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A Study on Hysteretic Characteristics of Arc-Shaped Damper Osaka City University

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Synopsis

Since significant damages during 1995 Kobe Earthquake, one of urgently needed is to retrofit frame type timber structures. In responding, the authors have proposed Arc-Shaped Dampers with mild steel and aluminum. In order to investigate seismic performance of the proposed damper, repeated loading tests were conducted focusing on hysteretic characteristics and effect of damping. Following results were obtained: 1) In both material dampers, maximum load in compression is smaller than that in tension and during 1/15 drift angle, rapid load increase is observed in tension, 2) Mild steel damper has high damping effect in larger drift angle, but not in smaller range, and 3) Aluminum damper provides higher damping in each drift angle than mild steel damper.

KEYWORDS: Arc-Shaped Damper, Frame type timber structure, beam column joint, Flexural plastic deformation

1. Introduction

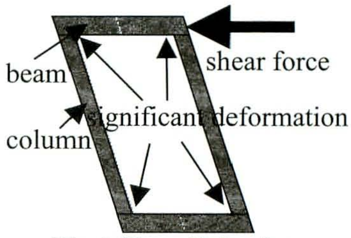

Fig.1 Shear Behavior

Since significant damages during 1995 Kobe Earthquake, upgrading of timber structures has been urgent issue. Horizontal drift dominates in the frame type timber structure under seismic action as shown in Fig.1 and as the result, beam column has significant deformation in to failure of the structure. It is effective measure to add energy dissipated damper inside of beam column corner section with preventing not only significant damage of principal element but collapse of the structure as well.[2)] In these backgrounds, we have developed simple and economical arc-shaped damper. The proposed damper assures not only buckling prevention but also stable energy dissipation with flexural plastic deformation. This report describes experimental and analytical investigation of two types of damper, produced with mild steel and aluminum, under cyclic displacement.

2. Hysteretic Characteristic of Mild Steel Damper

2.1 Experimental Test Procedure

As shown in Fig.2, damping device consists of double arc shaped mild steel elements and urethane in filled

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for composite action, where internal element has different curvature at welded section. Two specimens, i.e. with and without infill were tested under repeated displacement.

Fig.3 shows testing set up where repeated load application can be provided through L shaped loading frame of which both ends are connected to testing machine with actuator installed. Provided drift angles defined by δ and L as shown in Fig.3. are 1/120(0.0083), 1/60(0.0167), 1/30(0.0333), 1/15(0.0677) and 1/10(0.1) with three cycles for each. Measurements are load, entire displacement of loading frame, longitudinal and transverse displacement of test specimen and strain of the element.

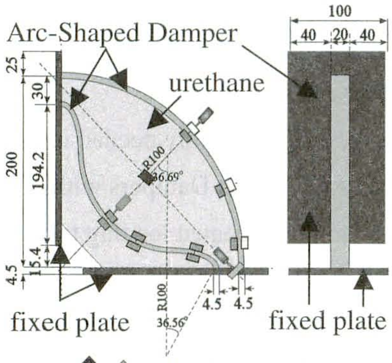


Fig.2 Specimens

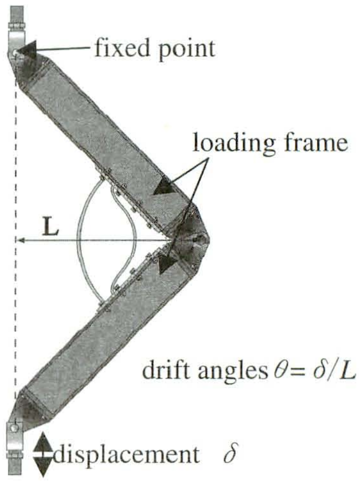
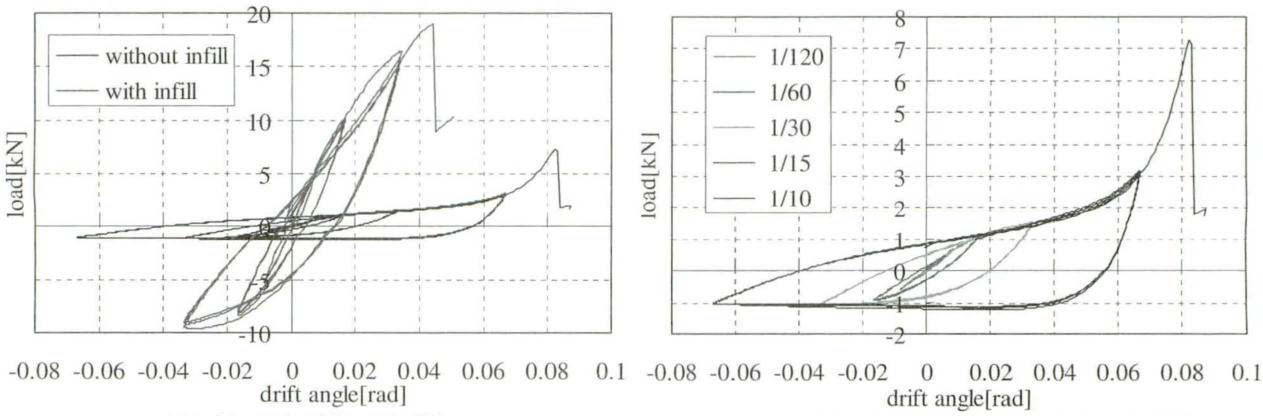


Fig.3 Loading Frame

2.2 Test Result

Fig.4 represents load-drift angle relationship, where both load and displacement is defined positive in tension. Elastic behavior for 1/120 and yield initiation for 1/60 drift angle are observed in Fig.4(b). During 1/30 drift angle, maximum load in compression is smaller than that in tension because flexural yielding section develops more with the arc shaped element externally deformed. During 1/15 drift angle, rapid load increase is observed in tension because elastic axial force dominates with the element linearly elongated. Fig.4(a) provides larger stiffness in the case with infill. Rupture occurred at the welded section of internal element during the first loading of 1/10 drift angle for no infill case and during the first loading of 1/15 that for infill case.



(a)with and without infill

(b)up to 1/15(rad) of without infill

Fig.4 Load-Drift Angle Relationship

2.3 Equivalent Damping Factor

Fig.5 represents equivalent damping factor obtained in the experiment, which provides larger value for no infill case in comparison with less for infill case in the large drift range. Plastic yielding area is widely developed in the no infill case, while less in the infill case because of deformation restricted by the infill. Equivalent damping factor at 1/15 of drift angle is less than that at 1/30 because of tensile axial force dominated in the larger displacement range.

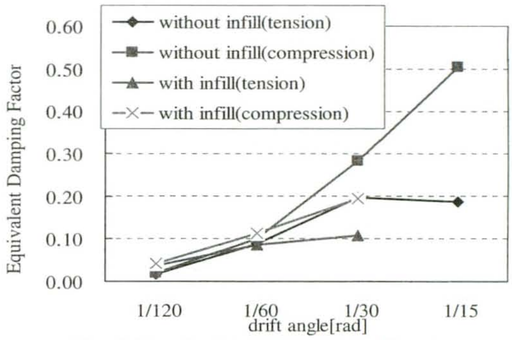


Fig.5 Equivalent Damping Factor

2.4 Analytical Procedure

For the case without infill, nonlinear analysis is conducted with the model as shown in Fig.6. As for displacement boundary condition, y and z directional displacement are restricted for node 1 and 2, y directional displacement restricted for node 3 and x directional displacement restricted for node 4. Test specimen including loading frame is modeled by assembly of beam elements, where external damper is modeled into 15 elements and internal one into 10 elements with ten layers respectively. Loading frame modeled by stiff elastic elements is eccentrically connected with the test specimen. With this model, material and geometric nonlinear FE analysis is conducted with kinematical hardening rule assumed for material constitutive law.

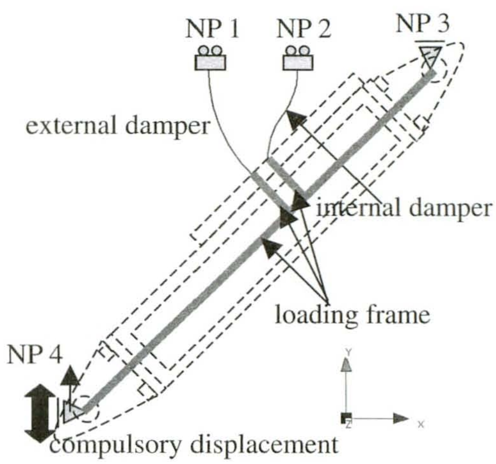


Fig.6 Analytical Model

2.5 Analytical Result

Fig.7 represents experimental and analytical comparison of load displacement relationship. Good agreement is obtained between both results. Stress distribution is illustrated in Fig.8 for the internal fiber of each damper at 1/120 and 1/15 of drift angle respectively, where red colored elements are yielded. At 1/120, only end section of external damper is yielded, while at 1/15, widely yielded.

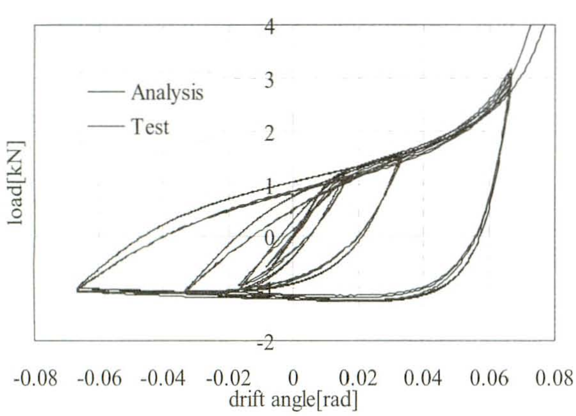


Fig.7 Comparison of Analysis and Test

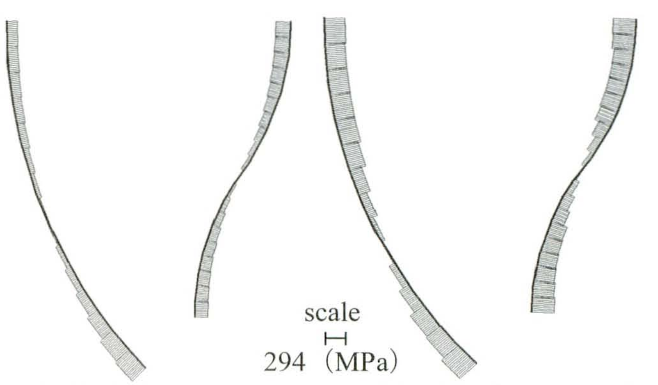


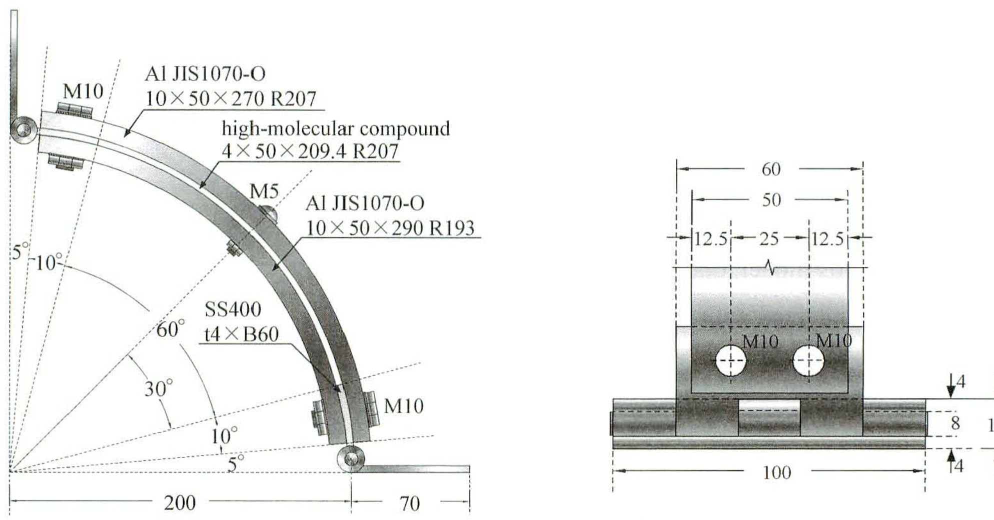
Fig.8 Stress Distribution

3. Hysteretic Characteristic of Aluminum Damper

Mild steel damper provided widely spread plastic yielding zone in the larger displacement range, however damping effect is around 10% in the smaller displacement, i.e. 1/120 and 1/60 of drift angle. Alternative proposal is aluminum damper with similar arc shape to resolve such issue.

3.1 Experimental Test Procedure

Fig.9 illustrates alternatively proposed damper in which aluminum (JIS 1070-O) is utilized for the arc section. Selection of aluminum is for reduction of yielding strength and increase of elongation capacity with 40% nominal ultimate strain. Another improvement is rotation free mild steel equipment product at damper end in place of fixed welding which assure less elongation capacity. Aluminum damper is connected with this equipment through 10mm diameter bolts and internal and external aluminum elements are expected as composite action through urethane or low repulsion rubber connected by adhesive. Role of infill is for composite action and for maintaining configuration as entire damper. Test specimens are with and without infill (two types of materials, urethane and low repulsion rubber).



(a) Arc-Shaped Damper (b) Rotation free equipment

Fig.9 Arc-Shaped Damper with Al Unit : mm

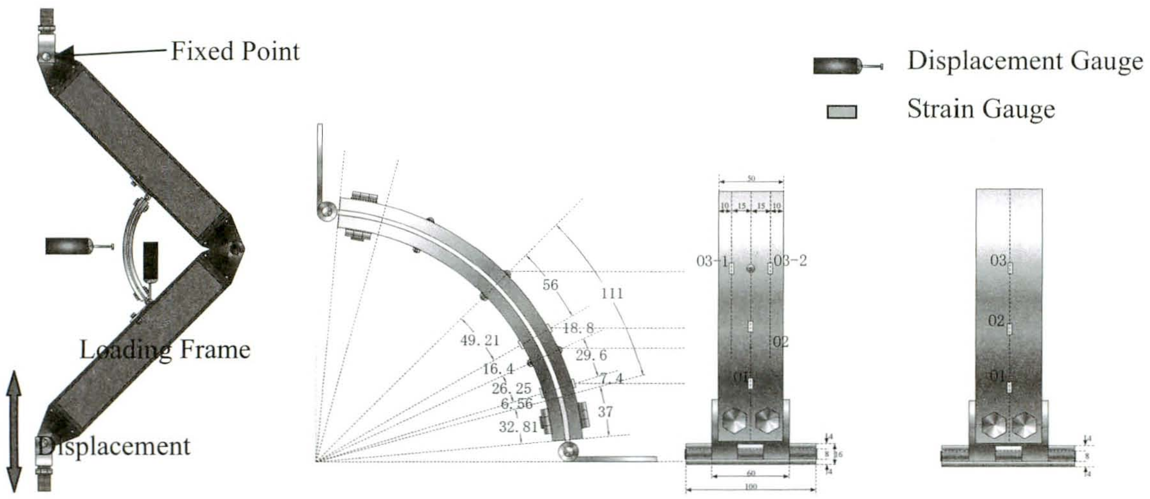
It is noticed that the low repulsion rubber of 5mm in thickness was compressed to 4mm thickness so as to similar that of urethane. Two types of adhesives are utilized for aluminum to rubber bonding, i.e. one of them is degeneration silicone (Product name is MOS7,), the other is epoxy (Product name is Quickmender). Experimental parameters are shown in Table-1.

In the displacement control loading test, drift angles provided is similar to the damper with SS400.

Measurement is shown in Fig10.

Table-1 Parameter of the Experiment

Name of Test Specimen	Infilled	Adhesive
Al-N	None	None
Al-U90-E	Urethane	Epoxy (Quickmender)
Al-LE-MOS7	Low Repulsion Rubber	Degeneration Silicone (MOS7)



(a) Measure Point of Displacement Gauge

(b) Al-U90-E, Al-LE-MOS7

(c) Al-N

Fig.10 Measurement Point Unit : mm

Fig.8 illustrates alternatively proposed damper in which aluminum (JIS 1070-O) is utilized for the arc section. Selection of aluminum is for reduction of yielding strength and increase of elongation capacity with 40% nominal ultimate strain. Another improvement is rotation free mild steel equipment product at damper end in place of fixed welding which assure less elongation capacity. Aluminum damper is connected with this equipment through M10 bolts and internal and external aluminum elements are expected in composite action through urethane connected by adhesive. Role of infill, i.e. urethane is for composite action and for maintaining configuration as entire damper. Test specimens are with and without infill.

3.2 Test Result

Fig.11 represents load-drift angle relationship. In all specimens with infill, it can be confirmed that stiffness and the load with infill increase more than that without infill during initial drift angel. Therefore, a synthetic effect can be expected in an initial drift angel. However, in larger drift angle range, the hysteretic loop in tension is similar between both specimens, i.e. with and without infill. This is because of adhesive peeled off (photo.1). On the other hand, in compression it can be said that larger load is obtained with filling rubber case. Therefore, composite action can be expected in the compression side.

In addition, similarly to the damper with SS400, larger stiffness and load are obtained at tensile drift angle of 1/15rad compared with that in compression. The reason is thought to be similar to SS400 case.

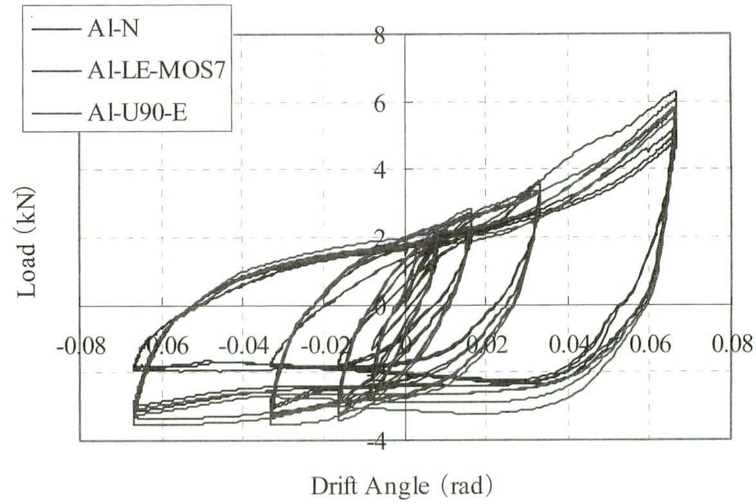


Fig.11 Load-Drift Angle Relationship

Adhesive Peeled off in 1/15rad on the Tension Side

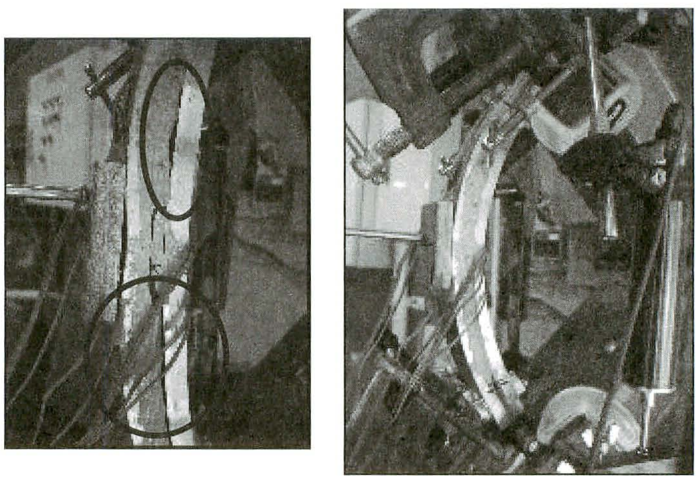


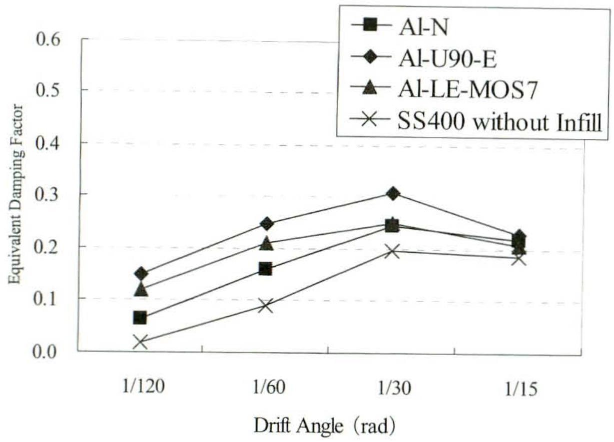
Photo.1 Static Loading Test (Al-U90-E)

3.3 Equivalent Damping Factor

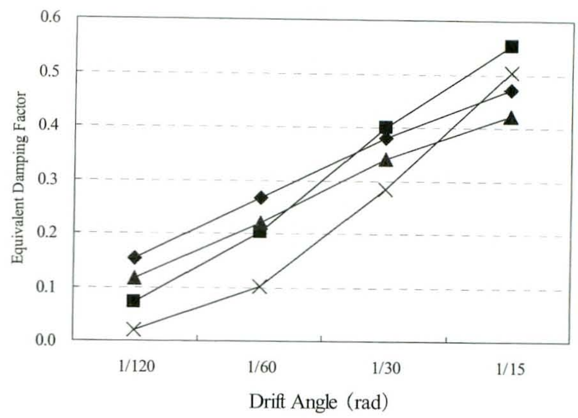
Fig.12 shows the obtained equivalent damping factor which is calculated from the second cycle hysteretic load-drift angle relationship. In comparison between dampers with and without infill, in tension side the factor of infill case is larger than that without infill, but similar in 1/15rad. It is because of loss of composite effect, and as the result, the same histories are obtained by the adhesive peeled off in larger drift angle.

On the other hand, in compression, obtained damping factor with infill is larger than the one without infill in initial drift angle, while opposite result is obtained in large drift angle. This is due to that load and stiffness increase by composite effect in rubber filling case, although load decreases gradually in the damper without infill.

Compared with the damper with SS400 and Al, equivalent damping factor of Al damper becomes larger than the that of SS400 damper. In the initial drift angle, the value of Al damper is larger than the one of SS400. Therefore, energy absorption characteristic can be improved some by using of aluminum as damper material.



(a) Tension Side



(b) Compression Side

Fig.12 Equivalent Damping Factor

Table-2 Equivalent Damping Factor

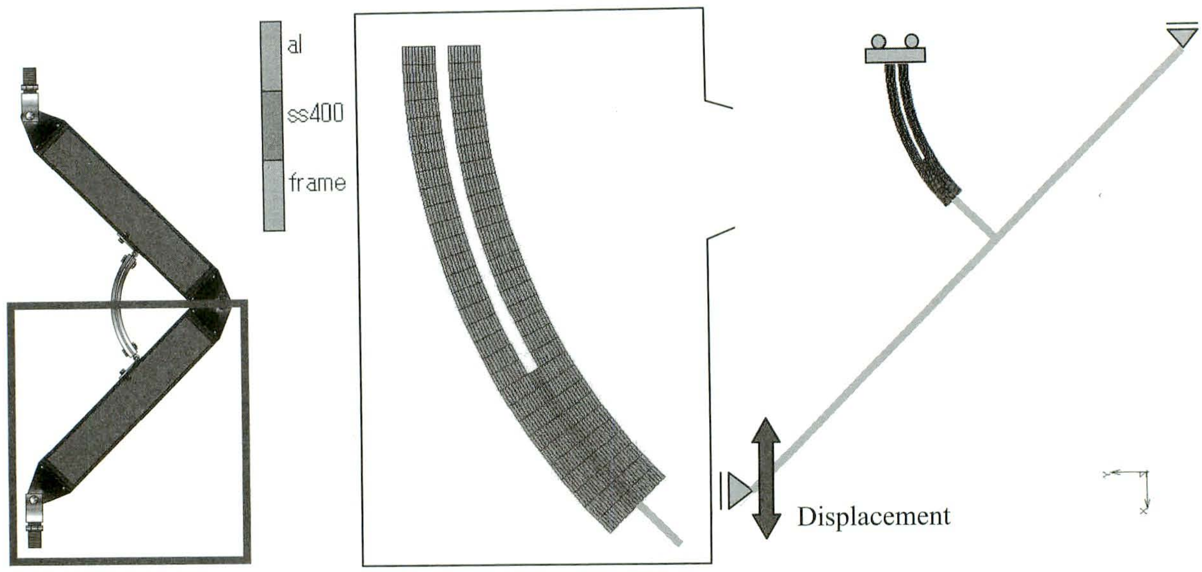
	Drift Angle (rad)	Al-N	Al-U90-E	Al-LE-MOS7	SS400 without Infill
Tension Side	1/120	0.065	0.149	0.119	0.018
	1/60	0.159	0.247	0.210	0.090
	1/30	0.245	0.309	0.249	0.198
	1/15	0.218	0.229	0.208	0.186

	Drift Angle (rad)	Al-N	Al-U90-E	Al-LE-MOS7	SS400 without Infill
Compression Side	1/120	0.070	0.153	0.117	0.020
	1/60	0.202	0.266	0.221	0.101
	1/30	0.401	0.381	0.341	0.283
	1/15	0.552	0.471	0.423	0.504

3.4 Analytical Procedure

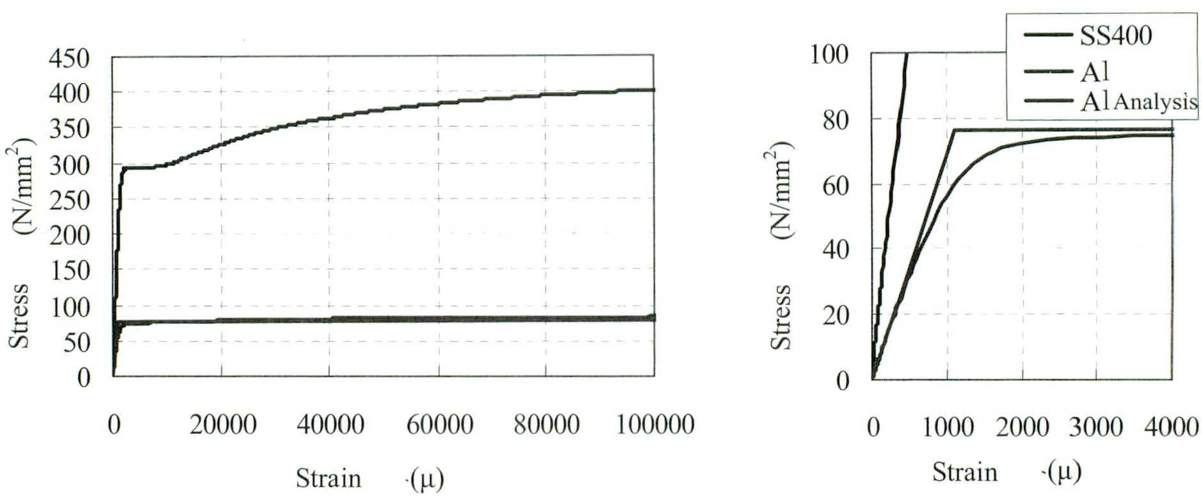
Fig.13 represents analytical model, where loading frame are modeled by beam elements and the arc section and the rotation free equipment section modeled by quadrilateral elements. Incremental vertical displacement is provided at the bottom of loading frame with assuming perfect bond between aluminum damper and infill. Moreover, contact is considered between aluminum in the outside.

Bi-linear Stress strain relationship is assumed for aluminum based on tensile test result shown in Fig.14 and stress-strain relationship is assumed for mild steel rotational equipment based on similar test result.



(a) Test Specimen (b) Analytical Model

Fig.13 Analytical Model



(a) Stress-Strain Relationship (b) Elastic Range Focused

Fig.14 Stress-Strain Relationship

3.5 Analytical Result

Fig.15 shows the comparison between experimental and analytical results. Though the difference is somewhat caused in the unloading range from tension to compression, it is roughly corresponding.

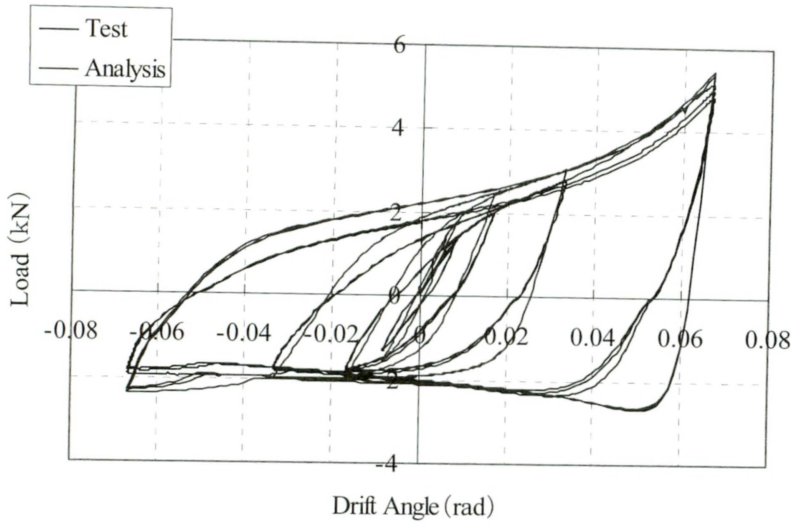


Fig.15 Load-Drift Angle Relationship

4. Concluding Remark

Followings are concluded.

As for mild steel damper;

1) Larger damping is expected in compressive loading because of flexural yielding zone widely spread.
2) In the larger displacement, larger damping is not expected in tensile loading because of elastic axial force action dominated.
3) When comparing two test specimens, larger increase of damping is expected for no infill case but less for with infill case because of damper deformation restricted by infill itself.

As for aluminum damper;

4) Effective damping is expected up to 1/30 of drift angle for both with and without infill.
5) In fill of urethane assure larger load capacity and stiffness. On the other hand, rupture in early stage, i.e. 1/15 drift angle suggests careful application in practice and future improvement needed.
6) Aluminum damper provides over than twice damping than mild steel damper.

5. References

1) Committee of Seismic Design Manual for Timber Structures: Seismic Design Manual for Traditional Timber Structures, Gakugei Printed Co.(2004) (in Japanese)

2) Ichinose H. and et.: Development of Viscous Damper for Beam Column Joint - Part3 Performance Test, Proceedings of AIJ Annual Conference, B-2, pp.317-318(2001) (in Japanese)