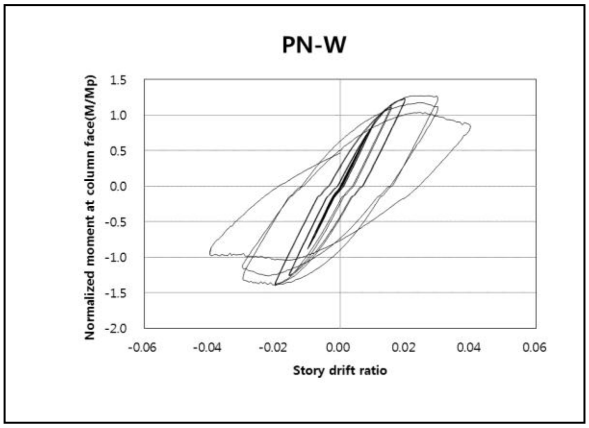

Figure 5. Hysteretic curve of story drift ratio of PN-W specimen.

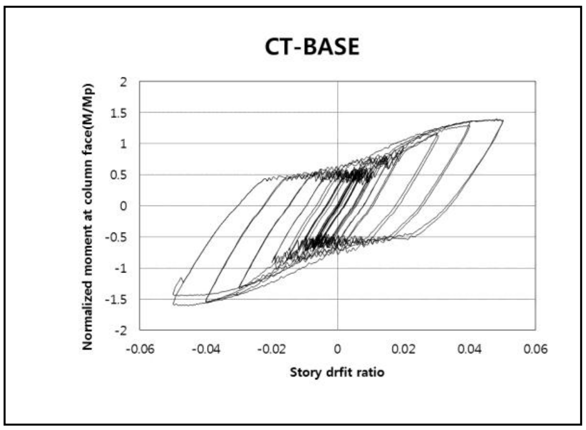

Figure 6. Hysteretic curve of story drift ratio of CT-BASE specimen.

TABLE II. SUMMARIZES OF TEST RESULTS

Group	*Specimen*	*P(kN)*	*M_f/M_p*	*Story drift ratio*
A	PN-W	235	1.27	0.0398
	FF-W	255	1.38	0.0398
	WFP-W	285	1.58	0.0388
	BFP-W	255	1.38	0.0399
	DST-W	239	1.33	0.0487
B	CT-BASE	263	1.40	0.0501
	CT-RBS	220	1.67	0.0499
	CT-DRBS	199	1.51	0.0499
	CTY600	265	1.41	0.0499
	CTY900	247	1.31	0.0501

A. ***Comparison with Story Drift Capacity***

Fig. 7 and Fig. 8 show the story drift ratio of group A and group B, respectively. As shown in Fig. 7, the normalized moment of WFP-W specimen was the highest in the group A. However, WFP-W specimen was occurred brittle fracture at 3% story drift ratio. The beam maximum moment of most specimens in the group A reached 1.0 times higher than the beam plastic moment, but story drift ratio of those did not reach 4% story drift ratio. Therefore, all specimens of group A was satisfied ordinary moment frame (OMF) conditions.

As shown in Fig. 8, all specimens of group B reached 1.3 times higher than the beam plastic moment, and story drift ratio of those reached 5% story drift ratio without brittle fracture. All specimens of group B were detected the bolt slip after about 1% story drift ratio. As shown in Fig. 6, measured forces steadily maintained without increasing during bolt slip. Later, it is considered that additional researches were needed to investigate the bolt slip under lateral force.

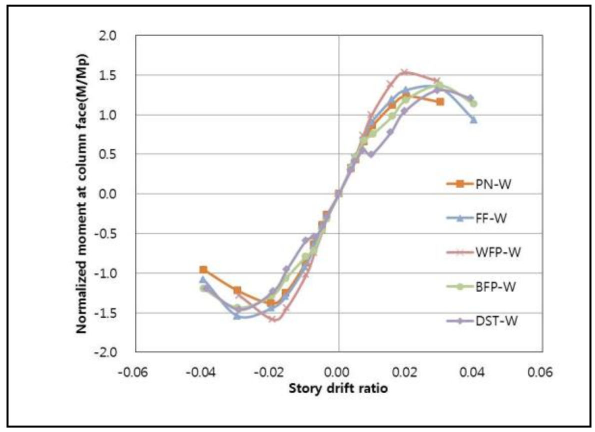

Figure 7. Comparison with story drift ratio of group A.

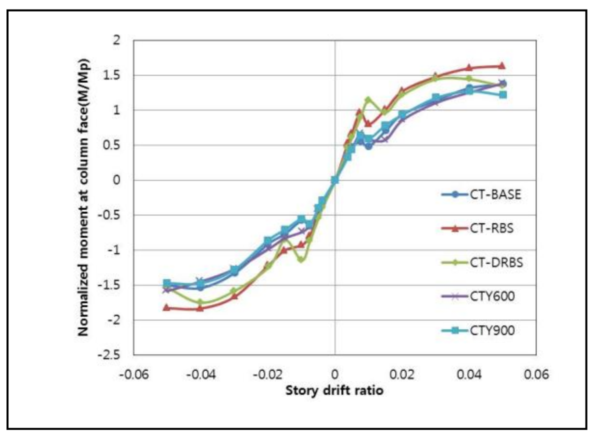

Figure 8. Comparison with story drift ratio of group B.

B. ***Energy Dissipation Capacity***

The energy dissipation capacity is an important index to evaluate the seismic performance of beam-to-column moment connections in steel moment frames, and it could be reflected through the area of load versus displacement curve. A summary of the accumulated energy dissipation capacity of each specimens were shown in Fig. 9 and Fig. 10, respectively. As shown in Fig. 9, the energy dissipation capacity of FF-W specimen was the best among the group A. However, the FF-W specimen dissipated the lower amount energy than the lowest specimen among group B. This indicated that the bolt slip helps the energy dissipation capacity.

Among the group B, CT-RBS specimen dissipated the largest amount of energy. The energy dissipation capacity of other specimens was similar. The energy dissipation capacity was the largest when the plastic hinge was clearly formed.

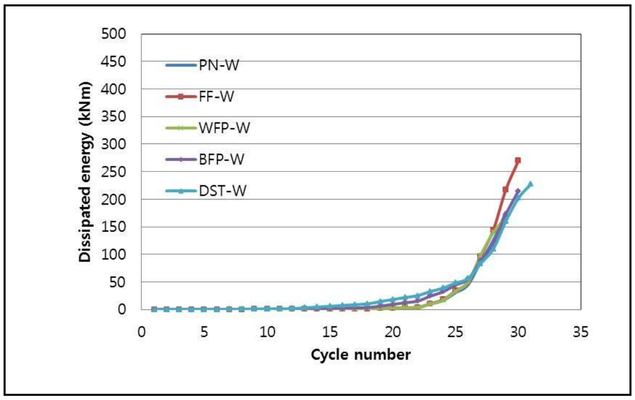

Figure 9. Comparison of accumulated energy dissipation of group A.

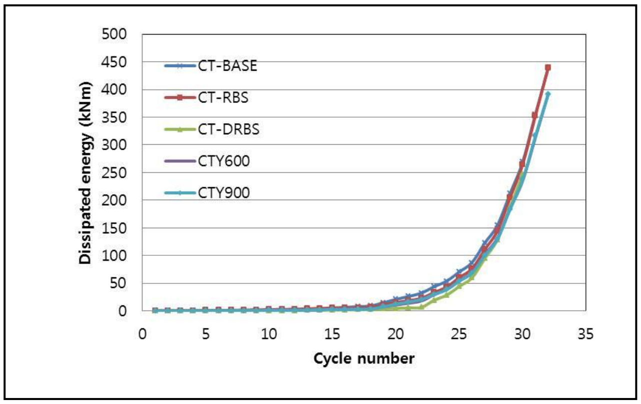

Figure 10. Comparison of accumulated energy dissipation of group B.

IV. Conclusion

Ten full-scale weak axis column-tree connection specimens were tested to evaluate their seismic performance. Group A was composed of weak axis prequalified moment connection proposed by FEMA, and Group B was composed of weak axis column-tree type connection. The following conclusions can be drawn from the experimental study.

These full-scale tests demonstrated the weak axis column-tree connections have significant ductility to sustain large inelastic deformation. All specimens of group B met the qualification criteria required by the AISC Seismic Provisions (AISC 2010) for use in special moment frames (SMFs). While all specimens of group A was not satisfied SMF conditions.

All specimens group B was detected the bolt slip, and the energy dissipation capacity of group B was the higher than that of group A. This indicated that the bolt slip can be a good resource to increase the energy dissipation capacity of column-tree. However, researches to establish the relation of bolt slip and column-tree were needed.

Although all specimens of group B satisfied SMF conditions, it was considered that additional researches was needed to set up design principal on weak axis column-tree connections.

Acknowledgment

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