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A NEW METHOD OF RESPONSE CONTROL FOR WOODEN HOUSES BY CONNECTING TO SEISMIC SHELTER WITH DAMPER

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Abstract

There are huge number of wooden houses without enough aseismic performance in Japan. Many of them are seriously damaged every time large earthquake occurs. However, seismic retrofitting for them haven't spread widely so far because the construction imposes a lot of cost and burden for their residents. Seismic shelter is an effective alternative to ordinary seismic reinforcement. It is used as a rigid box structure which protects people from collapse of wooden houses. On the other hand, this system cannot reinforce the house itself, therefore it is impossible to protect people who are outside of the shelter when a large earthquake occurs.

According to the background mentioned above, a new method to retrofit wooden houses by making use of seismic shelters is proposed in this paper. In this system, the shelters are connected to wooden houses with oil dampers. The purposes of the using dampers are not only to absorb seismic energy but also to avoid excessive forces entering shelter because it might destroy shelter itself. In order to make clear the effectiveness of this system, time history response analysis considering nonlinear behavior was conducted for various cases. In this paper, a one-story house with 10m×10m plane sizes was used as the target model to be reinforced. The construction of this house was assumed to be built by conventional framework construction method. A shelter with 2.73m × 2.73m plane sizes was installed in each house. Slip-bilinear type hysteresis model was adopted as the restoring force characteristics of both the house and the shelter. They were connected mutually with oil-dampers set at the 4 corners of the shelter. Besides the oil-dampers, normal steel member was also used as connecting members in order to compare with oil-damper's result. Several different types of waves, such as BCJ-L1, BCJ-L2, JR Takatori NS and JMA-Kobe NS, were used as input earthquake motions.

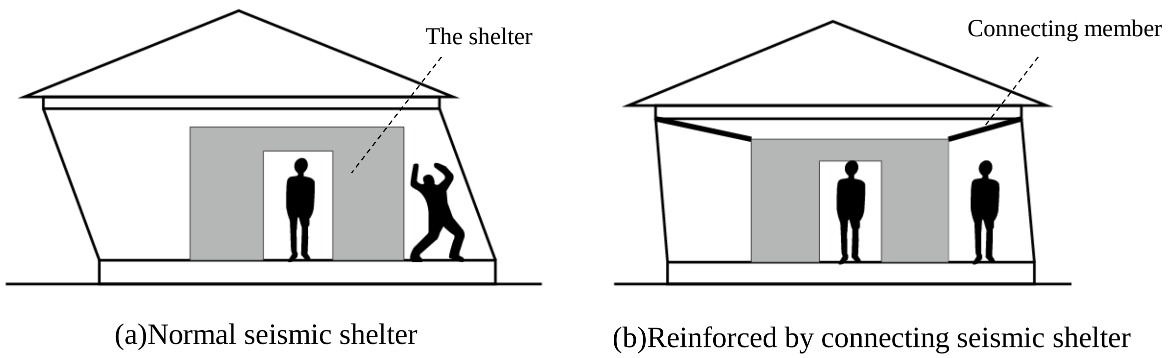
The reduction effects of these models were evaluated in detail by comparison with the results of houses without shelter. It is obvious that the deformation of the houses with shelters decreased significantly. As a whole, it is possible to expect that the responses of houses retrofitted by the proposed method will be reduced by 50-80% in comparison with the responses without shelter.

Keywords: seismic shelter; seismic reinforcement; response control; seismic performance;

1. Introduction

There are huge number of wooden houses without enough seismic performance in Japan. Many of them are seriously damaged every time large earthquake occurs. However, seismic retrofitting for them haven't spread widely so far because the construction process imposes a lot of cost and burden for their residents. Seismic shelters are effective alternatives to ordinary seismic reinforcement[1][2]. They are rigid box structures, and it can be expected for the shelters to protect people from collapse of wooden houses. Therefore, safety of people's life is assured as long as the people are inside the shelters. However, this method cannot reinforce the house itself and save the people who are outside the shelter at the moment large earthquake occurs.

From this background, authors[3][4] confirmed before that the seismic performance of wooden houses are improved by connecting them with the shelter by analytical research (Fig.1). Response reduction effects were verified by the series of time history response analysis.



(a)Normal seismic shelter (b)Reinforced by connecting seismic shelter

Fig.1 — Proposed seismic retrofit method

The large advantages of this method are that not only reliable safety inside the shelter but also improvement of the seismic performance of the wooden houses are expected. However, there is a risk that excessive horizontal force may flow into the shelters, and the shelters may be damaged. It is important to select appropriate combination of the shelter and the connecting members. Therefore in this paper, a new approach to utilize oil-dampers for the connecting members is examined. Vibration of wooden houses is restrained by absorption of seismic energy. In addition, it can be expected that relief mechanism of the dampers prevents excessive horizontal force from flowing into the shelters.

For the purpose to obtain fundamental knowledge about this system, models of one-story wooden houses are used in this analytical study.

2. Anelysis models and parameters

2.1 Outline of analytical models

3m height, 10m wide and 10m long was set as the size of the one-story wooden houses. They were assumed to be built by conventional framework construction method. 900N/m^2 for roof load and 600N/m^2 for wall load were set as loading conditions. Total mass of the models was calculated on condition that the roof area was 1.3 times larger than the floor area, and upper half of the wall was belonging to the mass of the roof. As a result, the total mass at the roof level was calculated to be 15,000kg.

The size of the shelters was set to 2.4m height, 2.75m wide and 2.75m long. The weight of the shelters was estimated to be 1500kg by considering the sum of structural members and the finishing. It was supposed that the bottoms of the shelters were fixed to the foundation of the wooden houses. The wooden houses and the shelters were connected at 4 corners of the shelter. Two types of horizontal yield strength of the shelters, 30kN and 60kN, were ready as the analytical parameter.

2.2Modeling method of restoring force characteristics

Restoring force characteristics of slip-bilinear were adopted for both the wooden houses and the shelters.The characteristics were created by combining the characteristics of slip type and bilinear type[6]. Fig.2 shows the feature of the restoring force characteristics. The yield displacements of types were set to be the same. The primary stiffness and the yield strength were combined at a rate of slip : bilinear=0.85:0.15. The stiffness reduction rate of both types after the initial yield were set to 0.00 or 0.05, respectively.

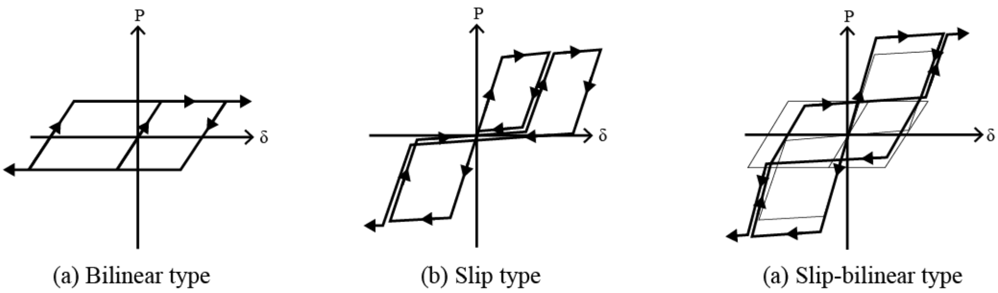


Fig.2－Restoring force characteristics of seismic shelter and wooden house

In this study, analytical models were made by replacing the wooden houses and the shelters for two-dimensional bracing structures models with equivalent structural feature as shown in Fig.3. Restoring force characteristics of slip-bilinear type were input to the bracing members as their axial behavior.

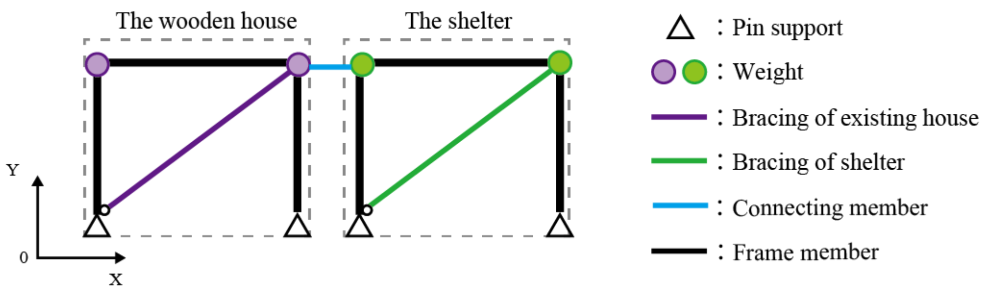


Fig.3－Analysis model by bracing structure replacement

Table 1 shows the analytical parameters of all models. ν_s indicates seismic performance of the wooden house, which is given by following equation

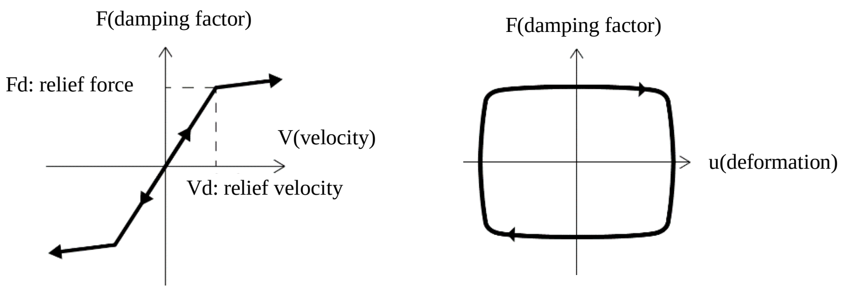
$$\nu_s = W_E / W_R$$

where W_R: total quantity of shear walls existing in the wooden house and W_E: necessary quantity of shear walls required on Japanese building codes.

The parameter ν_s were prepared from 40% to 100% by 20%. The characteristics of dampers were bilinear types having relief valves, and the secondary coefficient of viscous damping was set to 0.05[7]. In this paper, 6 types of dampers combining 3 levels of relief forces with 2 levels of relief velocity were prepared. Totally, 8 types of analytical model including, 6 D models, 1 N model (wooden house alone without shelter) and 1 C model (with rigid steel pipe ϕ 20 as connecting member) were analyzed.

Table 1－The parameters of the analysis model

The analysis model	Connecting member			ν_s of wooden house
	Type	Relief force(kN)	Relief velocity(m/s)	
N	no shelter			20% 40% 60% 80% 100%
C	with steel member			
D20-0.05	with damper	20	0.05	
D20-0.10			0.10	
D20-0.20			0.20	
D40-0.05		40	0.05	
D40-0.10			0.10	
D40-0.20			0.20	



(a)Relationship between damping factor and velocity
(b)Relationship between damping factor and displacement

Fig.4－Damper history model

Time history response analysis was conduct using the program created with numerical analysis software MATLAB. 4 earthquake inputs, such as BCJ-L1, BCJ-L2, JR Takatori NS and JMA-Kobe NS were used as input earthquake. Where, JR Takatori NS and JMA-Kobe NS were standardized at 50 kein. Fig.5 shows the response spectrum of acceleration and displacement of each earthquake.

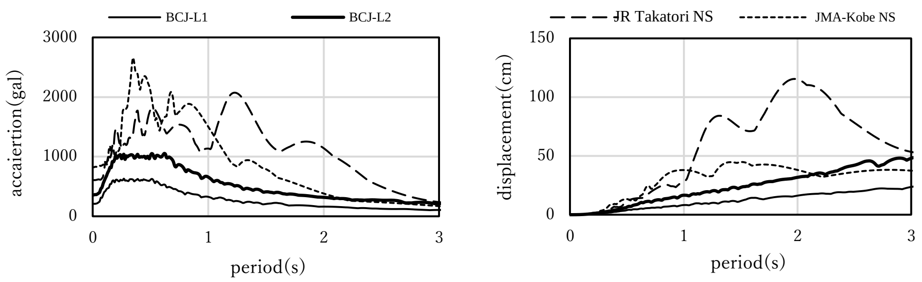


Fig.5－Response spectrum（damping constant 5%）

3.Results of the time history response analysis

The following study shows comparison among the results of N model, D20-0.10 model and D40-0.10 model. The displacement responses of wooden houses with ν_s of 60% for each earthquake are shown in Fig.6, and

Fig.7 shows the relationship between the story shear force and the horizontal displacement of the wooden house and the shelter when JMA-Kobe NS was input. Fig.8 shows the relationship between the damping force and the elongation of the damper.

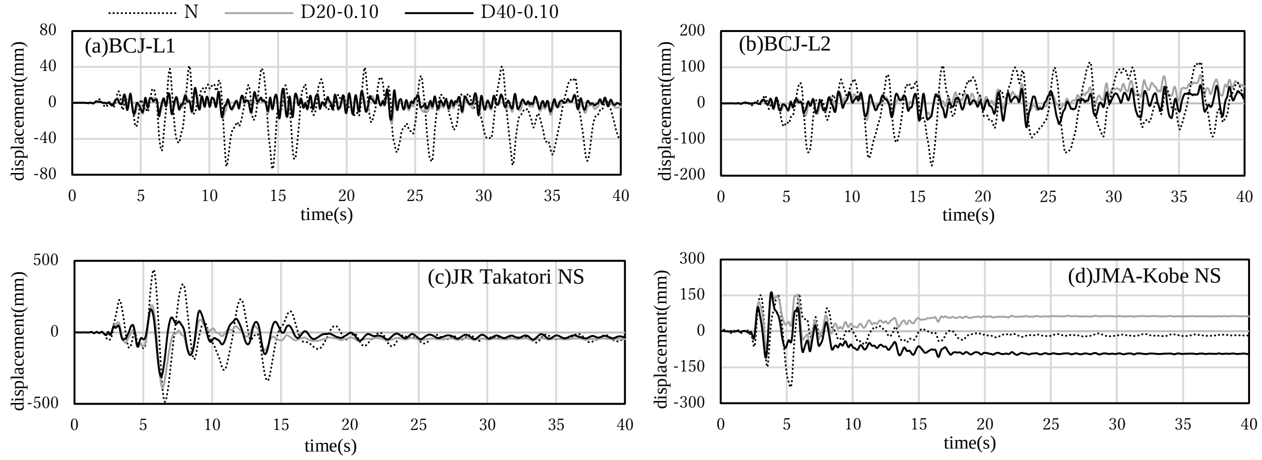
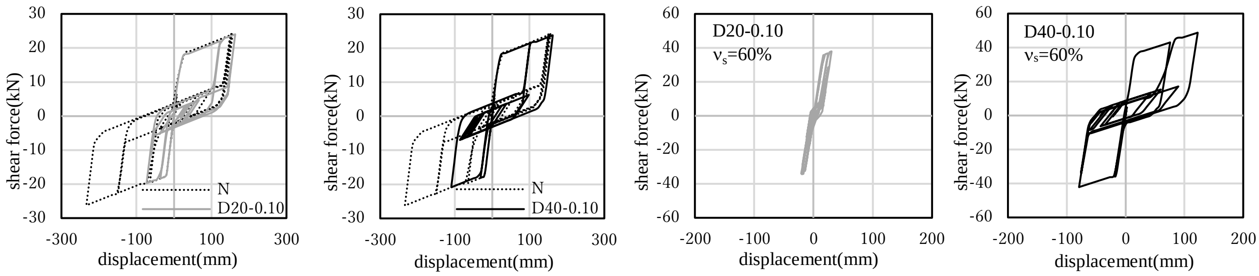


Fig.6－ Comparison with displacement response diagram（ν_s of 60%）

In Fig.6, under BCJ-L1 input, the maximum responses of D models are less by about 70% than that of N model. On the other hand, there are little differences due to relief forces of the damper. Under BCJ-L2 input, the responses of D models are also much less than that of N model. In this case, the response of D40 model is apparently less than that of D20 model. When JR Takatori NS input affects, the maximum responses of D models are reduced by 60% on positive side and 20-30% on negative side in comparison with N model. In the case of JMA-Kobe NS input, large residual deformations causes by lack of rigidity of wooden houses after yielding remained in both D20 and D40 models.



(a)Wooden house (b) Shelter

Fig.7－Relationship between shear force and horizontal displacement (JMA-Kobe NS, ν_s of 60%)

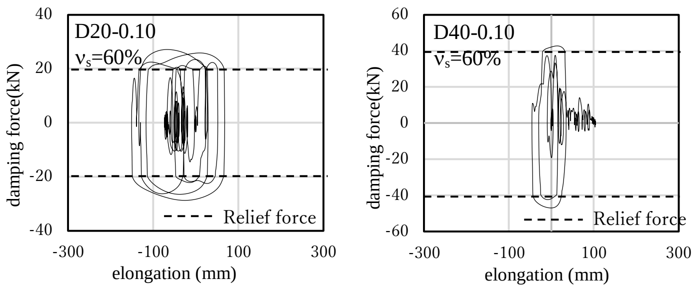
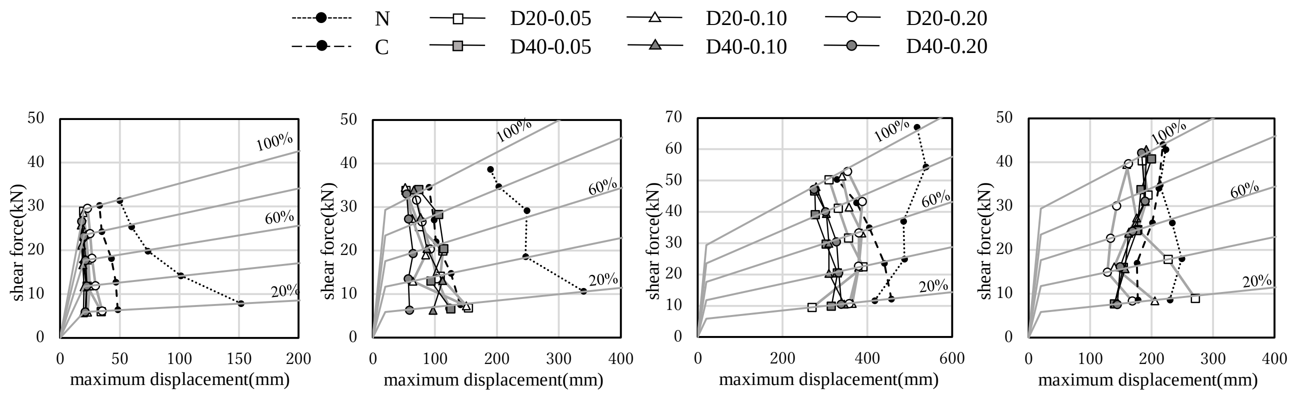


Fig.8－Relationship between damping force and elongation of damper（JMA-Kobe NS, ν_s of 60%）

Fig.7 shows the hysteresis history of slip-bilinear type. In comparison between the models with and without shelter, the maximum displacement and the maximum shear force of models with shelter are less than that of N model. In most cases, the responses of D40 model is smaller than that of D20 model. On the other hand, the shelter of D40 model was damaged more strongly than that of D20 model. Fig.8 shows that horizontal force flowing into the shelter is appropriately limited by the function of damper relief mechanism.

4. Confirmation of maximum displacement for each earthquake

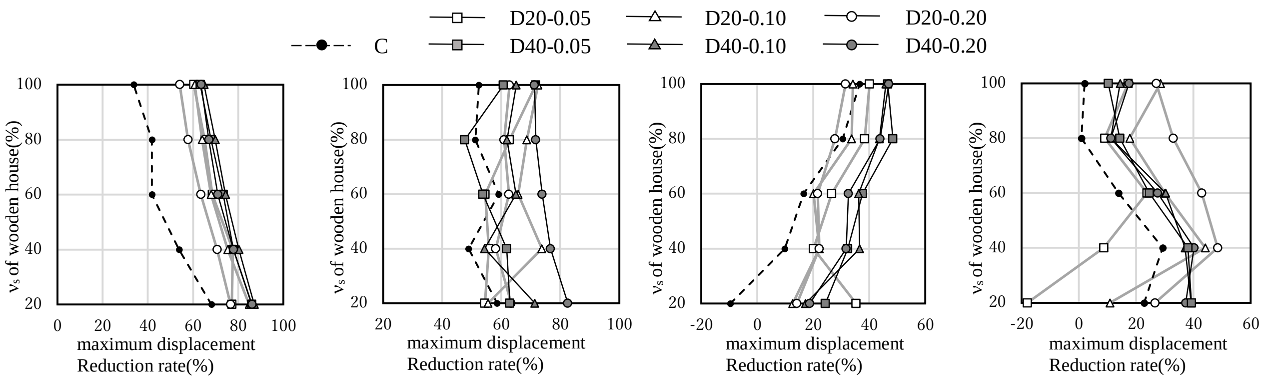
Focusing on the maximum displacement response of wooden houses, the effects of connecting member on the response are examined in this section. Fig.9 shows the relationship between the shear force and the maximum displacement of wooden houses for each cases. The gray straight line indicates the bilinear restoring force characteristics of wooden house for each ν_s.



(a)BCJ-L1 (b)BCJ-L2 (c)JR Takatori NS (d)JMA-Kobe NS

Fig.9－Relationship between shear force and maximum displacement of the wooden houses

Fig.10 shows the maximum displacement reduction rate of each model that is calculated by dividing the maximum response of the wooden house of each model with that of N model.



(a)BCJ-L1 (b)BCJ-L2 (c)JR Takatori NS (d)JMA-Kobe NS

Fig.10－Relationship between ν_s of wooden houses and maximum displacement reduction rate

In the case of the models with shelter, the maximum displacement and the maximum shear force of the wooden houses are low throughout. Among them, the reduction effects of D models are larger than that of C model.

The following is a consideration of each model.

(a)BCJ-L1

The reduction effect increases as ν_s goes down. Maximum response of D models is smaller than that of C model. In comparison between D20 and D40 models, the reduction effect of D40 models was slightly larger than D20's, however the difference between them is not so large.

(b)BCJ-L2

The reduction effect of D models is larger than that of C model. D40-0.20 model shows the smallest response among all models.

(c)JR Takatori NS

Contrary to results of BCJ-L2, the reduction rate increases as ν_s rises. In reference to relief velocity, the differences between them are comparatively amall. The average of the reduction rates is about 30%.

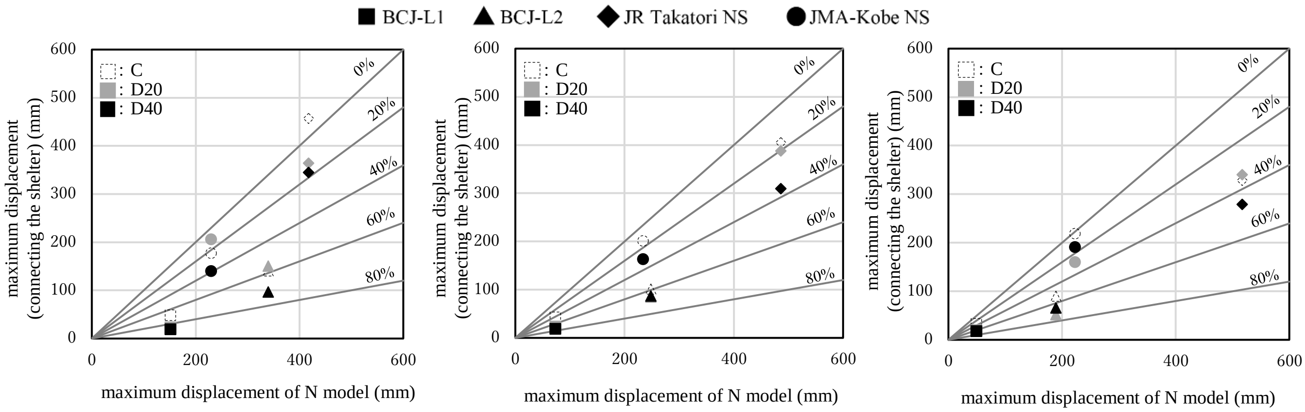
(d) JMA-Kobe NS

The reduction rate of D40 models exceeds the result of C model by around 10%. On the other hand, in some cases, the maximum response of D20-0.50 models are greater than N model.

Seeing each earthquake, it can be said that the reduction effects of this method are confirmed with a few exceptions.

5. About maximum displacement reduction rate of each earthquake rate

Fig.11 shows the relationship between the maximum displacement of N model and each of shelter connecting models in the case of ν_s of 20%, 60% and 100%. Diagonal line of each graph indicates reduction rate is 0% on the line, and the reduction rate increases as approaching to the horizontal axis.



(a)ν_s=20% (a)ν_s=60% (a)ν_s=100%

Fig.11－Relationship between maximum displacement of shelter connecting models(including D models and C model) and N model (relief velocity：0.10m/s)

In each cases, the responses of JR Takatori NS are the largest among the four earthquakes. On the other hand, large reduction effects can be seen under BCJ-L2 input. The reduction rate of JR Takatori NS increases as ν_s increases. As a whole, the rates of almost all models are located below the 0% line, therefore it is possible to say that the reduction effects on this system is confirmed.

6. Conclusion

A new method of response control for wooden houses without enough seismic strength by means of connecting to shelters with dampers is proposed in this paper. By conducting time history response analysis, it is confirmed that the response of wooden houses can be effectively controlled. The responses of models with dampers are largely reduced by the energy absorption effects of dampers. On the other hand, there are no clear differences due to their relief velocity. It is also possible to prevent excessive horizontal forces flowing into the shelter by the function of relief mechanism of damper. It is important to select appropriate dampers depending on the performance of the shelters.

7. Acknowledged

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