Aseismic Performance of an Arc Shaped Spring Damper for Strengthening at Corner of Structure

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SUMMARY:
An arc shaped spring damper that is able to strengthen stiffness and give a damping by viscoelastic material for a wooden structure was developed in this study. The spring damper is composed of viscoelastic material which is sandwiched by two circular arc shaped steel plates, and it is attached at corners of columns and beams of the structure. To investigate dynamic properties of the test spring damper, force and displacement curve were measured, and the bearing wall factor is estimated. In order to confirm dynamic vibration suppression, seismic vibration tests of a real scale wood unit frame are carried out by using a shaking table. It can be seen from the experimental results that the maximum deformation between the base and the top in case of the spring damper installed is decreasing about a half comparing with the case uninstalled. Finally, the effect of vibration reduction is confirmed experimentally.

Keywords: Damping, Aseismic, Vibration Control, Viscoelastic Material, Damper, Reinforced Structure

1. INTRODUCTION

The authors develop an arc shaped spring damper that is able to strengthen stiffness and reduce a damage of wood structure when the earthquake happens. The spring damper is composed of viscoelastic material which is sandwiched by two steel plates, and installed at corners of columns and beams of a structure. It is able to strengthen stiffness by the steel plates, and give a damping by viscoelastic material. It is good point that the damper is simply put into not only wood structures and also old structures for example castle, shrine, temple, and the strength of these structures can be improved in retrofit, because it can be installed easily enough. This device is already patented by co-author in Japan.

In this paper, at first in order to investigate basic properties of the material, shear tensile strength under thermal shock and heating, moment-displacement curves, durability and tensile strength of bolts are measured respectively. The adhesive strength is 2 MPa in average, the resisting moment of the damper is more than 3 kN while 1/30 radian, and durability is more than 250 thousands.

Next, in order to investigate effects of bearing wall and confirm vibration reduction, shear strength tests and seismic vibration tests using a test wall frame are carried out. The test wall frame, that has 2.73 m high and 1.8 m wide of Japanese cedar, is horizontally deformed by using an actuator, and force and displacement are measured. It is obvious from the experimental results that the Shear strength of the bearing wall can be increasing 50 % horizontally. Next the test frame is horizontally excited by earthquake using a shaking table and accelerations and relative displacements are measured. Several types of the frame which has braces and installs the dampers at corner of the frame are tested. The earthquake waves to be 400, 600 gal are inputted. It can be seen from the experimental results that the maximum relative deformation between the base and the top beam in case of damper installed decreases about a half comparing with uninstalled case, and the deformation is able to be less than angle of 1/30 radian. Moreover, simulations of a small benchmark structure with the damper are carried out, and the validity of the damping effect is confirmed. Finally, a feasibility study and aseismic performance of the damper is confirmed.

2. SCHEMATIC DESIGN

Figure 2. 1. shows a design diagram of the arc shaped spring damper which has been developed. The damper is installed between a column and a beam at corner of a structure, and fixed with 4 coach screw bolts. The damper is composed of a viscoelastic material sheet which is sandwiched by two circular arc shaped steel plates which has 55 mm wide. Thickness of the outer steel plate is 6 mm, the inner steel plate is 3.2 mm, and the viscoelastic material sheet which is contained by Styrene polymer is about 2 mm, respectively. The steel plate is SS400 of trivalent chromate plated, and total weight is 2.1 kg a unit. The outer steel plate is fixed by the coach screw bolts of M12, length is 75 mm, and two of them with a flanged washer that has 40 mm diameter and 8.2 mm high to the wood members as shown in Fig. 2. 1. (a) and (b). The inner steel plate has a long axis hole which is 28 mm for movable freely when radius of curvature of the two steel plates is changed each other. The damping force is caused by shear deformation of the viscoelastic material at middle layer. It is pointed out that the steel plate is riveted on circular center in order to prevent from the viscoelastic material swelling out of outside direction and exfoliating. It can be strengthen stiffness by the steel plates, and dissipate energy by the viscoelastic material. It is available for not only wood houses also old structure, for example castle, temple and shrine since it can be fixed simply.

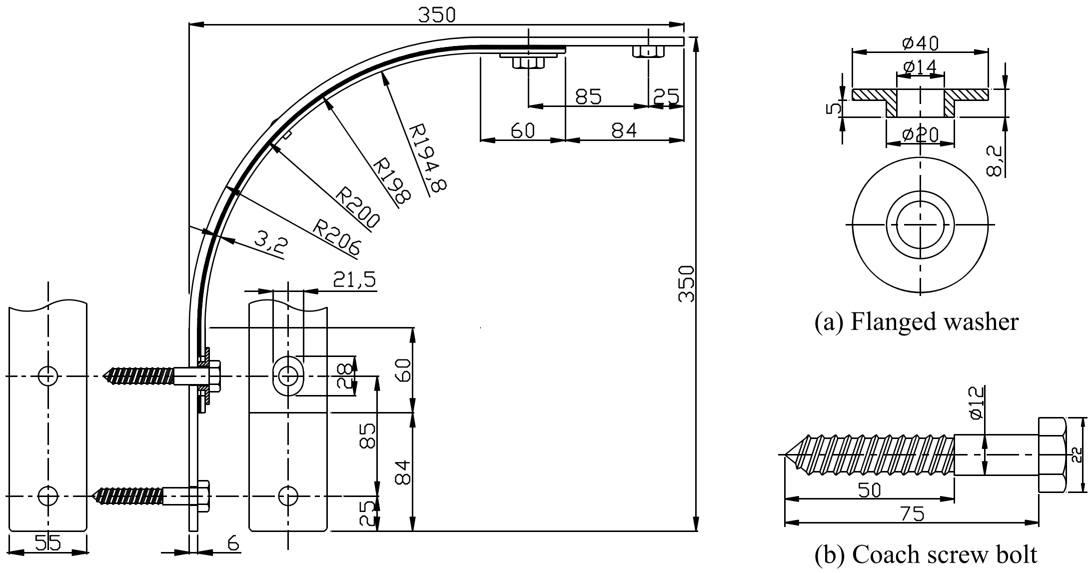


Figure 2. 1. Design diagram of arc shaped spring damper

3. BASIC PROPERTY

In order to know about basic property of the test piece which is manufactured, several tests are carried out.

3.1. Shear Tensile Strength

In order to investigate shear tensile strength between a steel plate and a viscoelastic material sheet, tensile tests are carried out. The viscoelastic material sheet is glued together two steel plate. Viscoelastic material is manufactured by cooperating worker, it defines as normal condition after gluing without any stresses. Material after thermal shock test of 10, 20 and 40 cycles, and after heat test of 100, 250, 500 and 1000 hours are used. In thermal shock test, the material is heated from 0 to 60 degree Celsius within 30 minutes in a cycle. In heat test the material is heated continuously 60 degree Celsius and 95 % humidity. Maximum force is measured when the sheet is exfoliated under tension. The cross sectional area of the viscoelastic material sheet is 30×30 mm^2, and the thickness is 2 mm. Several test pieces are made, and tested under tensile velocity of about 10 mm/min.

The experimental results in case of normal condition, after thermal shock test and heat test are shown in Fig. 3. 1. It is apparent from Fig. 3. 1. that the tensile strength slightly decreases as shock cycle and heat time, and the adhesive strength is around 2 MPa. So it is enough strength to use for the damper.

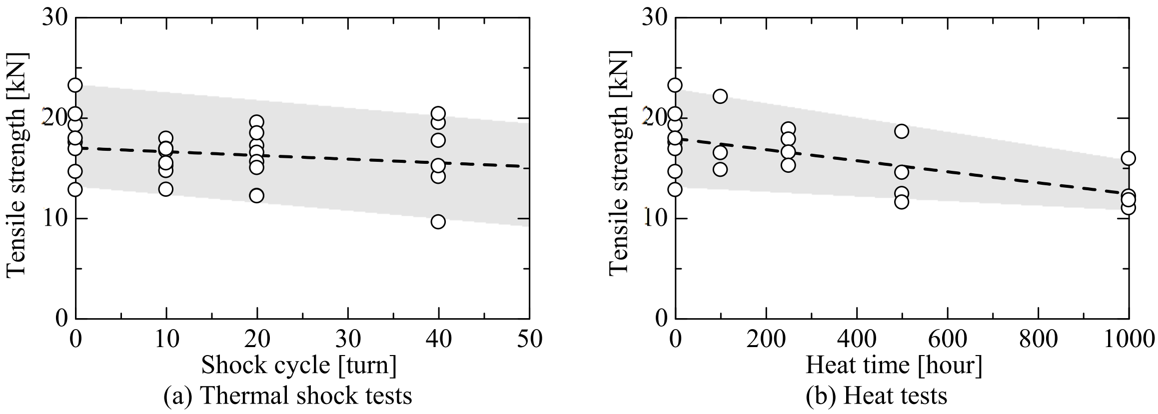


Figure 3.1. Adhesive strength of the viscoelastic material

3.2. Resisting Force

Resisting force characteristics are measured by using an L-shaped crank mechanism as shown in Fig. 3. 2. One side of the crank mechanism is attached to a fixed plate, and another side is excited by an electric servo fatigue test system. The crank mechanism that has an arm length of 520 mm is made by steel columns. Angle of neutral position is 90 degree when it starts. Four dampers under same condition are required, total number is 12 dampers.

Force-angle curves are measured by using a load cell and a displacement transducer when the L-shaped crank mechanism is subjected to sinusoidal wave of amplitude angle 1/30 rad, approximately 12.5 mm horizontal displacement inputted, and frequency 0.5 ~ 3.0 Hz in case of temperature of 25 degree Celsius in laboratory.

Figure 3. 3. shows the experimental results of normal condition, after thermal shock test and heat test in case of frequency dependent. It can be seen from Fig. 3. 3. that the damper has resisting force characteristics of a hysteresis damping effect by viscoelastic material, frequency dependent is not so high, and damping effect is decreasing as higher frequency range.

Figure 3. 4. Shows the shear storage modulus, shear loss modulus and loss factor of the damper, respectively. It is clear from the experiments that the three cases are not different each other, so dynamic performances are stably enough.

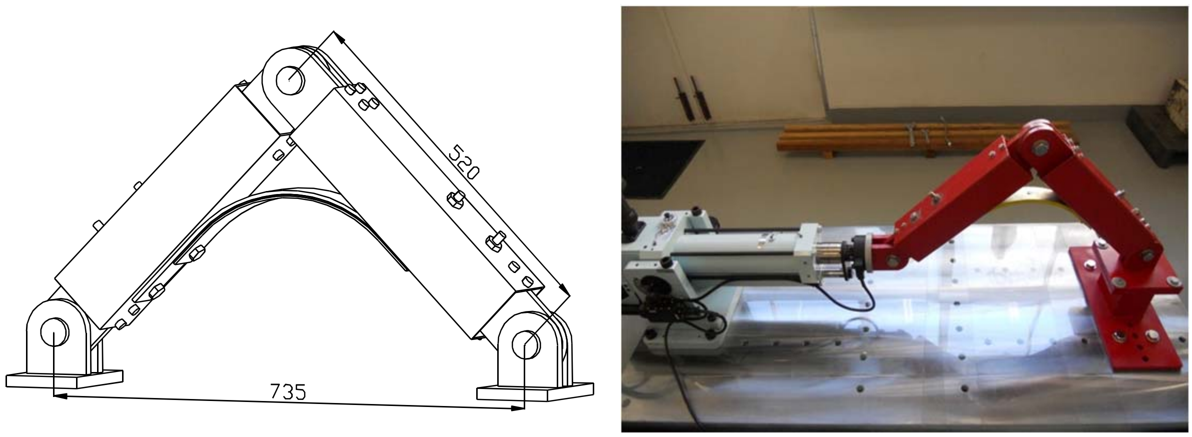


Figure 3. 2. L-shaped crank mechanism

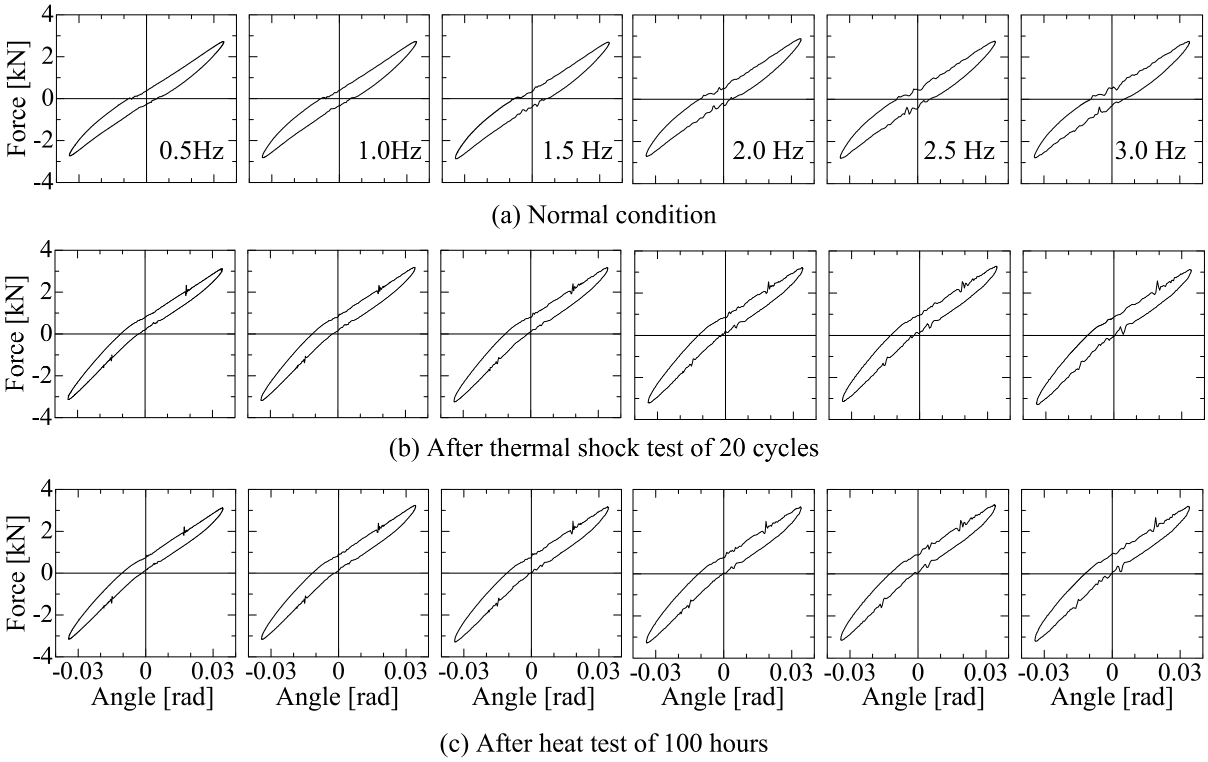


Figure 3. 3. Resisting force characteristics

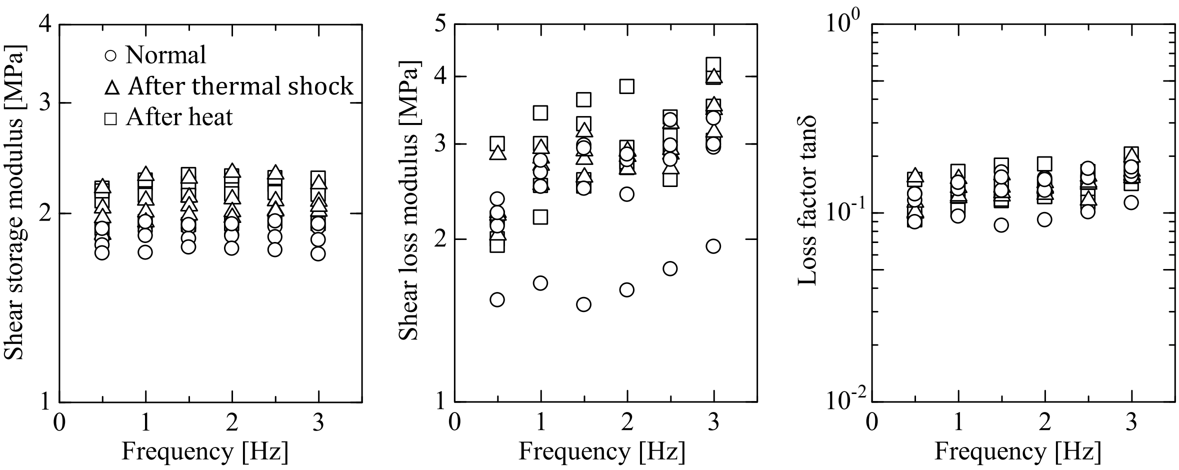


Figure 3. 4. Shear storage, shear loss modulus and loss factor

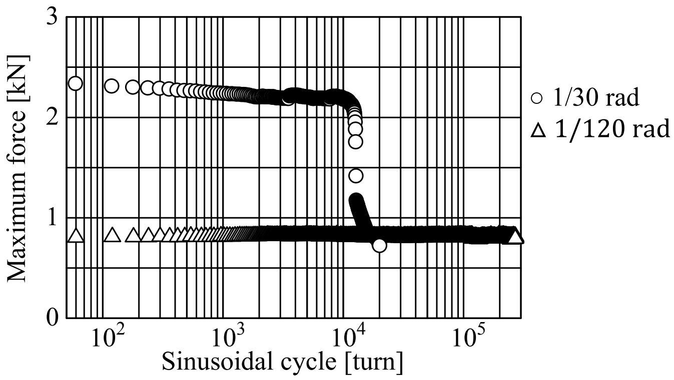


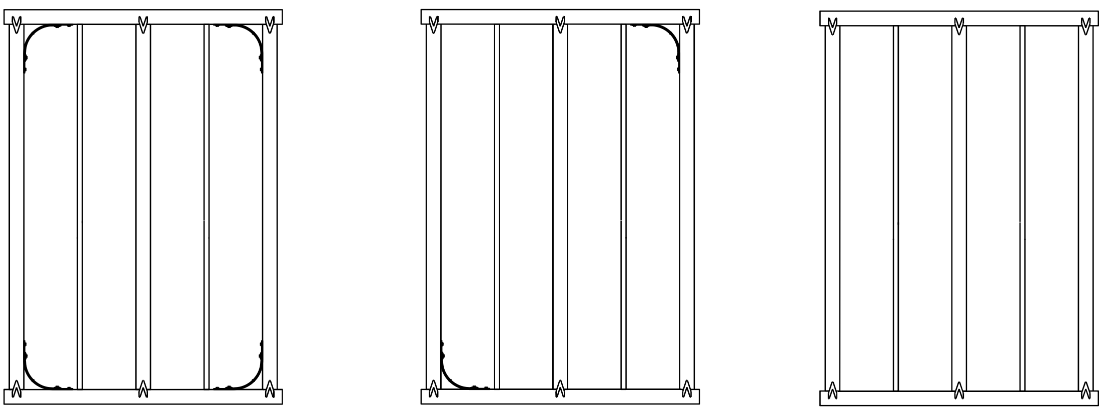
Figure 3. 5. Durability of the damper

3.3. Durability

Durability of the damper is measured by using L-shaped crank mechanism when it is continuously subjected to sinusoidal wave of amplitude angle 1/30, 1/120 rad, and frequency 1 Hz. The experimental result is shown in Fig. 3. 5. It is clarified from Fig. 3. 5. that durability is more than 250 thousands in case of 1/120 rad, and the damper will be failed over 10 thousands in case of 1/30 rad.

4. SEISMIC VIBRATION TESTS

In order to confirm vibration reduction of the damper for a real scale structure, seismic vibration tests using a unit wood frame are carried out by using a shaking table. The frame is 2.73 m high, 1.82 m wide, and consists of three main columns, two middle columns, and two braces as shown in Fig. 4. 1. The main column and beam are 105×105 mm, the middle column is 35×105 mm, and the brace is 45×90 mm of Japanese cedar woods, respectively. The columns and beams are rigidly fixed by V-shaped metal plates, and the braces are attached to metal plates at each corner. A bottom beam is rigidly bolted at a shaking table, and the top beam is supported by using tie rods for keeping horizontal movement through a long angle beam from a rigid wall as shown in Fig. 4. 2. The total weight about 100 kg, which is made by steel block, is installed at center of the top beam for adjusting weight in order to assume upper structure as like a roof. The shaking table is 2 m wide, 2 m span, and capacity is 1 G with 1 tons loaded, and can move to three degrees of freedom, however in this case only horizontal movement use.
Three types of earthquake waves, Kobe Marine Observatory at Japan Meteorological Agency of South Hyogo prefecture earthquake in 1995 North-South component, El Centro of Imperial Valley earthquake in 1940 N-S, and L2-Type of artificial wave in Building Center of Japan (BCJ-L2), in which are normalized to be about 4 ~ 6 m/s^2, are inputted three times each to the shaking table, respectively. Acceleration and displacement at the shaking table and the top beam are measured, and a relative displacement between the base and the top beam is calculated after tests. In the tests, the fallowing six cases of the frame are tested respectively.
1) Bearing wall without brace, and four dampers installed at each corners
2) Bearing wall without brace, and two dampers installed at diagonal corners
3) Bearing wall without brace, and damper uninstalled
Table 4. 1. shows experimental maximum and minimum acceleration values, and Fig. 4. 3. shows seismic response waveforms of seismic vibration tests. It is obvious from Table 4. 1. that the relative displacements in case of with 4 dampers decrease 1/2 ~ 2/5 comparing with no damper case, and these case of with 2 dampers also decreases 2/3 ~ 3/4, so that any of them are not exceed or almost less than 90 mm. It is notice that the displacement at the top beam is limit deformation 91 mm which is derived



4 dampers installed   2 dampers installed   Damper uninstalled

Figure 4. 1. Test frame types of bearing wall

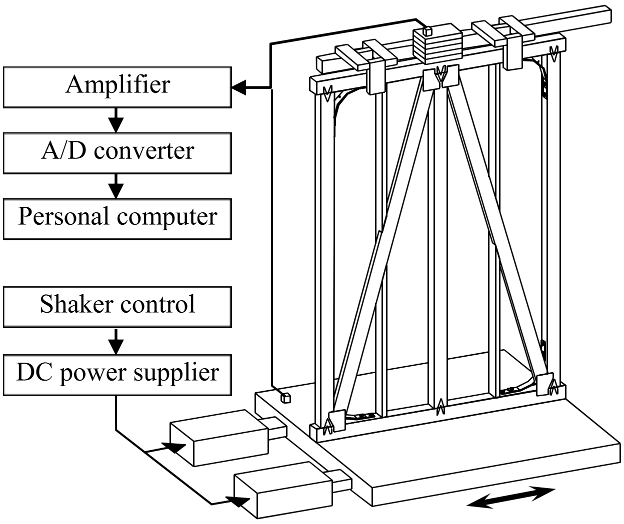


Figure 4. 2. Shaking test setup

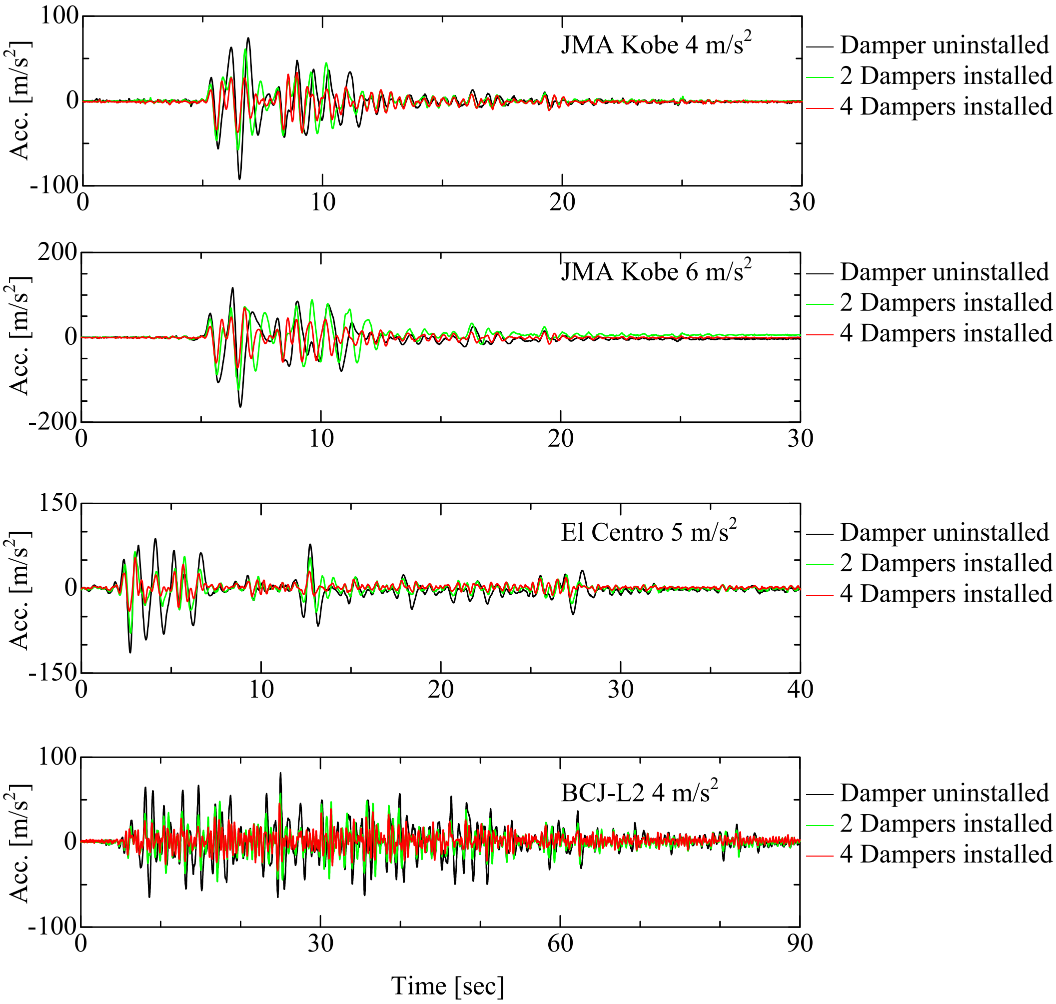


Figure 4. 3. Seismic response waveforms

Table 4.1. Experimental results of seismic vibration tests

Input earthquake	Type	Input acc.		Top beam acc.		Relative disp.	
		Min.	Max.	Min.	Max.	Min.	Max.
JMA Kobe 4 m/s^2	4 Dampers installed	3.50	3.58	7.56	7.64	35.7	37.5
	2 Dampers installed	3.42	3.44	7.84	7.96	59.7	61.0
	Damper uninstalled	3.40	3.44	8.17	8.58	82.8	92.5
JMA Kobe 6 m/s^2	4 Dampers installed	5.24	5.27	13.37	13.58	68.5	72.1
	2 Dampers installed	5.54	5.57	13.61	14.15	113.3	123.7
	Damper uninstalled	4.96	5.19	10.24	11.33	162.3	164.2
El Centro 5 m/s^2	4 Dampers installed	5.34	5.41	9.63	10.08	49.9	54.3
	2 Dampers installed	5.42	5.47	11.93	12.04	71.3	79.3
	Damper uninstalled	4.66	4.73	8.70	8.81	105.6	113.9
BCJ-L2 4 m/s^2	4 Dampers installed	5.07	5.12	8.07	8.14	44.0	45.9
	2 Dampers installed	4.84	4.88	6.82	6.85	55.5	57.5
	Damper uninstalled	4.87	4.91	5.70	5.80	80.0	81.9

by angle 1/30 radian of 2.73 m high. So, it can be seen that the effect of vibration reduction of the damper is confirmed enough.

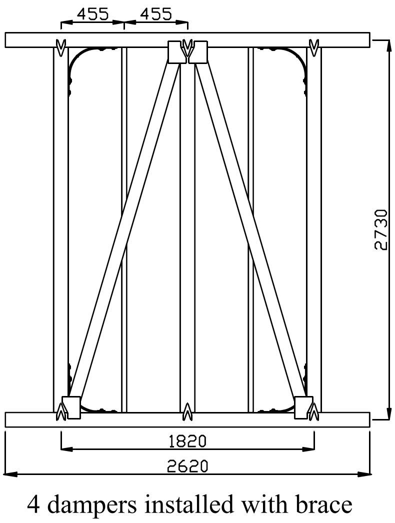
It is considered that the vibration reduction is depended on input wave form. For example in case of JMA Kobe, the vibration suppression is more effectiveness. One of the reasons is considered that the predominant frequency of the earthquake is lower than the others, so it makes the deformation smaller.

5. BEARING WALL TESTS

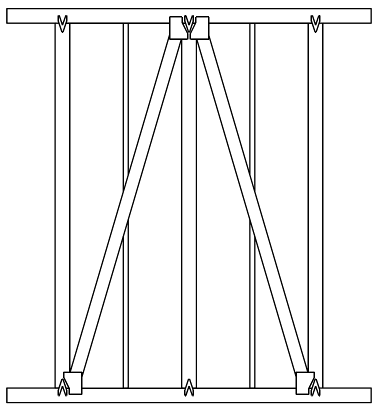
In order to investigate static aseismic performance of the damper, bearing wall tests using a frame unit are carried out by using an actuator. The frame is used as the same in seismic vibration tests. Force and displacement are measured when force is statically and horizontally applied at the top beam. In the tests, a bearing wall with brace and four dampers installed at each corners as shown in Fig. 5. 1. is tested, and four same specimens are used at same condition. In order to compare with normal type, conventional bearing wall is also tested. Figure 5. 1. show two experimental results samples of force-displacement curves.

6. COCLUSIONS

In this paper, seismic vibration test of frame unit with arc shaped spring dampers are carried out, and



4 dampers installed with brace



Damper uninstalled (Conventional)

Figure 4. 1. Test frame types of bearing wall

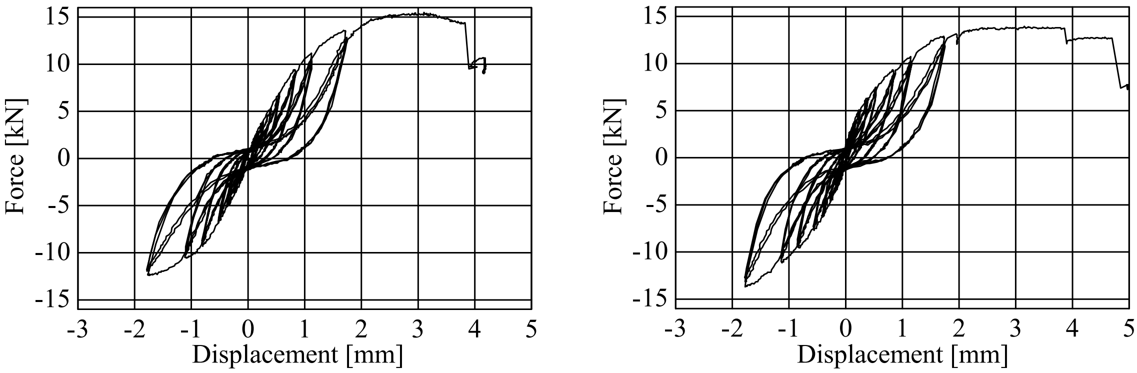


Figure 5. 1. Force-displacement curves of the test frame with wood brace

the vibration reduction is estimated experimentally. Primary conclusions may be summarized as follows:

Tensile strength between a steel plate and a viscoelastic material sheet is available for practical use.

The damper can have resisting force 3 kN while 1/30 radian of a hysteresis damping effect, shear storage modulus, shear loss modulus and loss factor of the damper are not different each other, and a high level of durability about more than 250,000 cycles in case of 1/120 rad.

From the seismic vibration test results, the relative displacements between the base and the top beam with the dampers decrease less than a half comparing with cases without damper, and are almost less than 91 mm of a limited deformation.

The vibration suppression is more effectiveness in case of JMA Kobe, since the predominant frequency of the earthquake is comparatively lower than the others.

AKCNOWLEDGEMENT

This work was supported by Japan Science and Technology Agency in 2009. The authors also would like to appreciate Dr. Hiroshi Endo of Kyodo Yushi Co. and some cooperating company for their supports.

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