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SEISMIC RESPONSE CONTROL OF WOODEN HOUSE PLACED ON SLIDING BASE

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ABSTRACT

Proposed in this study is the positive use of a hybrid structural system to upgrade seismic safety of a variety of light weight low rise houses. It consists of, from the bottom to the top, a concrete mat foundation on the ground, a high polymer sheet, a solid reinforced concrete (RC) base and an upper structure equipped with oil dampers. The point of this structural system is that the RC base is allowed to slide when it is subject to extremely strong ground motion, decreasing the seismic force transmitted to the upper structure. Since there will be no sliding when the ground motion is not strong, oil dampers are also installed to let the system be also effective even for minor ground motions or strong winds. It will be shown that the dampers also work to keep maximum deflection of the upper structure within that the house could be used soon after even extremely strong ground motions. Based on some preliminary experimental studies, we confirmed that the sliding between the smoothly finished RC surface and high polymer sheet yields quite stable load-deflection relation. Therefore, the next thing we had to do was to find out the proper value for the friction coefficient. There are some basic requirements for the system. For one thing, the RC base should not slide when subject to strong wind. And the other, maximum acceleration at the upper floors should be no greater than 400 to 500 cm/s^2, which is a bit greater than that expected for normal base-isolated house but is enough to prevent not only the house from severe damages but also the equipments from shifting, toppling and falling down. We finally identified the optimum value for the friction coefficient to be 0.2, which could be realized by the combination of RC surface and ultra high molecular weight polyethylene (UHMWPE) sheet. The study consists of three parts. First, we briefly explain how a proposed hybrid seismic response control system expected to work. Then, dealt with are analytical and experimental studies to identify a proper value for the friction coefficient of the sliding base. And finally, described are shaking table test and an analytical study to confirm the usefulness of the system in seismic design of wooden houses.

1. Introduction

In 1995 Kobe earthquake, nearly 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. We first developed a seismic response control system making use

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of oil dampers[1]. This is because we thought it would be quite urgent to do something to upgrade seismic safety of existing houses which are unfitted to the current seismic resistant design code. The point of installing oil dampers was to decrease maximum deflection of houses without inviting excessive acceleration response, making it possible to perform seismic strengthening of existing houses without expensive underground works. The reason why we want to recommend the use of small compression effective oil dampers with relief valves is that, in the case of strengthening existing houses, it is often difficult to find enough space for strengthening and that to let the existing structural members free of undesirable influence due to excessive tensile stress.

Thus we could propose a structural system to minimize seismic response of existing wooden houses. Needless to say, the system is supposed to work when it is applied to new houses. But, there is one important thing to note. That is, no matter how much dampers we install into a house, the maximum acceleration response on its ground floor would be the same as that of the ground. In other word, we cannot expect less acceleration response of the ground floor as long as the house is completely fixed to the ground. Therefore, to get rid of this, we developed a new structural system to let the house slide on the mat foundation, making it possible to cut off extremely strong seismic force. The general concept of the sliding base itself is not an original one. What we want to develop is the one that is so stable as to let the seismic response of the house be predicted very accurately.

2. Outline of Sliding Base System

2.1 Basic Idea

A structural system that we propose here is quite different from the ordinary base-isolation system. The ordinary base-isolation system makes use of rubber bearing to let the natural period of the whole structure long enough to be off the predominant period of ground motions. Or, it uses sliding isolators with very small friction coefficient to cut off the seismic load from the ground to the upper part of the structure. These base-isolation systems are already confirmed to be so effective as to reduce the maximum acceleration of the upper structure to be no greater than 200 cm/s^2. But these isolators are still quite expensive and so those base-isolation systems are mainly applied to large scale buildings. Under these circumstances, we thought of placing a house on a reinforced concrete base which is allowed to slide on a mat foundation to reduce seismic effect on houses. What we wanted is to develop a simpler and less expensive structural system which is stable and, at least, can prevent houses from un-repairable severe damage even when subject to extremely strong ground motions which are supposed to cause catastrophic destruction, though it is not so much effective to reduce acceleration as in the case of using a normal base isolation system.

2.2 General Structure of Sliding Base System

Figure 1 shows how the proposed system is constructed. First, we place a mat foundation on the ground. Then, a high polymer sheet is spread over the mat foundation. We use ultra high molecular weight polyethylene (UHMWPE) sheet. Next, a reinforced concrete (RC) base is constructed on the sheet on site. Proper friction coefficient between the RC base and the high polymer sheet is identified to be 0.2. In addition to a sliding base, the same oil dampers as introduced in the paper by the same authors[1] are supposed to be installed into upper structures. We anticipate that when the house is subject to a minor ground motion or strong wind, oil dampers alone work to decrease vibration. And when the ground motion is extremely strong, there will be a sliding between the ground and the upper structure, making it possible to reduce the maximum acceleration at the top floor of the house as low as 400-500 cm/s^2, which will not cause any serious structural and non-structural damage in the house, including toppling, falling or sliding of the equipments. As to the possible residual displacement, we have already confirmed that the possible maximum amount of residual displacement would be no greater than 30-40 cm. Since the friction coefficient is around 0.2, it is quite easy to let the upper house be back to the original position by means of some light oil jacks. In most cases, the sliding base system could be so designed as not to slide even when subject to extremely strong wind.

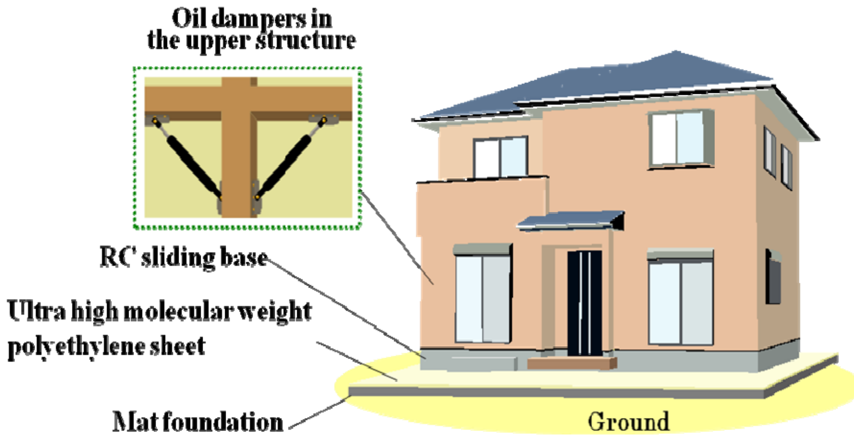


Figure 1. Concept of a house with sliding base

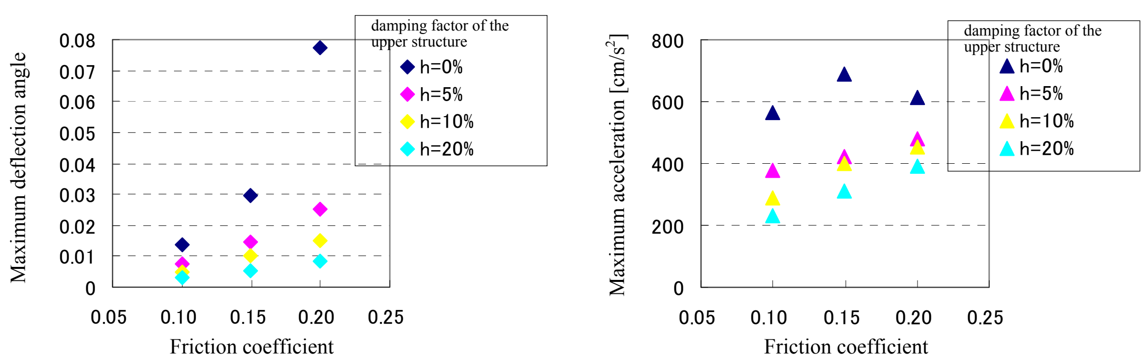


Figure 2. Identification of proper value for friction coefficient

2.3 Identification of Proper Value for Friction Coefficient

Figure 2 explains how we identified the proper value for friction coefficient. In this identification process, we took into account three important factors for effective use of the system. First, we don't need the system to be as effective as ordinary base-isolation system. But secondly, the maximum story deflection of the upper structure should be no greater than 1/100 in order that there will be no need of large scale repairing work even after intense ground motion. Thirdly, it is also required that the maximum acceleration of the top floor should be no greater than 400-500cm/s^2 in order that there would be no sliding, toppling or falling down of equipments in the house. We performed some parametric seismic response analysis making use of a two-story shear model of a wooden house that is subject to NS component of the original seismic acceleration record measured at JMA Kobe in 1995. On the left of Fig. 2, shown is the relation between the friction coefficient on the horizontal axis and the story deflection angle of the first story on the vertical axis. Different colors on these charts correspond to different values of damping factor of the upper structure. This figure indicates that if we install some oil dampers into upper structures, the maximum story deflection can be no greater than 1/100 for less friction coefficient than 0.2. It is also confirmed from the figure on the right, that the maximum acceleration at the top floor will be around 400cm/s^2 as long as the friction coefficient is no greater than 0.2. Thus we identified the proper value for friction coefficient to 0.2. Then, the next problem is finding out the proper combination of materials for the sliding surface.

2.4 Friction Coefficient between Concrete and UHMWPE

In the previous section, proper value of friction coefficient was identified to be around 0.2. So, next thing we have to do is finding out a proper combination of materials for a friction surface, taking into account that they would be not too expensive. We have finally decided to use UHMWPE sheet, on which concrete base is cast on site. Fig. 3 shows how we manufactured a small concrete block used as a test specimen. In the preliminary study, we ground concrete surface trying to make it as smooth as possible. But now instead, we place UHMWPE sheet in the bottom of a wood mold and then concrete is cast. Roughness of the concrete surface decreased to be 1/2 of that finished with a grinder. We thus could decrease friction coefficient from 0.24 to 0.20. We performed an experiment to identify both static and dynamic friction coefficients. Photograph 1 shows the shaking table test of the concrete block placed on the UHMWPE sheet and subject to a 0.5 Hz sinusoidal displacement.

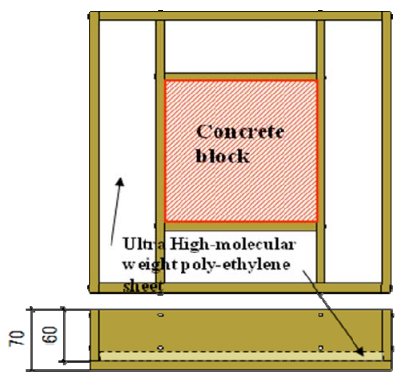
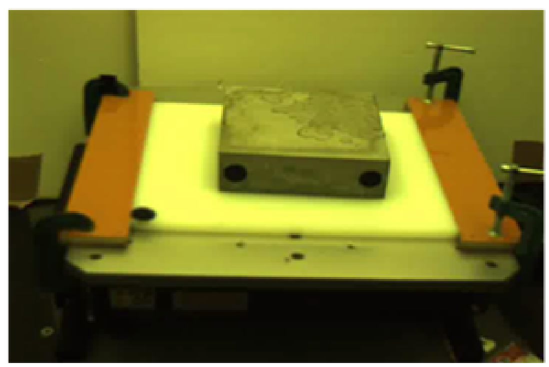


Figure 3. Mold for scaled concrete block



Photograph 1. Shake table test to identify friction coefficient

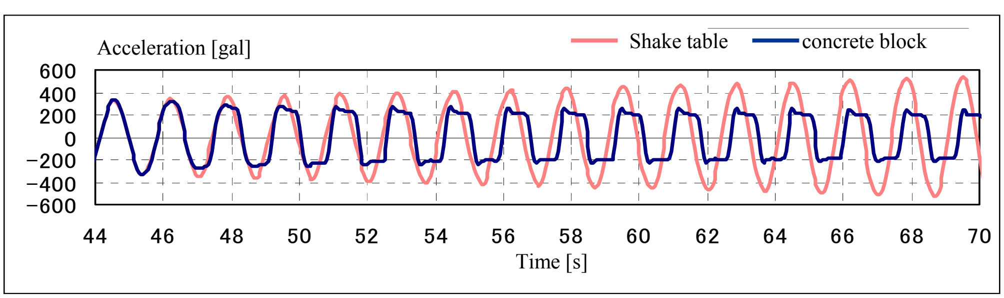


Figure 4. Time histories of acceleration measured on the shake table and concrete block

Figure 4 shows acceleration time histories. The pink line corresponds to the shaking table and the blue line to the concrete block. With the increase of shake table acceleration, inertia force reaches the static friction force and the concrete block starts to slide. When sliding is once triggered, friction force decreases to dynamic one, which almost corresponds to the identified proper value for friction coefficient of 0.2.

3. Full-Scale Shake Table Test

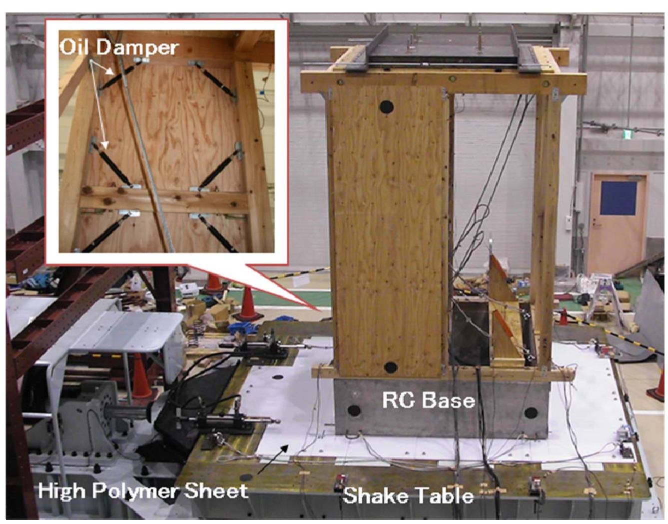
3.1 Test Structural Model

Photograph 2 shows the whole view and the bottom surface of the sliding base. The base is made of reinforced concrete, which is to be cast on site. However, in this test, the base was cast in a mold in the bottom of which a vinyl chloride sheet is spread. From the picture on the right, we can confirm that the concrete surface is quite smooth, as smooth as it shines.

Photograph 2. Whole view (left) and bottom surface (right) of sliding base

3.2 Test System

The whole view of the test system is shown in Photo. 3. UHMWPE sheet is spread out on the shake table. An RC base is placed on the sheet. A wooden frame is connected to the base by means of ground sills and anchor bolts.



Photograph 3. Wooden walled frame provided with oil dampers and sliding base

We conducted the experiment as follows. First, we installed oil dampers in the upper frame and repeated the test increasing the intensity of the ground motion until the maximum deflection of the upper structure becomes around 1/100 of structural height. Then we renewed plywood panels and removed the dampers, and conducted the test following the same manner.

3.3 Test Results

Tests were carried out using the NS component of 1995 JMA Kobe earthquake ground motion. Intensity of the ground motion was normalized to be 30 %, 60 % and 100 % of the original record. There is one thing to note. That is, an almost the same fixed base wooden structure without dampers introduced in the paper[1], collapsed when subject to the same ground motion normalized to be 60 %. In this test on sliding base system, even when the system is subject to the second 100 % ground motion, the upper wooden structures did not collapse regardless of the dampers being installed or not. From Fig. 5, we see notable difference between the two cases, with oil dampers and without oil dampers. In the figure on the top, three different acceleration time histories are compared. The one recorded on the shake table by orange line, the one recorded on the top of the wooden frame by blue line and the one recorded at the RC base by pink line. We can see here that although the maximum acceleration on the shaking table reached nearly 1000 cm/s^2, the other acceleration remains within 400-500 cm/s^2, which is assumed to be

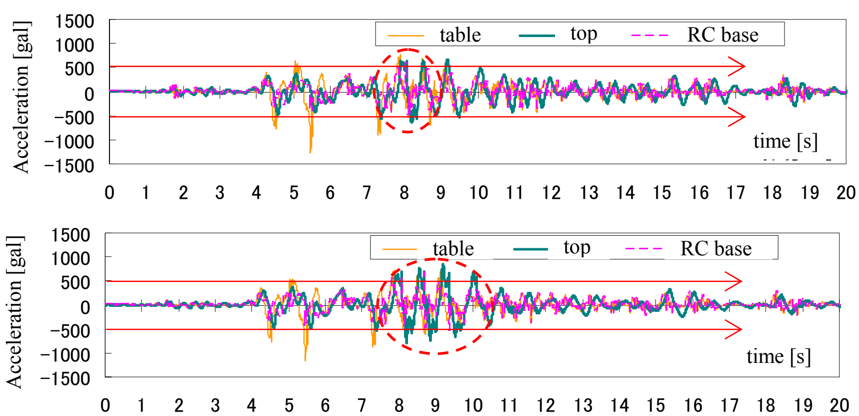


Figure 5. Time histories of the acceleration response of frame with oil dampers (top) and without dampers (bottom)

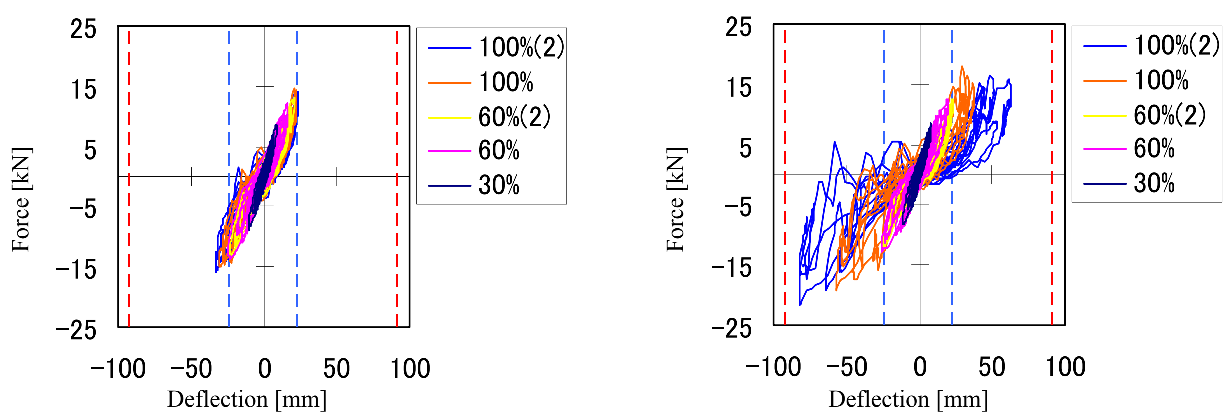


Fig.6 Load-deflection relations of frame (left: with dampers, right: without damper)

the maximum allowable acceleration in the upper structure. If there is no oil dampers, the maximum acceleration seem to be higher than that of the case with oil dampers. The cause of this higher acceleration could be attributed to uplift i.e., rocking motion of the RC base. Since the rocking motion could be prevented by limiting the aspect ratio of the structure to a certain proper value, we can conclude that sliding base structural system is quite useful to avoid excessive acceleration response.

The second point that we regard as the advantage of installing oil dampers is that they work to minimize strength and stiffness deterioration of the upper structure even when the structural system is subject to intense ground motion several times. In the case that oil dampers are installed, load-deflection relations for all tests are superposed in Fig. 6 on the left. Even when 100% Kobe earthquake ground motion is applied twice, the maximum deflection would not be greater than 1/120 of story height, which is usually regarded as the damage level that needs no repair. Contrary to this, we see from Fig. 6 on the right that, if there is no damper, with the increase of the intensity of the ground motion, the maximum deflection increases to be nearly 1/30 of story height, which is usually regarded as the damage level that needs some strengthening work.

Figure 7 shows how natural frequency of the upper structure decreases as the intensity of input ground motion increases. It is seen that if there is no dampers, the upper structure will be severely damaged. By contrast, if proper amount of dampers are installed, the structural deflection will sure remain within allowable damage level. Thus, we came to the conclusion that the proposed sliding base system is quite useful to prevent houses from severe structural damage against even maximum possible intense earthquake ground motions.

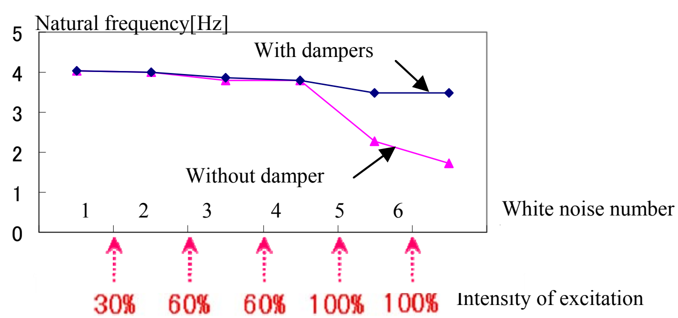


Figure 7. Deterioration of stiffness

3.4 Analytical Simulation for the Fixed Base Model

We could not conduct the test in which the structural system is not allowed to slide. Therefore, seismic response behaviors of both cases are compared by analysis. In this analysis, distribution of friction coefficient is assumed to be uniform, and dynamic friction coefficient between the RC base and UHMWPE sheet is set to 0.2. In the analysis, intensity of the 1995 Kobe earthquake ground motion was gradually increased. First one is 30%, next one is 60%, and next one is again 60% and last one is 100% of that of the original record. Load-deflection relations for different intensity level of ground motions are superposed in Fig. 8. Two figures on the left are given for the case that upper building is placed on the sliding base, in which the top figure corresponds to the case without oil dampers and on the bottom the case with oil dampers. Two figures on the right are given for the case that the same house is fixed to the ground. From the figure on the bottom right, we see that oil dampers do work to prevent the house from total collapse even if the house is fixed to the ground. But if a house is placed on the sliding base and equipped with proper amount of oil dampers, the maximum deflection of the house would not exceed 1/120 of the story height and there would be no need of repair work even after exceptionally strong ground motion.

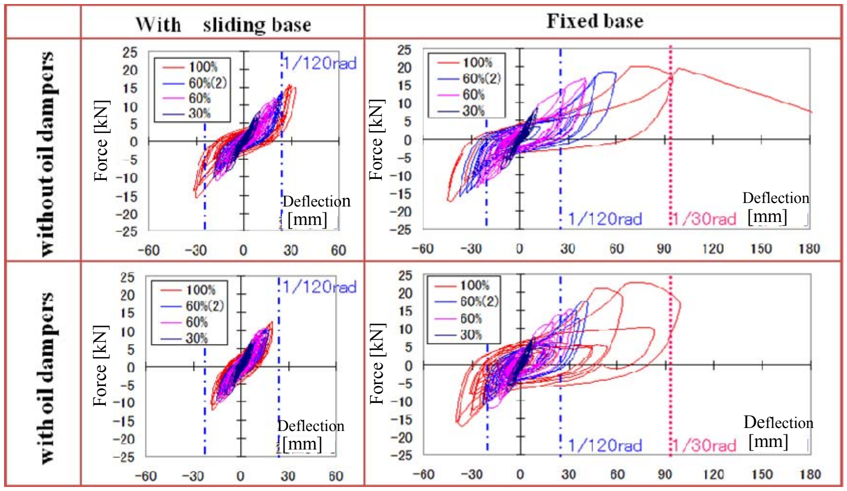


Figure 8. Comparison of Load-deflection relations between the case with (left) and without (right) sliding base

4. Conclusions

Wooden houses, which are so designed as to be regally 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.

In order to get less acceleration response on the ground floor, newly proposed sliding base system is found to be quite effective. The system makes it possible to keep the maximum deflection angle of a normal wooden house within 1/120 without causing greater acceleration than 400-500 cm/s2. Proposed two seismic response control structural system is quite useful because their seismic performance is readily and accurately simulated by analysis.

Acknowledgments

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