Characteristics of Viscous Wall Damper of Intense Oscillation Test against Large Earthquakes

Kazuhiko Sasaki, Mitsuru Miyazaki & Takeshi Sawada
Oiles Corporlation, Japane

SUMMARY
Viscous damper can efficiently absorb energy of small and large vibrations like wind and seismic movements. The characteristics of Viscous Wall Damper that had been designed to be effective against earthquakes similar to those tested already and those predicted for the future. The earthquake that occurred in Tohoku region on March, 11, 2011 was larger than the predicted. Furthermore it is possible that similar earthquakes will happen in the future. However the damper had not been tested at such intensity because the Tohoku earthquake was stronger than predictions. After intense oscillation tests, the damper was revealed to have no damage and is therefore effective against stronger earthquakes.

Keywords: Viscous wall damper, Intense oscillation test, Long-period earthquake

1. INTRODUCTION

Viscous dampers are widely used for many kinds of shock absorber of buildings. They can absorb energy of small and large vibrations like wind and seismic movements to reduce the energy. The viscous damper treated in this paper is Viscous Wall Damper the shape of which is flat and thin in order to be set in building walls. The force had been calculated in order to resist against earthquakes those tested already and those predicted for the future. Therefore the formula does not always allow for unprecedented earthquakes like the 2011 off the Pacific coast of Tohoku Earthquake.

The damper had not been tested at such intensity because the predicted earthquakes had not been stronger than the Tohoku Earthquake. But it is important to grasp properties of the damper for huge earthquakes may happen in future. This paper looks into whether the Viscous Wall Damper is effective against test conditions similar to the Tohoku earthquake. And if modifications to the formula are needed, it is going to be fixed.

2. SPECIFICATIONS OF TEST VISCOUS DAMPER

2.1. Mechanism and Characteristics formula of Damping force

The viscous damper is constituted of viscous material and a variety of steel plates. The properties of the damper mostly depend on the material the viscosity of which is 8,000 Pa・s at 30 ºC. The viscous material is filled between plates. Damping force occurs when plates move. Formula (1a, b, c) is viscous damper force F (kN) and contains viscous temperature T (ºC), velocity V (mm/s), shear area S (m^2) and shear space d (mm). It is basically proportional to index velocity. Sin wave's hysteresis curves of damping force and displacement is nearly elliptical shape. In conclusion, the viscous damper is effective in small oscillation like wind sway the large ones like seismic shaking.

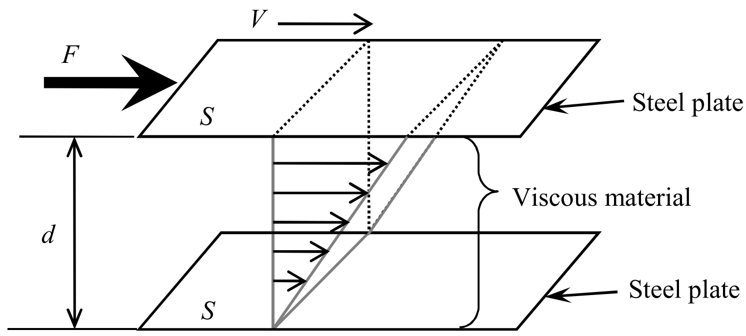

Figure 1. Mechanism of damping force

$$V/d < 1 \quad , \quad F = 41.2 \times e^{(-0.043\,T)}\, S\,(V/d) \tag{1a}$$

$$1 \leqq V/d < 10 \quad , \quad F = 41.2 \times e^{(-0.043\,T)}\, S\,(V/d)^{0.59} \tag{1b}$$

$$10 \leqq V/d < 100 \quad , \quad F = 63.7 \times e^{(-0.043\,T)}\, S\,(V/d)^{0.4} \tag{1c}$$

2.2. Structure of viscous damper

There are a variety of viscous damper for building vibrations. Viscous force of the damper mainly comes from the material characteristic as described in Figure 1 of section 2.1. The damper is flat like a wall. It contains inside plate and container that is welded to steel plates and filled with viscous material in Figure 2. Test device size is 2.27m×2.1m×0.27m, shear area S is 13m^2 and shear space d is 2mm in Figure 3.

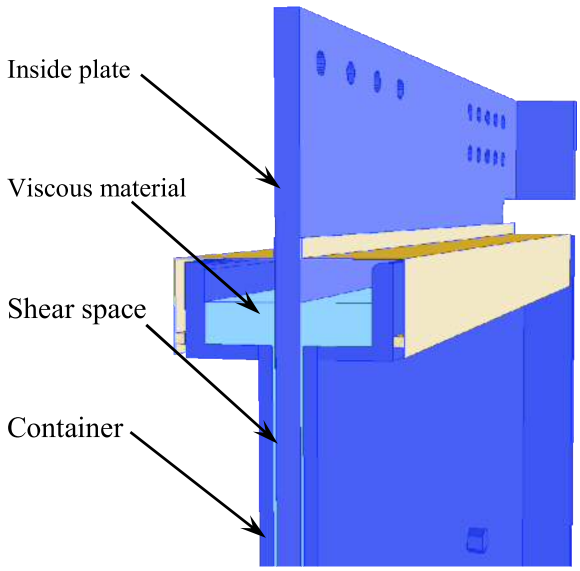

Figure 2. Structure of the damper

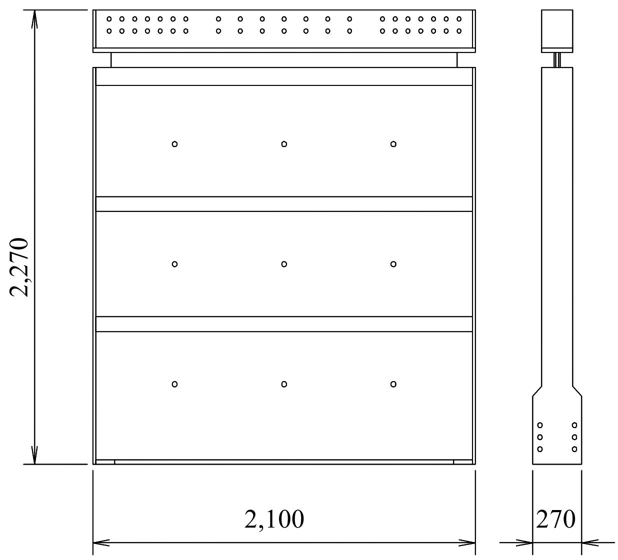

Figure 3. Test devicesize size

3. SHAKING TEST OF VISCOUS WALL DAMPER

3.1. Testing apparatus

Figure 4 shows the testing apparatus that horizontally shakes the test device shown in photo 1 and set in the centre of the frame. It is a frame structure installed horizontally the oil actuator of which maximum force is ±3000kN, displacement is ±50mm and velocity is ±400mm/s without load. It has shaking the table placed on the linear guides to withstand a bending moment from horizontal force.

3.2. Measurements of Characteristics of test device

There are 3 main measurements of apparatus's. They are viscous force, displacement and temperature of the test device in Figure 4. Each of them were measured with load cell placed between the shaking table and the actuator, displacement measurement at the top of the test device and temperature measurement in viscosity of the top of the device.

Photo 1. Test device set in frame

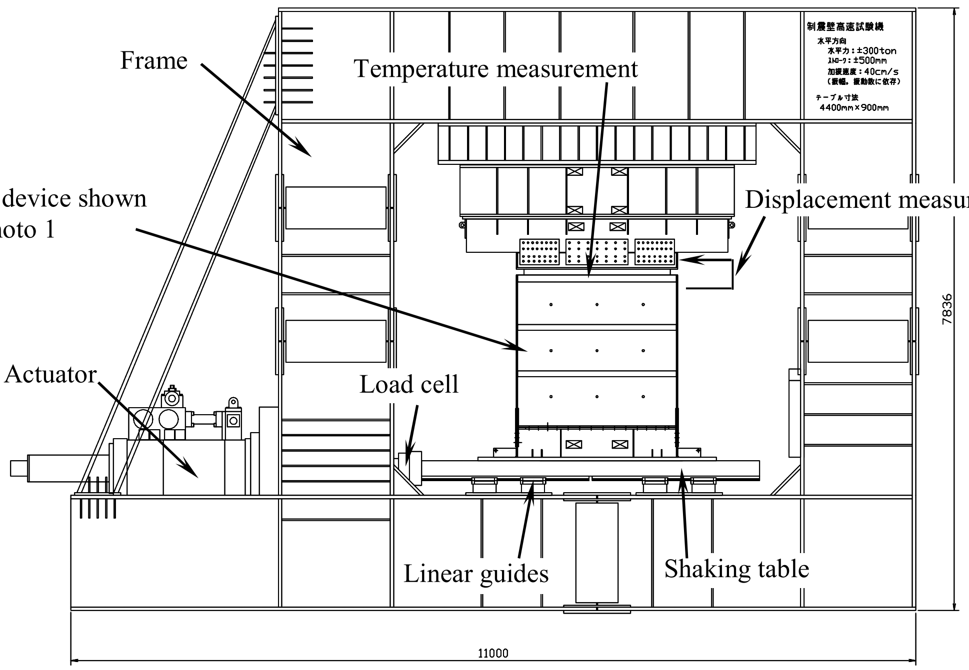

Figure 4. Test apparatus, test device and measurements

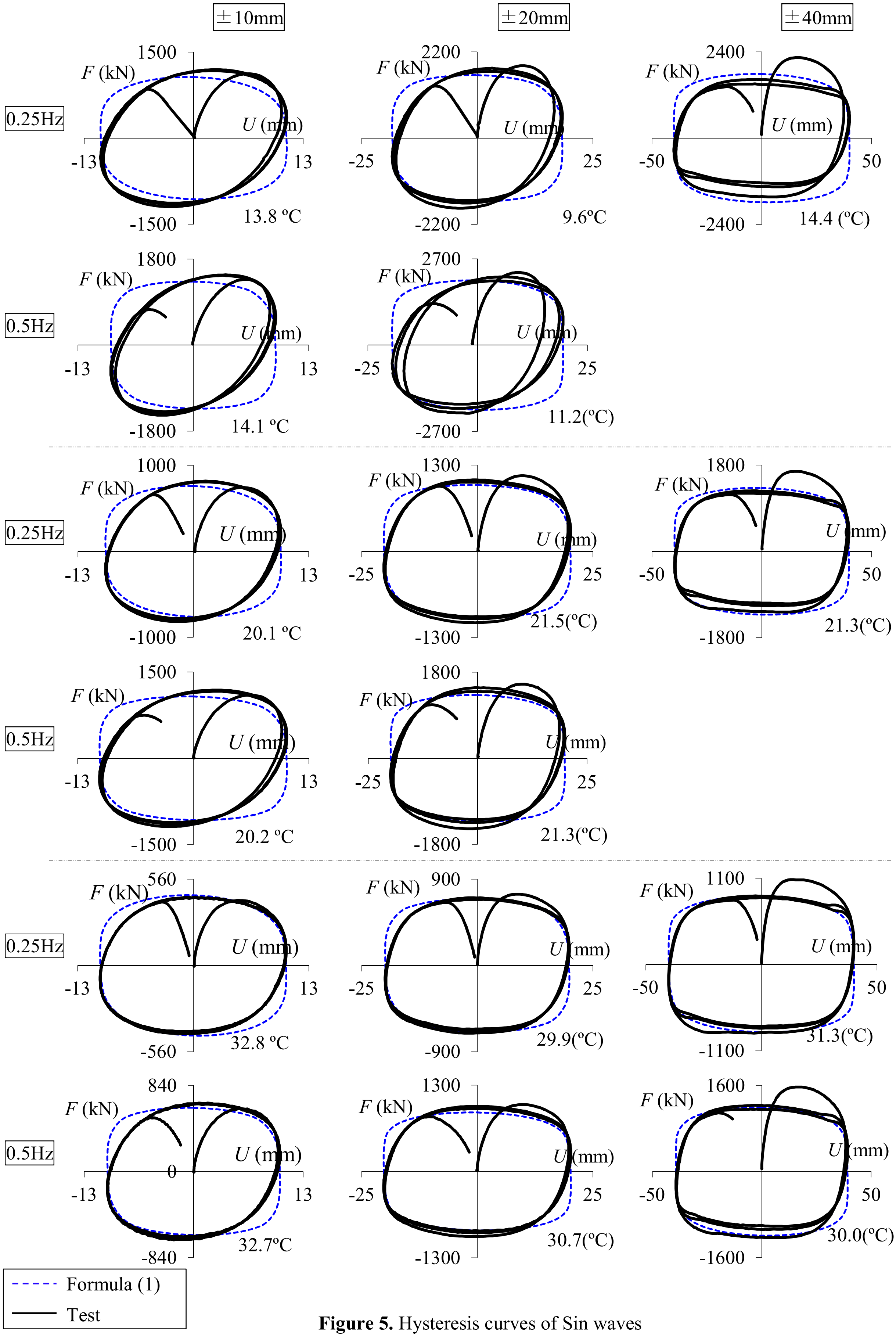

Figure 5. Hysteresis curves of Sin waves

4 DYNAMIC OSCILLATION TEST IN SHORT TIME

4.1. Characteristics of sin wave

The conditions of shaking the test device are 16 types of 3-cycle sin waves. They are combinations of temperatures of 10, 20 and 30ºC, frequencies of 0.25 and 0.5Hz, and amplitudes of ±10, ±20 and ±40mm. Maximum velocity was about 13kine at 30°C. Figure 5 are hysteresis curves of damping force *F*(kN) and amplitude *U*(mm) under the conditions. Solid lines are tests and the dotted lines are Formula (1a, b, c) in section 2.1. The curve shapes of tests are almost elliptical and similar to rectangle as amplitudes are larger. And these shapes look like to contain the elastic element as temperature and amplitude are smaller. But the curves of the tests follow closer predictions using Formula (1a, b, c). Figure 6 shows relationships of the intercept force *F*(kN) and the maximum velocity *V*(mm/s) of Figure 5. Dots are tests and line is Formula (1a, b, c).

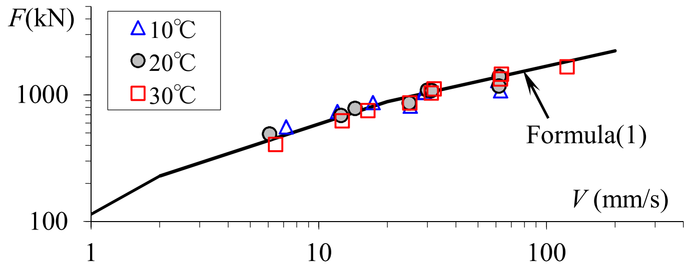

Figure 6. Characteristics of *F* and *V*

4.2. Characteristics of random wave

This random wave is adjusted from maximum displacement in the response analysis of 24 stories building with the El Centro seismic wave to about 40mm. Figure 7 is time history and spectrum of displacement. Peak frequency is about 0.37Hz. Figure 8 is hysteresis curves of the test result and Formula (1) as the same form of Figure 5. The relationship between the test and the formula are similar. Figure 9 is time history of temperature *T* and energy dissipation *E*. *T* increases by about 11ºC. *E* using with Formula (1) was about 10% larger than *E* of test.

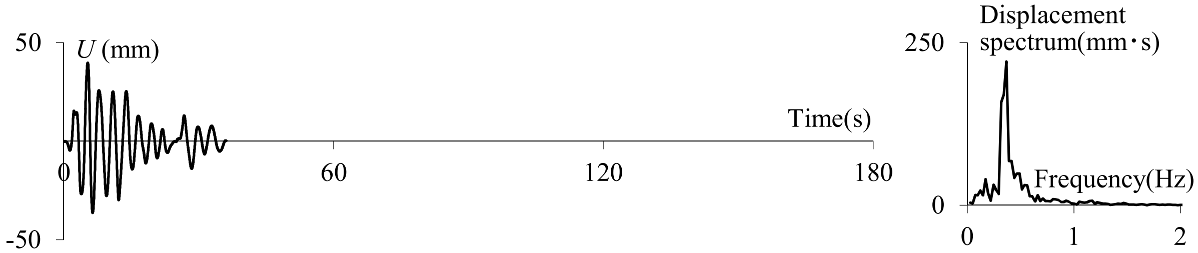

Figure 7. Displacement time history and spectrum of random wave

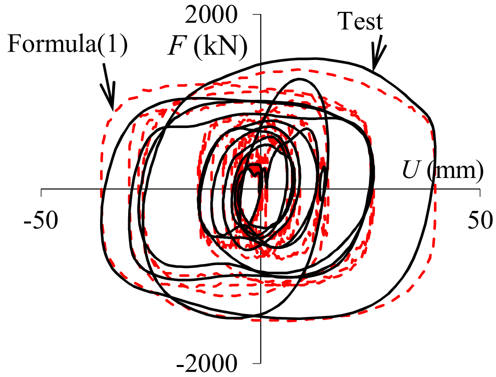

Figure 8. Hysteresis curve of Random wave

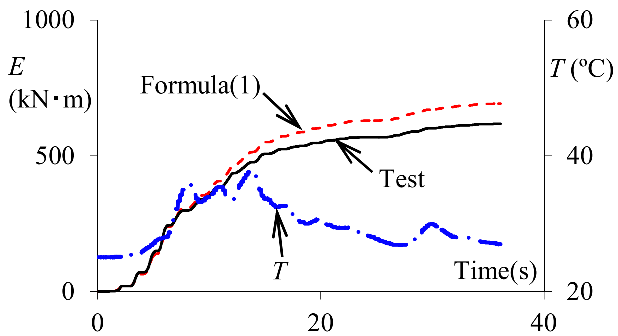

Figure 9. Time history of Energy and Temperature

5. DYNAMIC OSCILLATION TEST OVER AN EXTENDED TIME

5.1. Characteristics of sin wave

To test the device characteristics of intense vibrations like huge earthquakes, the numbers of sin wave cycles were much larger than those discussed in the tests in chapter 3. The standard control condition of intense sin wave was that temperature was 20ºC, frequency was 0.25Hz and amplitude was ±20mm. The characteristic of it is going to be compared with those of others conditions. They are combinations of temperatures between 10 and 24ºC, frequencies between 0.1 and 0.5Hz, amplitudes between ±10 and ±40mm and shaking number between 75 and 150cycles.

Standard control condtion (0.25Hz ±20mm, 20ºC, 150cycle)

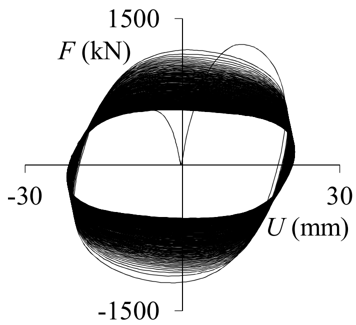

Figure 10. Hysteresis curve of standard condition

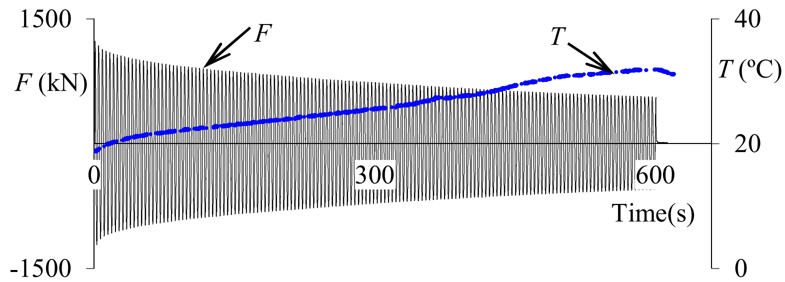

Figure 11. F and T time history of standard condition

Figure 10 is hysteresis curve of damping force F (kN) and amplitude U (mm). Figure 11 is time histories of F and temperature T (ºC) in the standard control condition 0.25Hz ±20mm 150cycles 20ºC. They show that F is down by about 50% and T is up by about 14ºC from the beginning to the end. The longer the shaking time, the lower F is. This tendency of the standard control condition is represented by Formula (2). β is the rate of each cycle force F_n against the first cycle force F_0 with the energy dissipation E (kN·m) and the shear area S (m^2). E/S of the standard control condition is about 550kN/m and twice that (2600kN·m/13m^2=200kN/m) of the intense random wave in section 4.2. Consequently the standard control condition is enough in order to test characteristics of the device in intense vibrations. Formula (2) will show at the right graphs in Figure13, 14 and 15 and compare with others condition properties at the next page. Moreover, using β of Formula (2), Formula (3) is the reduced force of Formula (1). Formula (3) is going to be applied to the force of random wave in section 4.2.

$$\beta = F_n / F_0 = \exp\left\{-0.01\left(E/S\right)^{0.67}\right\} \tag{2}$$

$$F_r = \beta F \tag{3}$$

In order to test the reduced F could recover after the intense shaking, the test device was shaken in short time sin wave 0.25Hz ±5mm 3cycles before and after the standard control condition. Figure 12 is time history of recovery of R_F. It is the force rate of tests against Formula (1) in short time sin wave. R_F was +4% before the standard control condition and it was -20% just after, but it recovered +3% after approximately 20 hours. This means the test device maintains relatively little damage after intense vibrations such as those of large earthquakes.

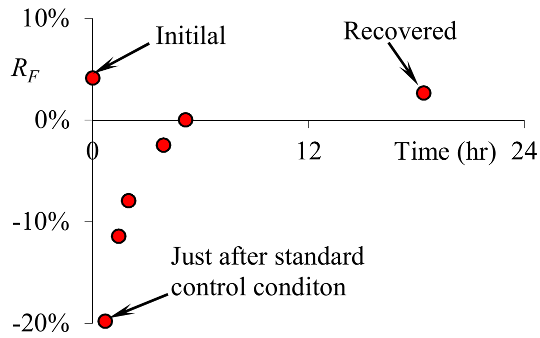

Figure 12. Recovery of short time sin wave before and after standard condition

Figure 13, 14 and 15 show differences of characteristics between the standard control condition and other intense oscillations. The left figures are hysteresis curves except for the standard control condition, the right are the rate β (= F_n/F_0) of 3 kinds of test results and Formula (2) (in section 2.1) for E/S. Figure 13 shows difference of temperature, Figure 14 shows that of frequency and Figure 15 shows that of amplitude and oscillations number. The larger E/S, the less force and β are. Formula (2) is nearly consistent with almost all test results. However Formula (2) was decided with characteristics of this test device, so it is necessary to consider characteristics of other different type dampers in order to be more precise.

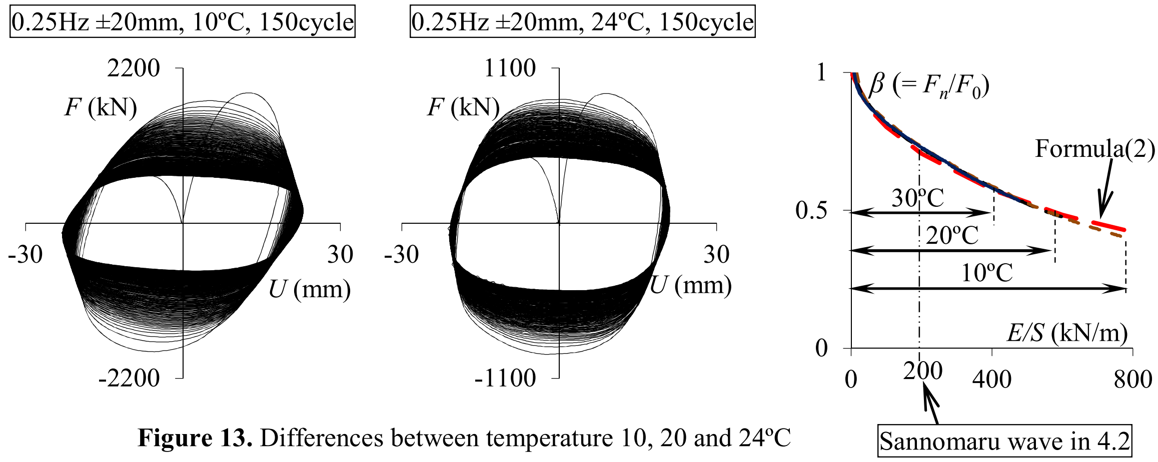

Figure 13. Differences between temperature 10, 20 and 24ºC

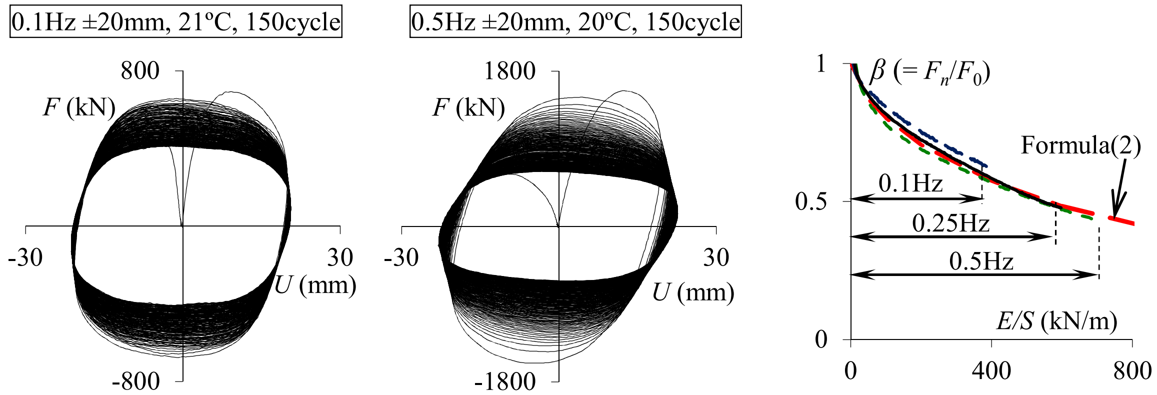

Figure 14. Differences between frequency 0.1, 0.25 and 0.5Hz

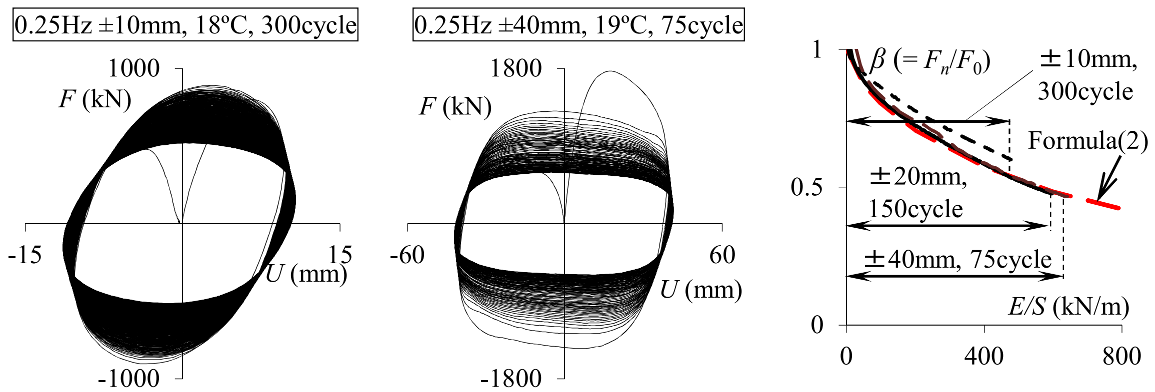

Figure 15. Differences between amplitude ±10mm300cycle, ±20mm150cycle and ±40mm75cycle

5.2. Characteristics of random wave

Random wave is the displacement of response analysis of 23 stories building with the Sannomaru wave that is the long-period earthquake ground motion produced by Ministry of Land, infrastructure, Transport and Tourism Chubu Regional Development Bureau and the architectural design offices at Aichi prefecture. Figure 16 shows time history and spectrum of displacement of the random wave. It is the wave picked out from the original's, it's time is less than the original's about 300s. The maximum displacement is about 40mm and the dominant frequency is about 0.42Hz. Due to the length of the oscillation this is a very sever vibration. Though the maximum displacement and the peak frequency are similar, the length is about 5 times that of the vibration in section 3.2.

Figure 17 is time history of temperature T and energy dissipation E of the test, Formula (1) in section 2.1 and Formula (3) in section 4.1. E of the Formula (1) is about 36% larger than that of test: Formula (1) cannot express characteristics of vibrations of such length. However E of Formula (3) is about 6% larger than that of test and almost consistent with it. That means the accuracy of Formula (1) depends on E because E in this section was about 4 times larger than that in section 3.2. Figure 18 is hysteresis curves of test result and Formula (3). It shows that Formula (3) is consistent with test result. Consequently Formula (3) can refuse Formula (1) in order to be applicable to Viscous Wall Damper's characteristics of huge earthquakes.

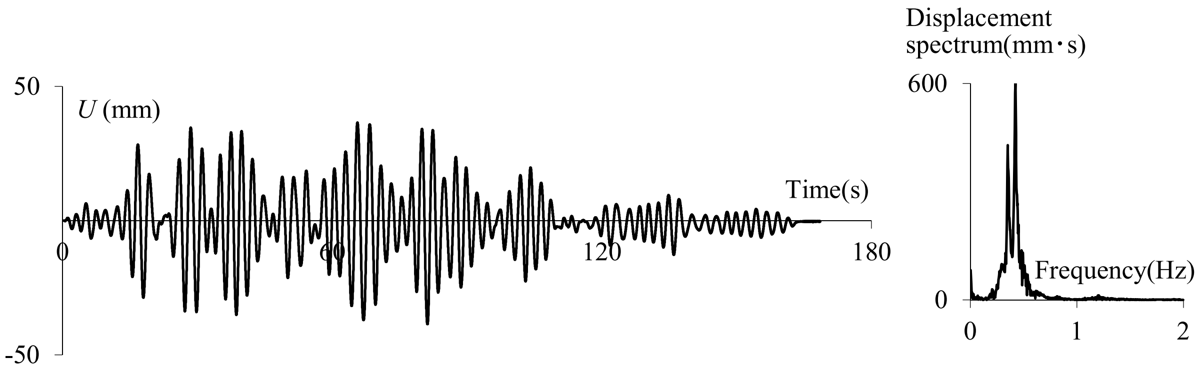

Figure 16. Displacement of random wave time history and spectrum

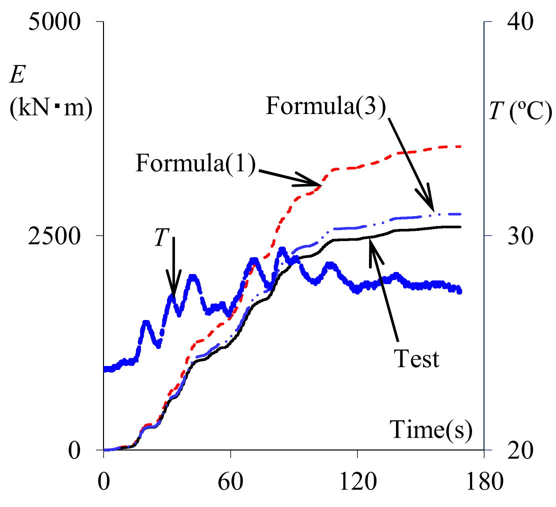

Figure 17. Time history of Energy and Temperature

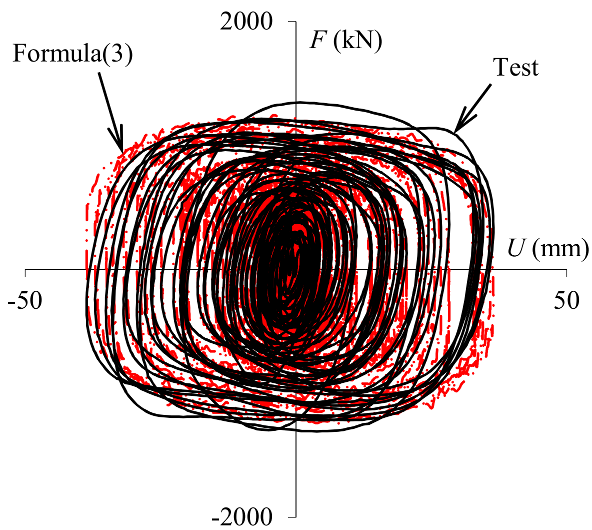

Figure 18. Hysteresis curve of Random wave

6. CONCLUTION

Characteristics of Viscous Wall Damper of intense oscillations were clarified with tests. The damping force decreased in such conditions, but can absorb energy of oscillations and be effective for them. It had no damage and recovered after tests. And results of tests revived Formula (1) used for the past in order to apply properties of huge earthquakes.

REFERENCES

The Japan Society of Seismic Isolation. (2005). Mnanual for Design and Construction of Passively-Controlled Buildings (2nd Edition)

Sato, S., Ikenaga, M., Mochimaru, M., Kondo, T., Okabe, A. and Suzuki, M. (1997). High Veocity Test of Viscous Damping Wall. *SUMMARIES OF TECHNICAL PAPERS OF ANNULA MEETING ARCHITECUTRAL INSTITUTE OF JAPAN* B-2, pp861-862.

Okimura, A., Nagashima, K. and Mochimaru, M. (2004). Developments of Cylindrical Viscaous Damper : Characteristic of Damper. *SUMMARIES OF TECHNICAL PAPERS OF ANNULA MEETING ARCHITECUTRAL INSTITUTE OF JAPAN* B-2, pp101-102.

Kochiyama, O., Takenaka, Y., Nakamura, T., Yamamoto, H. and Miyazaki, M. (2006). The heat characteristics of LRB1000 for a long period earthquake : 1/1 sccale response wave compression & shearing test. *SUMMARIES OF TECHNICAL PAPERS OF ANNULA MEETING ARCHITECUTRAL INSTITUTE OF JAPAN* B-2, pp603-604.