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ANALYTICAL STUDY ON SEISMIC BEHAVIOR OF WOODEN HOUSES WITH ROCKING PILLAR

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Abstract

In Japan, large earthquakes occur every few decades and they cause large amount of collapses for wooden houses. In most case, they appear as story collapse on the first floor. The reason why the first-story collapses frequently is not only that the maximum story shear-force is always generated on the floor but also that it is difficult to secure enough baring walls because most of wooden houses have large spaces like garage and living room on the floor. On the other hand, it is very common that the upper floors have enough walls to spare. It means that if it is possible to utilize the remaining strength on the upper floor, the safety of these houses can be largely enhanced. In addition, the improvement of freedom for planning can be capable.

In this paper, a new method to enhance the seismic performance of wooden houses by inserting rocking pillars is proposed. The rocking pillars should have sufficient rigidity and strength, and they are linked to each story at the floor level. They are infixed in structural frames of X and Y directions and fixed on the ground floor with pinned support. The pillars have a role of redistributing shearing forces in the whole building. In order to evaluate the efficiency of this system, parametrical study by means of time history response analysis was conducted.

Two-storied wooden houses were prepared as analytical model. Time history response analysis by means of Newmark-β method($\beta=1/4$) were conducted and the responses of the models with rocking pillars were compared with the results of the models without pillars. Damping factor is set to be h=0.05. Three different types of waves, BCJ-L2, JMA-Kobe NS(standardized to 50kine) and JR Takatori NS(standardized to 50kine) were used as input waves.

It is proved that the utilization of rocking pillars is a very effective method to enhance the safety of wooden houses without sufficient baring walls on the first floor.

Keywords: Rocking pillar; Wooden house; Vibration analytical; Time history response analysis method

1. Introduction

In a land of earthquakes like Japan, one of the most common collapse mechanism of wooden houses is the story collapse on the first floor(Figure 1). Large spaces, such as living room and garage, are tend to be arranged on the first floor while small spaces like bed rooms are planned on the upper floor. Especially in urban area, it is so difficult to secure space with wide frontage for private houses that most of Japanese wooden houses cannot possess enough shear walls on the first floor. It is easy to estimate that the main cause of the first-story coppase is the lack of enough strength on the first floor even though the story shear force on the first floor is the most sizable in multi-story buildings.

In general wooden houses built by conventional system, shear walls on each floor work only for their own story. If it is possible to utilize surplus shear strength of the upper floor for the first floor, it can reduce the possibility of story collapses. In addition, it might realize more flexbile planning for wooden houses.

Wada et al.[3] proposed a research about the function of rocking pillar targeted at seismic retrofit of reinforced concrete building(Figure 2). By installing rocking pillars with sufficient rigidity, it is possible to redistribute story shear forces to the entire building and suppress the possibility of story collapse.

The purpose of this study is to adapt the method of rocking pillar to wooden houses. Through time history response analysis, the effect of this system was examined.

Fig.1 A wooden house damaged by story collapse on the first floor[1]

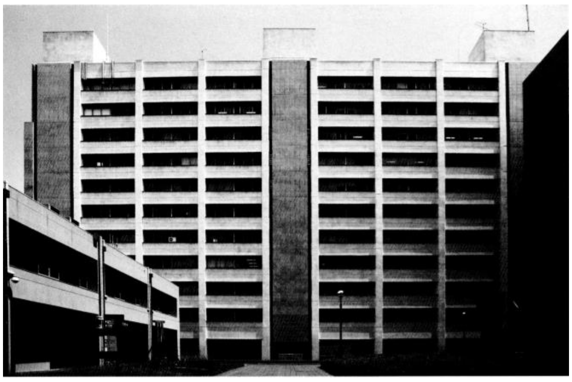


Fig.2 The reinforced concrete building retrofitted with rocking pillars[2]

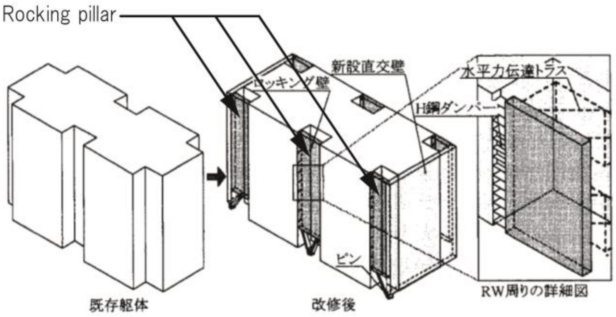


Fig.3 The isometric drawing of this system[3]

2. Study method

Figure 4 shows the outline of study models in this research. They are assumed to be Japanese conventional wooden houses with two stories. To secure enough rigidity and strength for the rocking pillars the property of glulam timber was adopted as the material of them.

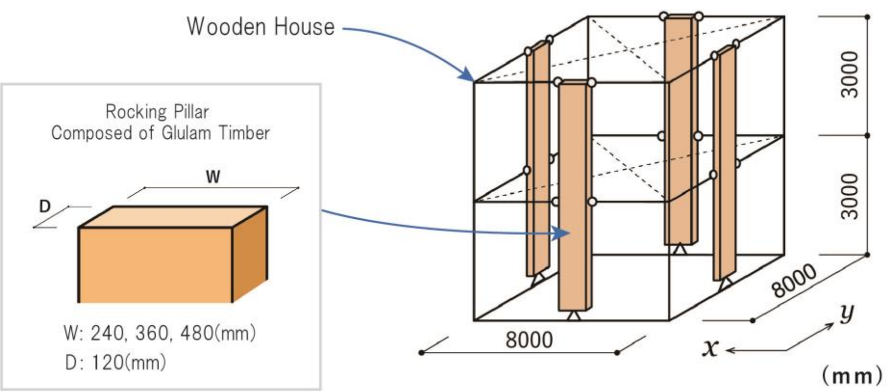


Fig.4 Image of combining wooden house and rocking pillar

Table 1 presents the list of analytical models used in this study. Where, ν_S indicates seismic performance of wooden house, which is given by following equation

$$\nu_S = W_E / W_R$$

Where W_E: total quantity of shear walls existing on each story, and W_E: necessary quantity of shear walls required on Japanese building code. Four values of ν_S are prepared for each story. In case of ν_S=100%, the story share strength is 1.82(kN/mm) for the first floor and 0.94(kN/mm) for the second floor respectively in each one direction.

In this study, parameter ν_S were set assuming cases that the quantities of share walls on the first floor are insufficient while there were enough walls on the second floor. Specifically, ν_S were prepared between 40-100% every 20% for the first story and between 100-220% every 40% for the second story.

Glulam timbers with 13,500(N/mm^2) bending elastic modulus were employed for the rocking pillars. Two pillars were installed in X and Y direction respectively and they were supported at the bottom by pinned support.

Table 1 Parameters of analytical models

W24-04-10 ① ② ③ ④			
Rocking Pillar		Wooden House	
①With or Without	②Cross Section of pillars	③$\nu_{S\text{-}1F}$	④$\nu_{S\text{-}2F}$
N：Without rocking pillar W：With rocking pillar	24：120×240(mm) 36：120×360(mm) 48：120×480(mm)	04：40(%) 06：60(%) 08：80(%) 10：100(%)	10：100(%) 14：140(%) 18：180(%) 22：220(%)

In this study, the models were analyzed by replacing them with simple two-dimensional braced frame models as shown in Figure 5. Total mass of 25(ton) and 15(ton) were added at 2F level and RF level respectively. Figure 6 shows the restoring force characteristic of each floor for horizontal force input by using "slip-bilinear type". Slip-bilinear ratio was set to 0.85: 0.15 based on the previous research[4] and the yield point in inter-story drift angle was set to 1/150 (rad).

Time history response analysis was conducted by Newmark β method (β = 1/4). Rigidity proportional type of damping with damping factor of h=0.05 was adopted.

Table 2 presents the three seismic waves, BCJ-L2, JMA-Kobe NS(50 kine) and JR Takatori NS(50 kine) used in this study. Maximum velocity of the two observed waves JMA-Kobe NS and JR Takatori NS was standardized to 50 (kine).

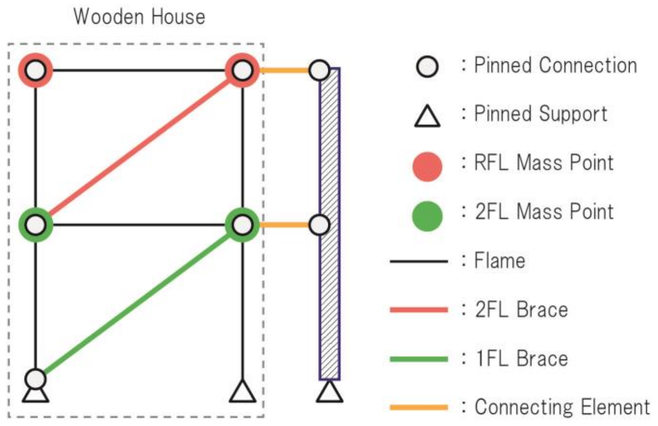


Fig.5 Summary of analytical model

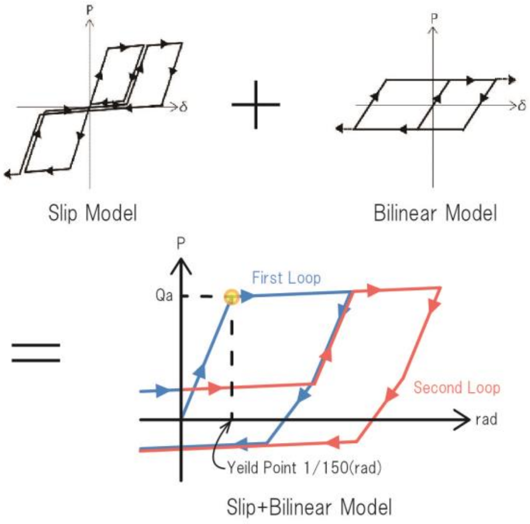


Fig.6 Restoring force characteristic of wooden houses

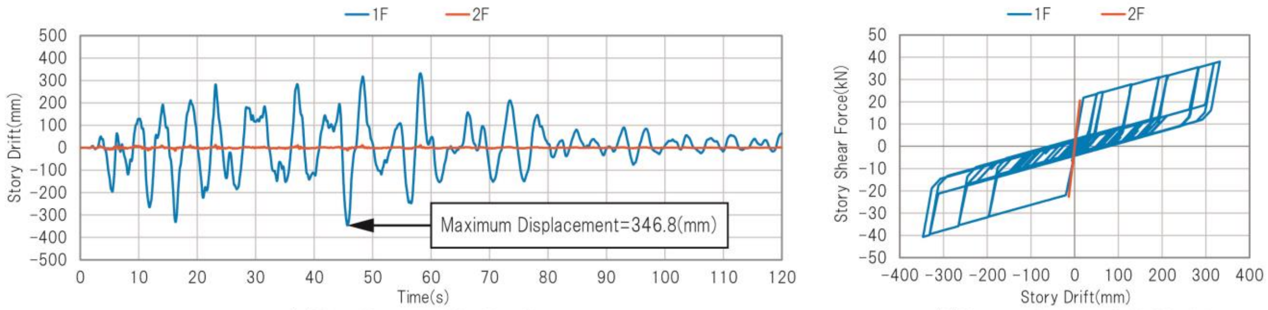
Table 2 Basic information of the input seismic wave

Waves	Year	Direction	Maximum Acceleration (gal)	Maximum Velocity (kine)	Time(s)
BCJ-L2	-		356	50	120
JMA-Kobe NS(50kine)	1995	NS	424 (818)	50 (96.5)	40
JR Takatori NS(50kine)	1995	NS	233 (608)	50 (129.7)	40

The numerals inside ( ) are origins

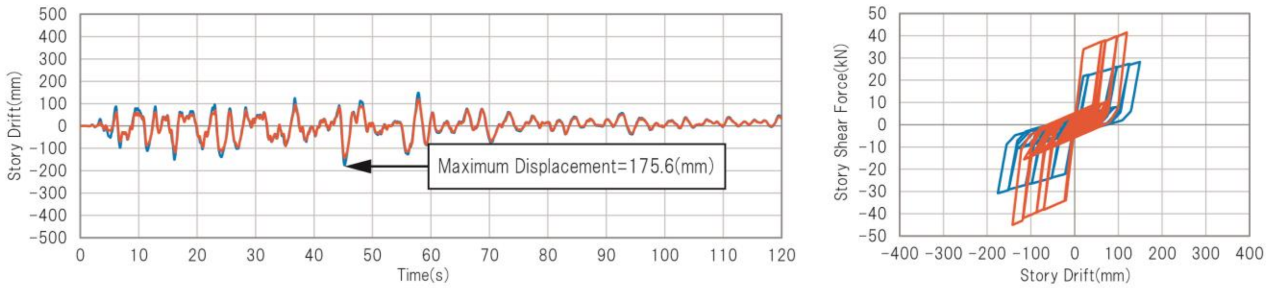
3. Result of time history response analysis

Figure 7-9 shows some examples of the results of time history response analysis.



(a)Time history of N-06-18

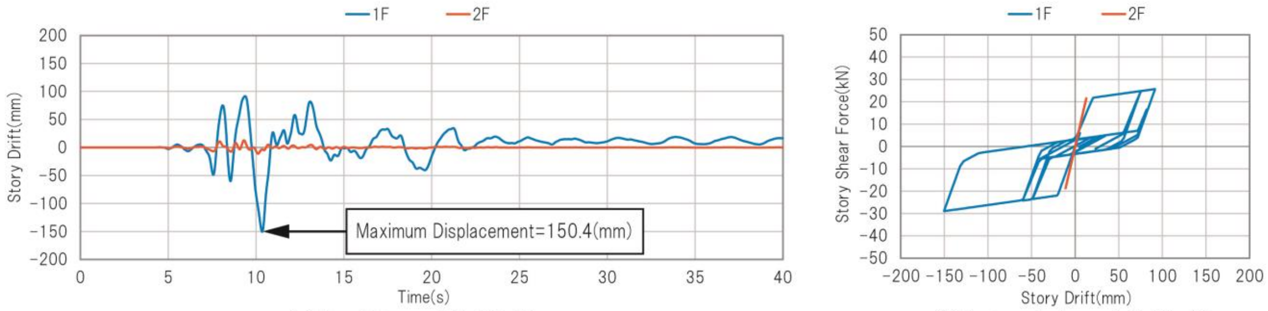
(b)Hysteresis loop of N-06-18



(c)Time history of W36-06-18

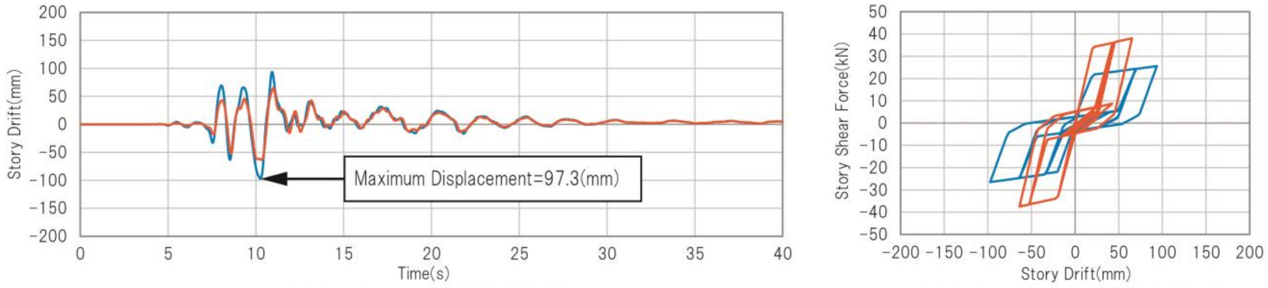
(d)Hysteresis loop of W36-06-18

Fig.7 Results of time history response analysis under BCJ-L2



(a)Time history of N-06-18

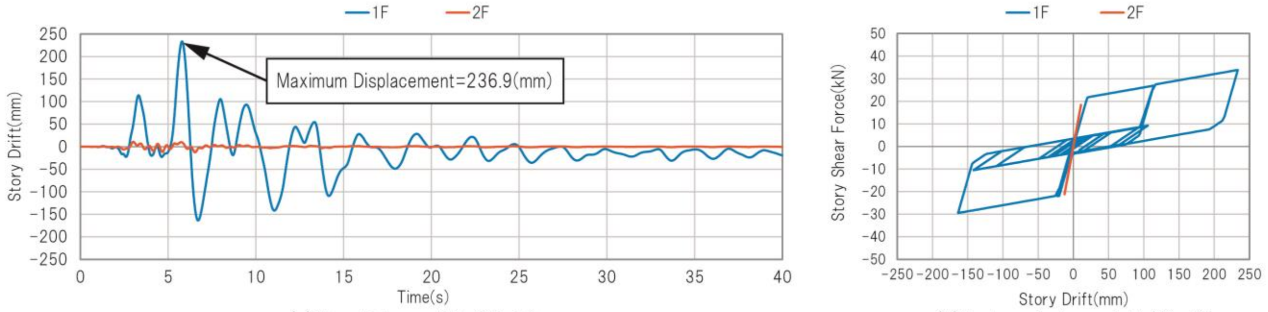
(b)Hysteresis loop of N-06-18



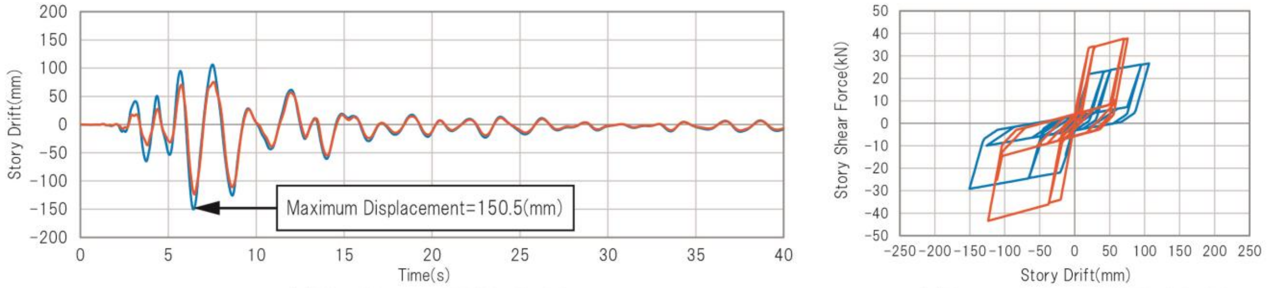
(c)Time history of W36-06-18

(d)Hysteresis loop of W36-06-18

Fig.8 Results of time history response analysis JMA-Kobe NS(50kine)



(a)Time history of N-06-18 (b)Hysteresis loop of N-06-18



(c)Time history of W36-06-18 (d)Hysteresis loop of W36-06-18

Fig.9 Results of time history response analysis JR Takatori NS(50kine)

As shown in the displacement response of these three figures, it is obvious that the second floor responses of the models without rocking pillar (hereinafter called N model) are very low while the first floor shakes very strongly. Comparing with the response of the models with rocking pillar(hereinafter called W model), the maximum inter-story drift of W models are 37-49% lower than that of N model. Focusing on their hysteresis loops, it can be seen that the second floor of N model hardly share horizontal force and most of seismic energy concentrates on the first story. On the contrary, in the case of W model, rocking pillar could disperse the first story's shear force to the second floor.

From these results, rocking pillars work very effectively to reduce the response of the first floor by redistribute story shear forces to the entire building.

4. Maximum displacement reduction due to rocking pillar width

Figure 10 shows the maximum story drift on both the first and the second story of each v_S for three input waves.

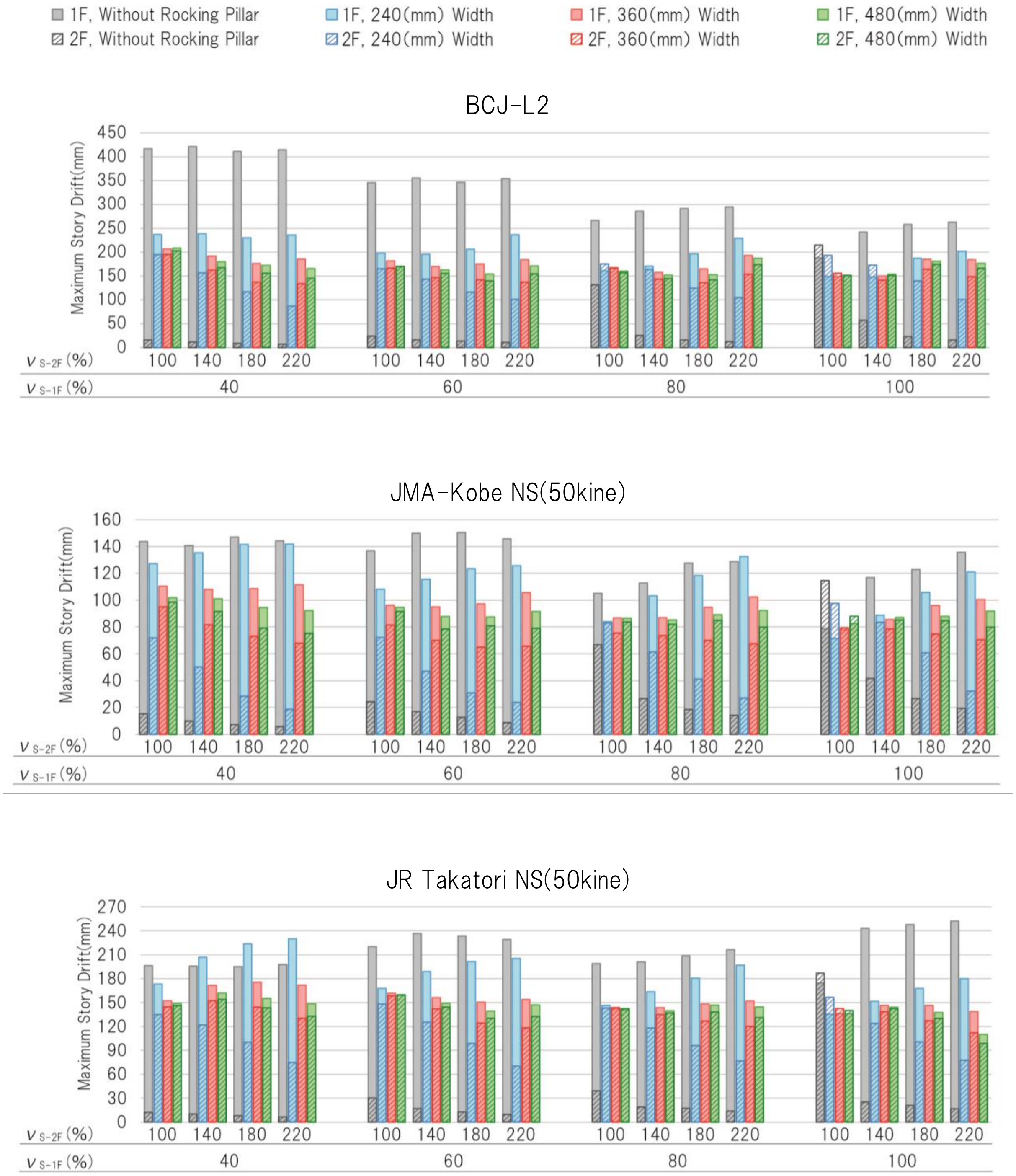


Fig.10 List of maximum story drifts

Under BCJ-L2 input, with regard to the maximum displacement on the first floor, the values of W models are much lower than that of N models for all parameters. According to the magnitude of differences between $\nu_{S\text{-}1F}$ and $\nu_{S\text{-}2F}$, the strength of the rocking pillars influences the response of each story.

Under JMA-Kobe NS (50kine) input, almost all values of W models are lower than that of N models with a few exceptions. The differences between the responses of N models and W24 models are relatively small. Therefore, it is assumed that the rigidity of the pillar with 240mm width is not enough in order to redistribute story shear forces.

When JR Takatori NS (50kine) is input, in the case of $\nu_{S\text{-}1F}$=40%, some W24 models show larger deformation than N models. Like the results under other waves, the strength of the rocking pillar strongly affects the behavior of the models.

While it can be assumed that the rigidity of the pillar with 240mm width is insufficient, the differences between the results of W36 models and W48 models are relatively small. In any case, there are clear reduction effects in most cases.

5. Maximum displacement reduction due to seismic waves

Figure 11 shows the reduction rate of maximum displacement on the first floor under using rocking pillar with 480[mm] width for each seismic wave.

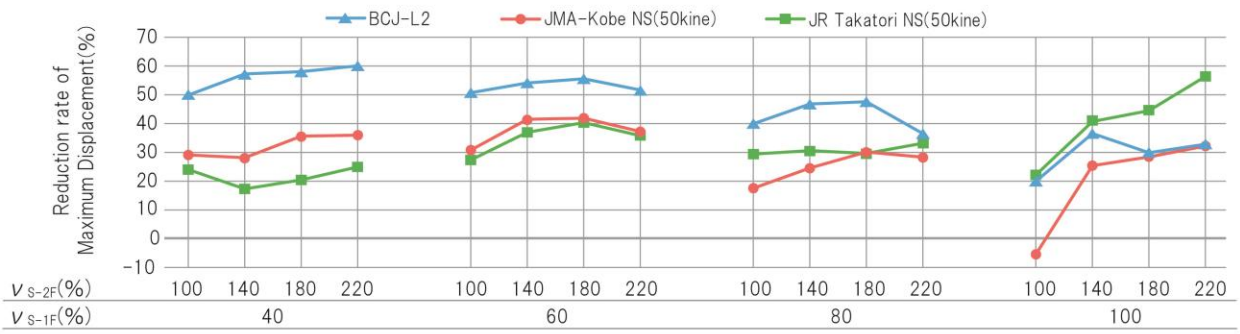


Fig.11 Reduction rates of W48 model’s maximum displacement on the first floor

As a whole, the reduction rates are 20% or more for almost all parameters. Especially W48 models with $\nu_{S\text{-}1F}$=40% show large reduction rates under BCJ-L2 input. Only the maximum deformation of W48-10-10 is larger than that of N model. However excluding that, all model shows 20-60% reduction rates.

6. Conclusion

A new response control method by installing rocking pillars in wooden houses is proposed. The effects of response reduction are confirmed through parametric study using time history response analysis.

By using pillars with enough strength and rigidity, it is possible to reduce the responses under large seismic motions and enhance safety of wooden houses without enough strength on the first floor for large earthquakes.

7. References

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