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EXPERIMENTAL STUDY ON SEISMIC RESPONSE CONTROL OF WOODEN HOUSES WITH SMALL KNEE-BRACE OIL DAMPERS

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ABSTRACT

This study proposes a structural system which aims at improving the seismic performance of new and existing wooden houses making use of oil dampers. Problems to install any special damping devices into wooden structures are known, for one thing to be the wood being brittle in bending and the other the strength of the joint between the device and wood being relatively low. Therefore, to get rid of these problems, we developed an oil damper which works only when subject to compression and is provided with relief valves to limit the maximum resistance. First part of the study deals with a series of harmonic loading tests to see if the damper exhibits the same properties as designed beforehand. Then, the dampers are mounted as knee braces at the corners of wood panels which is subject to dynamic loading tests in two ways. First one is a test to apply sinusoidal displacement to an isolated panel. Second one is a shaking table test on full scale single-story wood frames. From these tests, we confirmed that the damper can absorb as much as nearly 60% of seismic input energy. It is also confirmed that the installment of the damper makes it possible for wooden frames that collapses at the first strike of strong ground motion to withstand the same ground motion several times with no significant damage accumulation to main structures. Lastly, these test results are compared to analytical results and it is concluded that the proposed structural system do work to improve seismic safety of wooden houses.

1. Introduction

In 1995 Kobe earthquake, about five thousand people were killed under the collapsed wooden houses, which accounts for nearly 80% of the death toll caused by the Quake. Since then, upgrading seismic safety of new and existing houses has been our top priority to prepare for coming strong ground motions. Actually, many methods have been proposed. But mainly due to lack of scientific rationality and low cost performance, they have not been widely put into practice. In the case of strengthening existing ordinary wooden houses, it is often difficult to find enough space for strengthening. It is also difficult to let the existing structural members free of undesirable influence due to excessive stress. Therefore, we developed a new small oil damper that works only

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when it is subject to compressive force. Since the dampers are small, we do have to install no less than 50 to 100 dampers in each house. But, it is confirmed that the use of the dampers are quite promising, because not only they really work to decrease seismic effects but also they are not too expensive and quite easy to handle.

2. Compressive Oil Damper

The structure of a compressive oil damper is almost the same as a normal oil damper except for the stop valve being installed to the piston as schematically shown in Fig. 1. There are two holes in the piston, large one and small one. When the piston rod is pulled, stop valve moves away from the piston, opening the large hole to let the oil freely flow through the both holes, exhibiting less resistance. On the other hand, when the piston rod is pushed, the stop valve moves towards the piston to close the large hole and to let the oil flow only through small hole, exhibiting greater resistance.

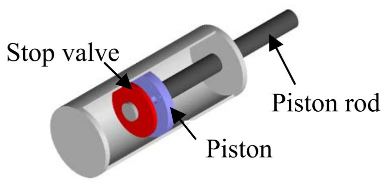


Figure 1. Conceptual mechanism of damper

Photograph 1. External appearance of compressive oil damper

Photograph 1 shows a real damper which will be used in the following studies. It is 305mm long. Its weight is about 5.6N and stroke is ±30 mm. It has a relief valve to limit the maximum resistance within +15kN and -1kN. Fig. 2 is the load-deflection relations of the damper when it is subject to sinusoidal displacement with different amplitude. The damper mostly exhibit resistance when it is subject to compression and it is confirmed that the relief mechanism do work. Fig. 3 shows the relation between the velocity and the resistance. The slope of each straight line corresponds to the initial and the second damping coefficient.

Figure 4 shows where and how this damper is installed into a real wooden house. By means of small metal mountings and small number of screws, damper is fixed to a beam to column connection as a knee-brace.

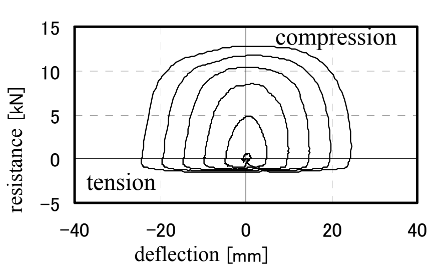


Figure 2. Load-deflection relation of compressive oil damper (1.0Hz)

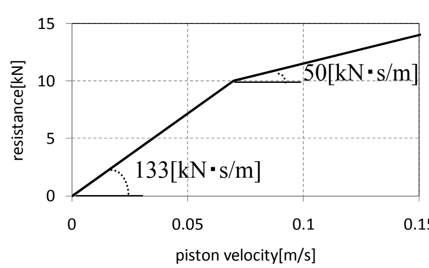


Figure 3. Damping coefficients of the damper

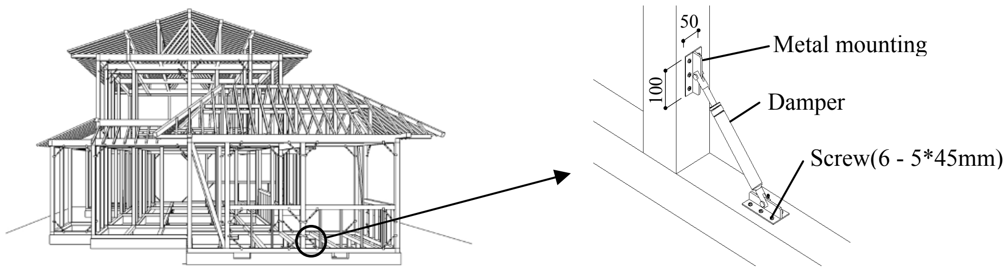


Figure 4.   Installment of the damper into wooden house

3. Damping Capacity of Wooden Frame with Dampers

3.1 Full-scale Dynamic Loading Test

3.1.1 Test Frames

We tested two types of wooden frames. Fig. 5 shows the dimensions of each test frame. The left figure is an open frame and the right one, a walled frame. The walled frame has a partial opening, the area of which is about 40 percent of the total area enclosed by columns and beams. Photograph 2 shows a whole view of the dynamic loading test system. Lateral displacement of the upper beam is restrained by means of a load-cell. Dynamic sinusoidal displacement is applied to the lower beam by a dynamic actuator.

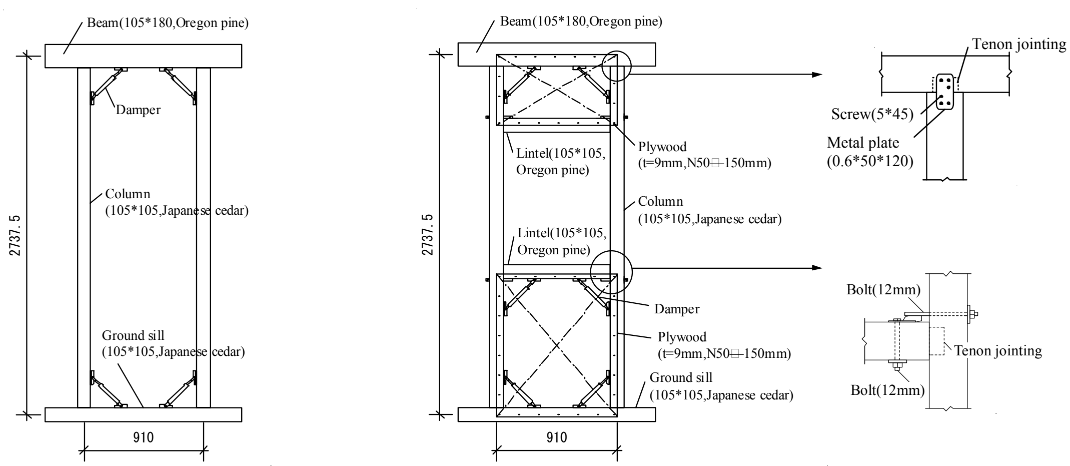


Figure 5.   The dimensions of test frames (left: open frame, right: walled frame)

Photograph 2.   Dynamic loading test system (left: open frame, right: walled frame)

3.1.2 Test Results

Figure 6 shows the load-deflection relations obtained in the test for the open frame without dampers on the left and for the one with the dampers on the right. It is confirmed from these figures, that the energy absorbing capacity of the open frame with the dampers could be 5-10 times as much as that of the frame without dampers. Fig. 7 is obtained for the walled frame. The left figure shows the case of no dampers, and the right one, the case with the dampers. We can confirm that, even in the case of walled frame, energy absorbing capacity increases to about twice as much as that with no dampers.

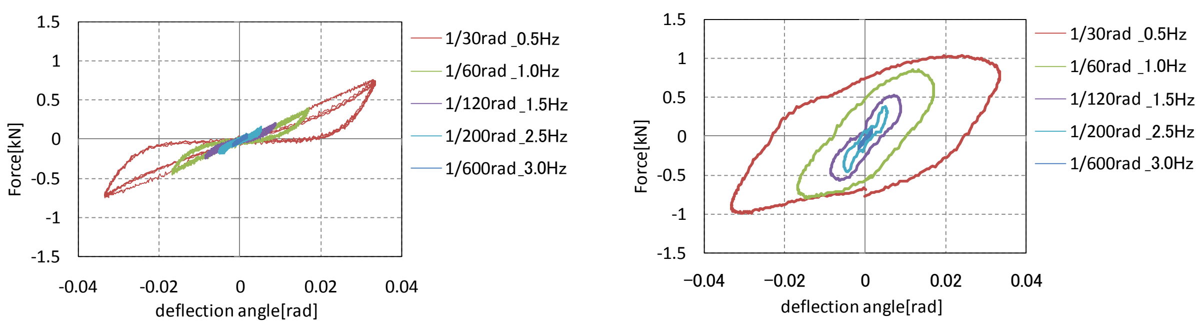


Figure 6. Load-deflection relations of the open frames (left: without dampers, right: with the dampers)

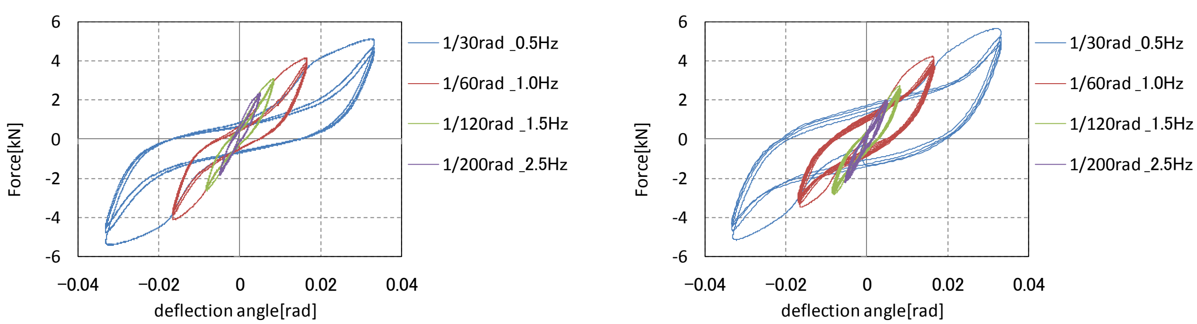
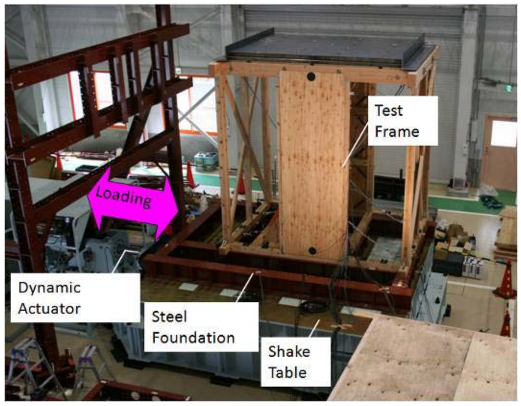


Figure 7. Load-deflection relations of the walled frames (left: without dampers, right: with the dampers)

3.2 Full-scale Shake Table Test

3.2.1 Shake Table Test System

In the previous section, we have confirmed that the damper is capable of absorbing considerable amount of input seismic energy. Therefore, in this section, we see if the dampers really work when the house is subject to intense earthquake ground motions. Photograph 3 shows the whole view of the shake table test system that we used in the test. Test frame is placed by means of steel foundation beams. This shake table is capable of producing a maximum velocity of no less than 200 cm/s. It can move only in one direction. We tested two walled frame systems. One is installed with the dampers, the other, without dampers.



Photograph 3. Shake table test system

3.2.2 Test Frames

Figure 8 shows the dimensions of the test frame. The arrow indicates the loading direction. The frame is 2.85m long in the loading direction. The structural height is 2.74m. When the dampers are installed, they are attached to beam-to-column connections inside the walls. Since the frame has two walls, total number of the dampers is 24. According to simple geometrical relation, the additional equivalent damping factor by the dampers is about 6 percent, on condition that the stiffness of the frame is defined as the secant stiffness at 1/600 in story deflection angle. The frame holds 37.6kN weight on the roof. The total strength of the frame is so designed as to correspond to the minimum requirement by the Japanese Construction Standard Act.

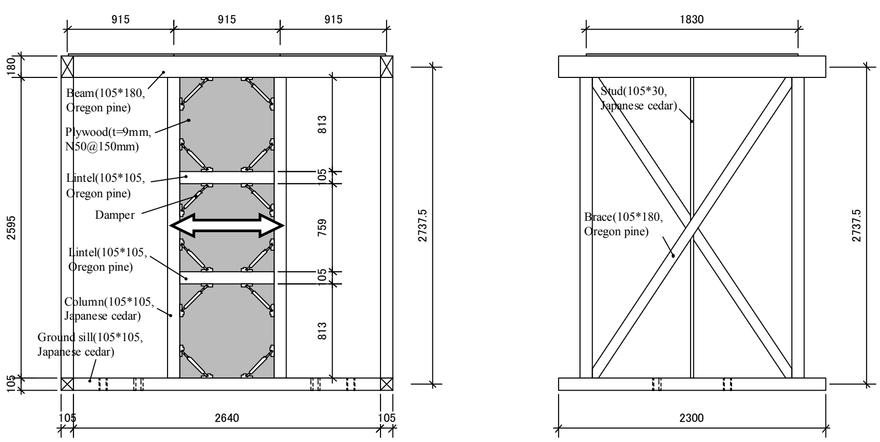


Figure 8.   Elevations of the test frame with dampers

3.2.3 Test Procedure

Since the frame without dampers were more likely to collapse than that with the dampers, the frame with dampers was tested first. A series of tests were started from the 1995 JMA Kobe ground motion of which intensity is normalized to be 10% of its original record, followed by the 30% and the 60% until the story deflection angle reaches nearly 1/20. Besides these earthquake ground motions, we also performed minor level shaking test by stationary white noises, which are used to identify such basic dynamic properties as natural period, damping factor, etc.. During the second shaking test by 60% JMA Kobe ground motion, story deflection angle of around 1/20 was registered. So, after that, plywood boards and damaged strengthening metals were replaced. And then, without installing any dampers, shaking tests were restarted, following almost the same manner as in the case of the frame with dampers.

3.2.4 Test Results

Figure 9 compares transfer functions of the two frames. Dashed line indicates the frame without dampers and continuous line, with dampers. From this figure, we can assume that initial mechanical properties of the two frames are almost the same regardless of the dampers being installed or not.

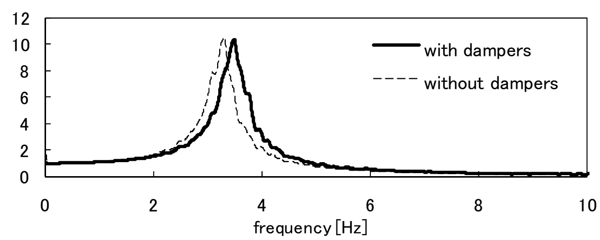


Figure 9.   Transfer functions of test frames with/without dampers

In Fig. 10, shown are load-deflection relations of the frame with dampers on the left and those of the frame without dampers on the right. In the left figure, yellow line, red line, blue line and green line respectively corresponds to the case when subject to the 10%, the 30%, the 60%, and the second 60% level ground motion. During the second 60% shaking test, the story deflection angle reached nearly 1/20 and experiment was called off. Then the frame was renewed and was subject to 10%, 30%, and 60% level shaking without dampers. In this case, the frame collapsed during the first shaking by 60% JMA Kobe ground motion. This comparison indicates that additional oil dampers really worked to prevent the same frame from collapse even when the frame is subject to the same strong ground motion twice.

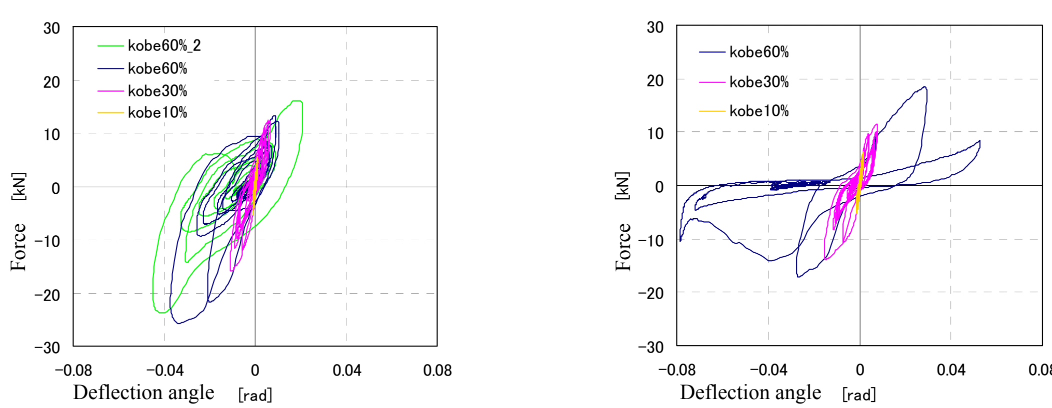


Figure 10.   Load-deflection relations for test frames (left: with dampers, right: without dampers)

Time histories in Fig. 11 show how the input energy is absorbed in the dampers for different ground motions with different intensity levels. The ratio of absorbed energy to total input energy is defined by α. It is seen that the ratio α increases as the shaking intensity increases or the deterioration of the frame is promoted. We can conclude that nearly 60% of input energy could be absorbed in the dampers, keeping the maximum deflection of the frame with legally required minimum strength within the deflection that is assumed to be quite safe against the strongest ground motion.

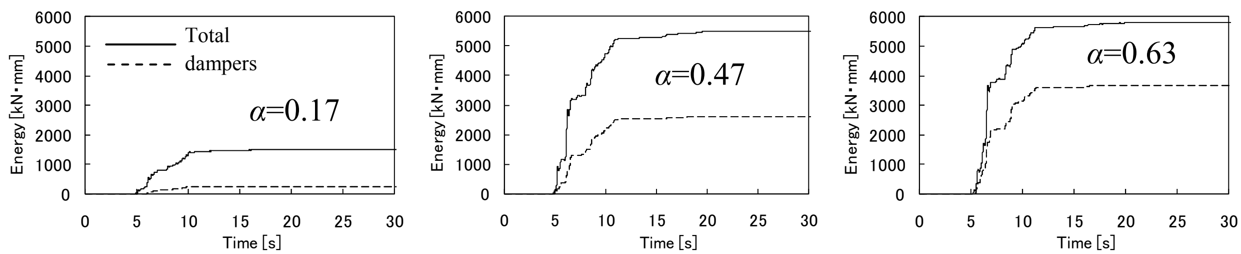
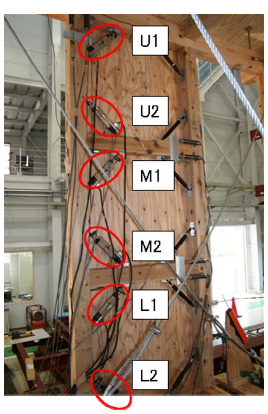


Figure 11. Ratio of absorbed energy in damper to total input energy (left: JMA Kobe 30%, center: JMA Kobe 60%, right: JMA Kobe 60%_2nd)

In the test, not only the story deflection, but also the damper deflections were measured. In photograph 4, the places where the dampers were installed and how their displacement was measured were shown in red circles. Fig. 12 compares the ratio of damper deflection to story deflection for different six places. According to simple geometric relation, the ratio should be 0.065 as is represented by a pink straight line in the figure. So, we can conclude that story deflection and damper deflection have a one-to-one correspondence on average. This conclusion is quite important to make sure the accuracy seismic response analysis of a wooden frame with knee-brace oil dampers by making use of a simple shear model.



Photograph 4. Arrangement of dampers and deflection gauges

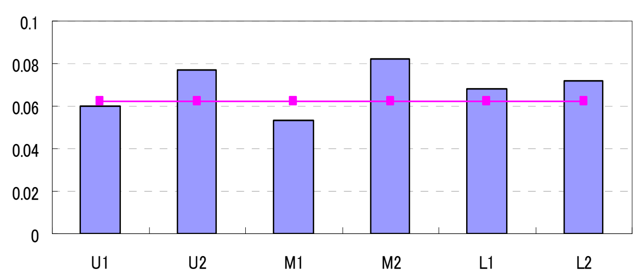


Figure 12. Ratio of damper deflection to story deflection

3.2.5 Simulated Results

In this section, we examine if the test results can be simulated by analysis using a simple shear model. Fig. 13 shows the acceleration time histories measured during the test on the shake table. Four records are combined in series to perform seismic response analysis at a stretch to take into account the gradual deterioration of the frame. An extended NCL model[1)] is used to represent analytical load-deflection relations for the test frames. Damping coefficient of the oil damper is determined based on the diagram represented in Fig. 3. Fig. 14 compares the experimental results in black line and analytical ones in red lines. They are obtained while the frame with the dampers is subject to a series of ground motions with different intensities, from 10% to 60% of the original. It is seen that seismic response is quite stable and it is easy to predict the maximum value by analysis.

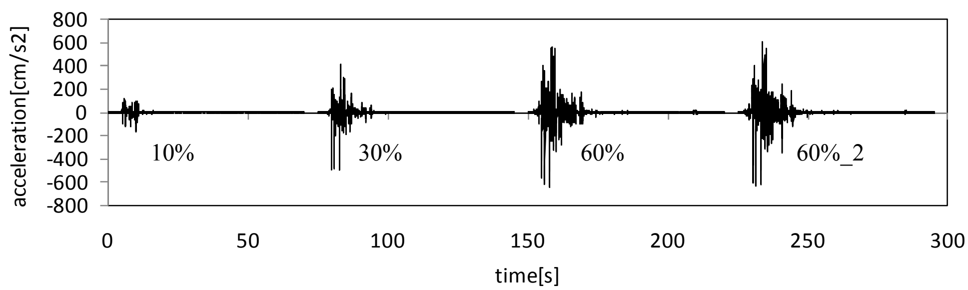


Figure 13. A series of accelerations recorded on the shake table

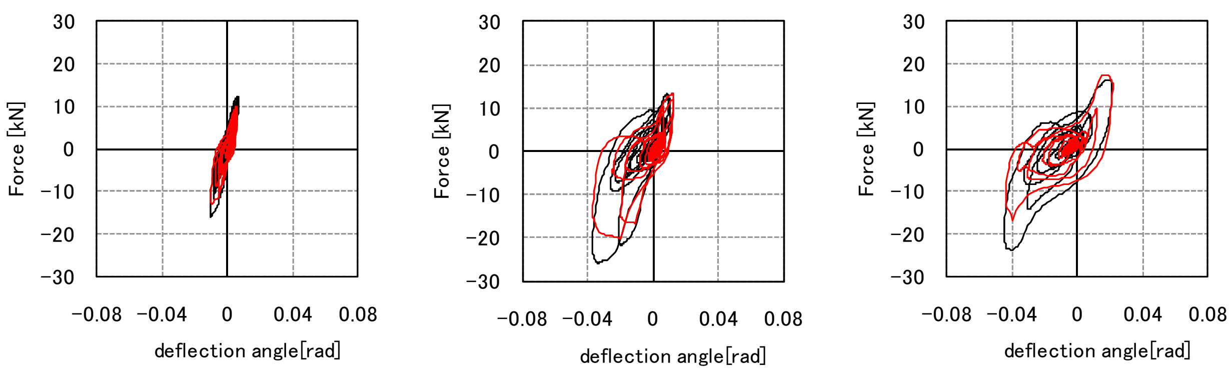


Figure 14. Comparison between experimental results and analytical results (left: JMA Kobe 30%, center: JMA Kobe 60%, right: JMA Kobe 60%_2nd)

4. Conclusions

In this paper, we proposed the structural system using the compressive oil damper, and confirmed the seismic performance of the system through a series of dynamic loading tests. Wooden houses, which are so designed as to be legally consistent with the minimum seismic safety requirement might collapse when it is subject to extremely strong ground motions. However, installment of proper amount of oil dampers works to prevent the houses from collapsing even when subject to those strong ground motions several times. We can conclude, therefore, that seismic strengthening of wooden houses by compressive knee-brace oil dampers is quite effective.

Acknowledgments

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References

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