Multi-dimensional Earthquake Response of Self-Centering Building Structural System Using Uplift Mechanism

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SUMMARY:
A self-centering building structural system using uplift mechanism is proposed. This system, which is also called a rocking system, allows buildings to uplift during earthquakes and prevents them from yielding residual deformation using effect of self weight. In this paper, seismic performance of the proposed system is examined by earthquake response analyses. A steel frame model, which has 10 stories and 1 by 3 bay, is picked up as an application example. The height is 37.8m and the floor dimension is 7.5m and 18m. As input ground motions, three dimensional component records of the 1995 Kobe earthquake (JMA Kobe) are used. Seismic responses of the self-centering frame model are compared with those of the original frame model with fixed bases. Based on these analysis results, multi-dimensional responses of the proposed system are investigated. And the response reduction effects are discussed.

Keywords: Self-centering system, Uplift, Rocking, Multi-dimensional response

1. INTRODUCTION

Past studies have pointed out that the effects of rocking vibration accompanied with the uplift motion may reduce the seismic damage to buildings subjected to strong earthquake ground motions (Meak 1975, Rutenberg et al. 1982, Hayashi 1996). Based on these studies, structural systems have been developed that permit rocking vibration and uplift motion under appropriate control during major earthquake ground motions (e.g. Clough et al. 1977, Huckelbridge 1977, Kasai et al. 2001, Iwashita et al. 2002, Midorikawa et al. 2003, 2006, Azuhata et al. 2004). When rocking structural systems are applied to building structures, some advantages are expected in the seismic building design as shown in Figure 1 (Midorikawa et al. 2006). Using effect of building’s self weight; the rocking system can realize a ‘smart’ self centering system easily and can prevent the building structure from yielding residual deformation even after a severe earthquake. Furthermore, these systems can bring a more rational and economical seismic design of not only super structures, but also foundations.

Usually the rocking system has been applied only to slender buildings. To expand the coverage of it to wider buildings with multi-bays, the authors have proposed a coupled rocking system as shown in Figure 2 (Azuhata et al. 2008).

This study aims to investigate multi-dimensional responses of a building structure to which is applied rocking systems in both x and y directions. In short side of the plan, a single rocking system is applied: in long side, a coupled rocking system is applied. And the response reduction effects of the proposed system are examined.

2. CASE STUDY

2.1. Application example

A steel frame model used in this study is shown in Figure 3. It has 10 stories and 1 by 3 bay.

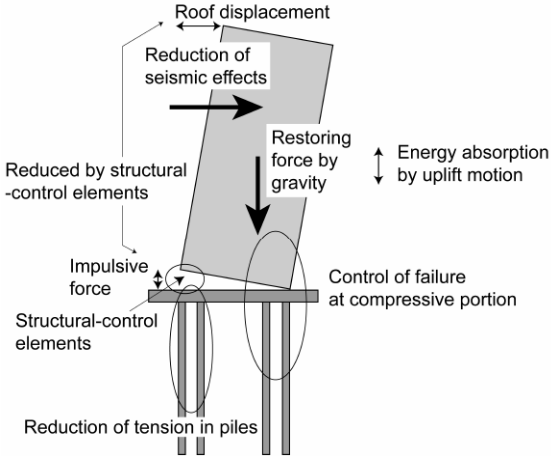


Figure 1. Structural rocking system

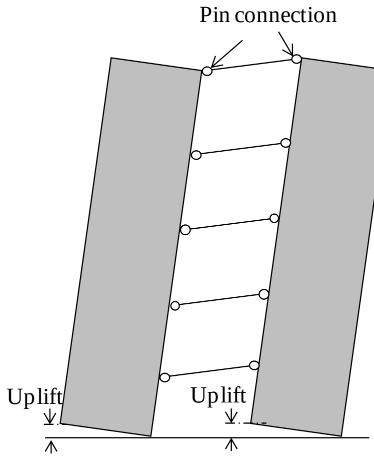
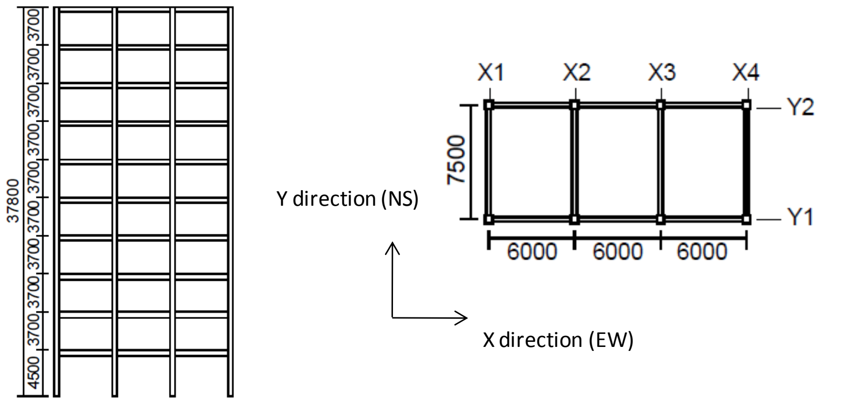


Figure 2. Coupled rocking system



(a) Elevation (b) Plan

Figure 3. Frame model for case study

Table 1. Cross section of structural members

	Floor	Section
Column	8-10F	□-500x500x19
	1-7F	□-500x500x25
Beam		
(X direction)	7-RF	H-440x300x11x18
	5-6F	H-488x300x11x18
	2-4F	H-588x300x12x20
(Y direction)	7-RF	H-588x300x12x20
	2-6F	H-700x300x13x24

The height is 37.8m and the widths are 18m and 7.5m in x and y direction, respectively. The weight of each floor is 1150kN. The cross sections of columns and beams are listed in Table 1. The yield stress of steel used for all members is 294 N/mm^2.

Figure 4 shows application of a proposed rocking system to the frame model. The outline of uplift devices is shown in Figure 5. Devices with friction dampers are inserted in the middle part of the columns on the first floor. The friction dampers control seismic uplift response of columns and dissipate seismic input energy. In Figure 6, the effect of installation point of devices to moment distribution in the frame is examined. It is appropriate to consider the devices a pin, because we can hardly expect the devices to convey bending moment. If the devices are inserted in the column at its bottom, the bending moment of the beam edges become too large as shown in Figure 6 (a). Thus we propose to insert them in the middle part of the columns as shown in Figure 6 (b). More specific view of the proposed devices is shown in Figure 7.

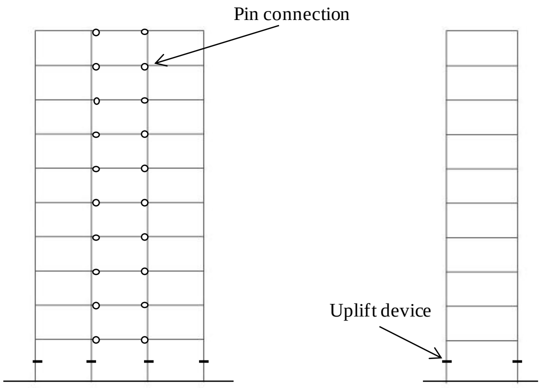


Figure 4. Application of rocking system

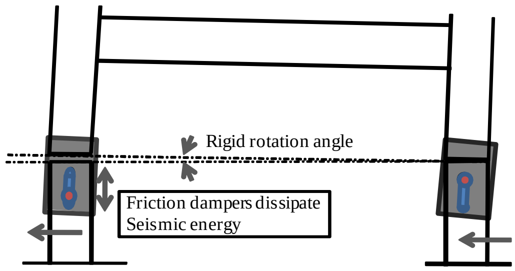
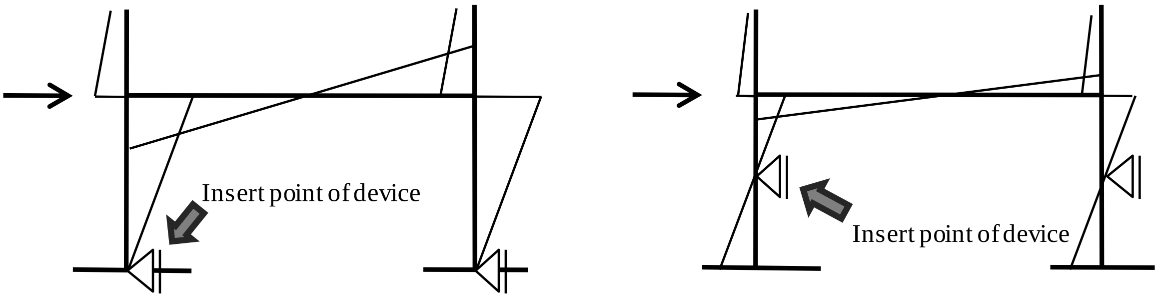


Figure 5. Conceptual model of uplift devices



(a) Insert of devices at bottom

(b) Insert of devices at middle point

Figure 6. Effect of insert point of devices to moment distribution

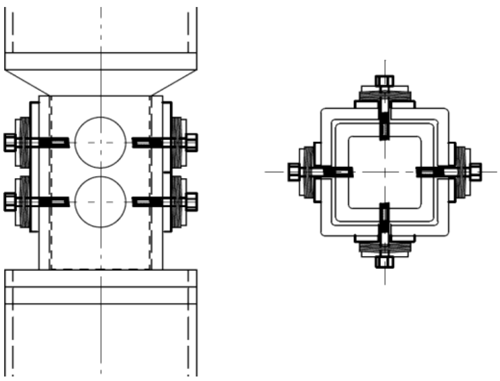


Figure 7. Specific view of uplift devices with friction dampers

2.2. Analytical Procedure

To verify the efficiency of the proposed rocking system, earthquake responses of the original frame model with fixed bases (F model) are compared with those of the improved rocking model (R model). For seismic response analyses, a step-by-step time history integration method (linear acceleration method) is used. Damping is assumed to be proportional to the initial stiffness with 2 % damping ratio. Rigid floor diaphragm assumption is adopted. Figure 8 shows the numerical model of the uplift devices with friction dampers. In vertical direction, a rigid plastic spring, which reveals the friction damper, is combined with non-linear elastic spring, which has gap part. The length of the gap means the deformation capacity of the dampers. The stiffness of the lateral spring is equal to the contact pressure stiffness of column and that of the vertical non-linear elastic spring is equal to the axial stiffness of the column.

As input ground motions, three dimensional component records of the 1995 Kobe earthquake (JMA Kobe) are used. The linear response spectra for 1-DoF systems with damping ratio h=0.05 are shown in Figure 9

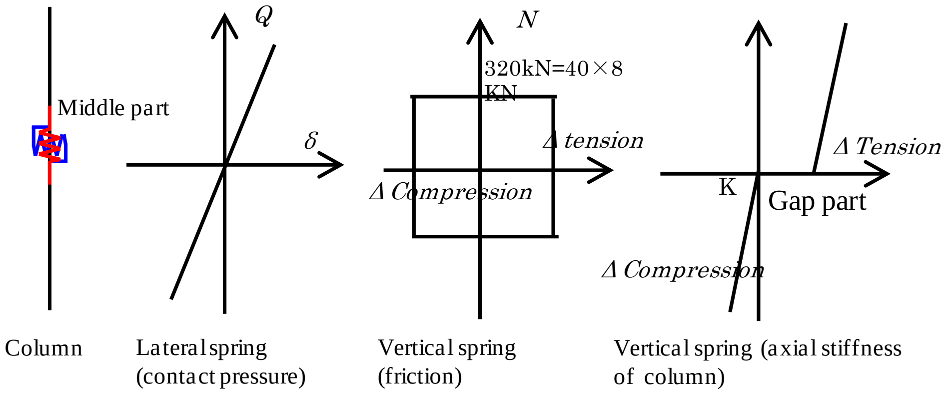


Figure 8. Numerical model for uplift device with friction dampers

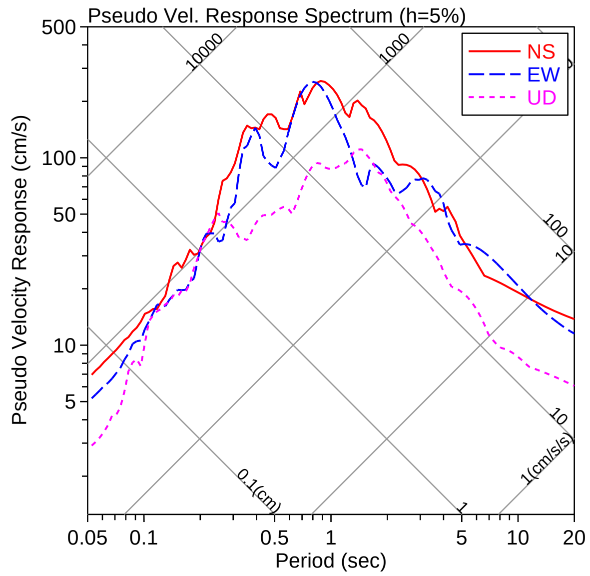


Figure 9. Response spectra of JMA Kobe (h=5%)

2.3. Analysis Results

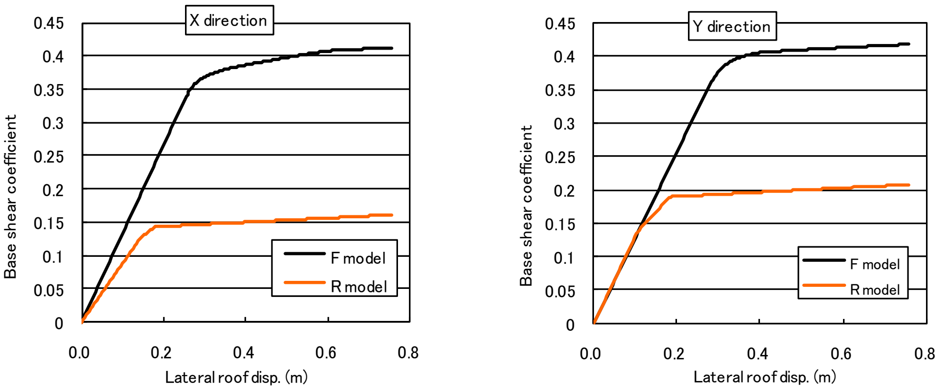
First natural periods in x and y directions of each model are shown in Table 2. And relationships between lateral roof displacement and base shear coefficient are shown in Figure 10, which are calculated by pushover analyses. Figure 11 shows plastic hinges which occurs in F model when its roof displacement drift angle reaches 1/75 (0.504m). On the other hand, Figure 12 shows deformation of R model. Before plastic hinges occur in frames, the structure starts uplifting.

In Figures 13 and 14, lateral roof displacements of R model are compared with those of F model. The lateral roof displacements of R model become larger than those of F model.

Figure 15 shows rotation response of top floor in R model. This model has no structural eccentricity. But when the structure uplifts, it shows rotation responses due to multi-dimensional input effects.

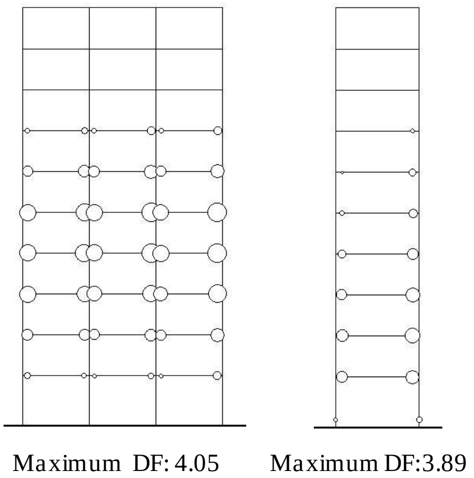
Table 2. First Natural period of each model

	X direction (EW)	Y direction (NS)
F model	1.25 s	1.30 s
R model	1.50 s	1.30 s



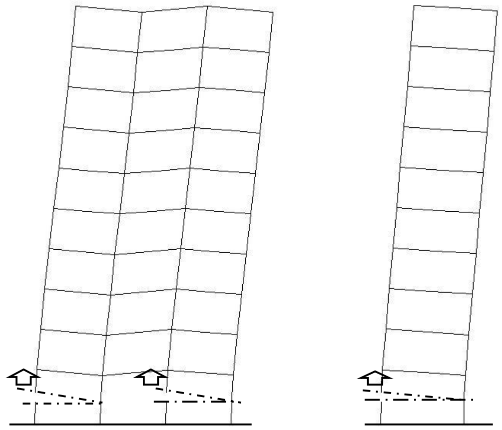
(a) X direction (b) Y direction

Figure 10. Relationship between lateral roof displacement and base shear coefficient



(F model)

Figure 11. Damage aspect of F model when its lateral roof displacement angle reaches 1/75



(R model)

Figure 12. Deformation of R model when its lateral roof displacement angle reaches 1/75

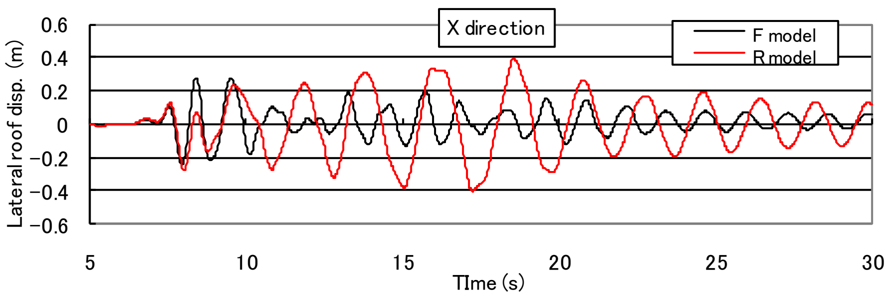


Figure 13. Lateral roof displacement in x direction

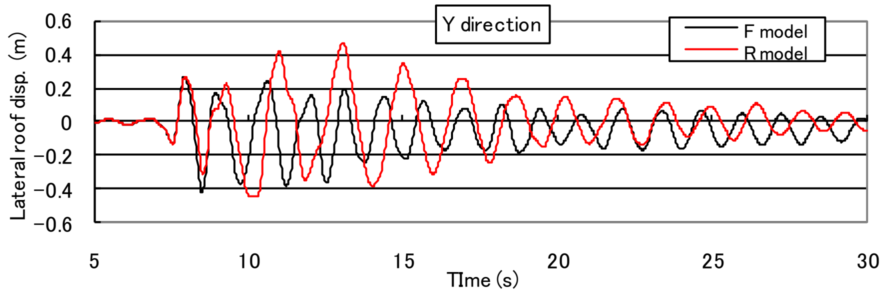


Figure 14. Lateral roof displacement in y direction

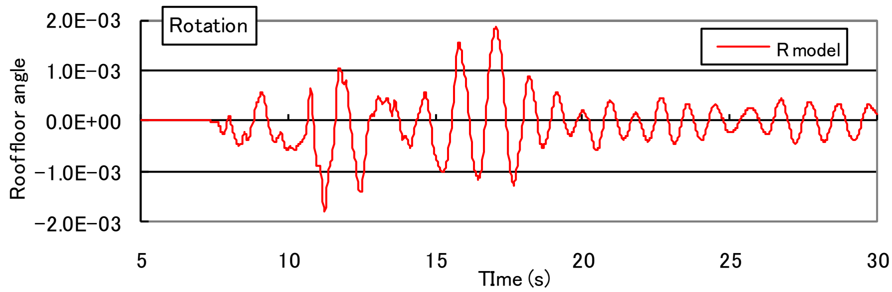
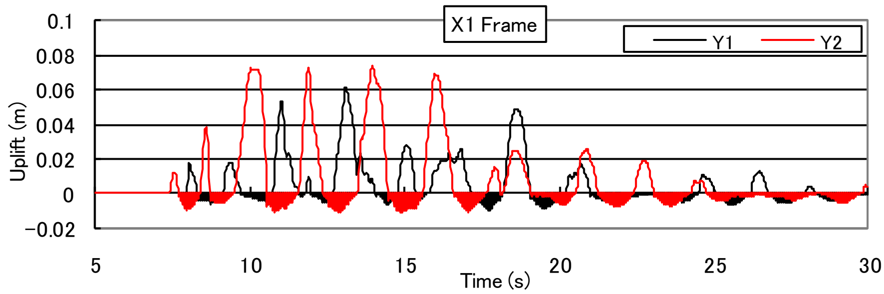
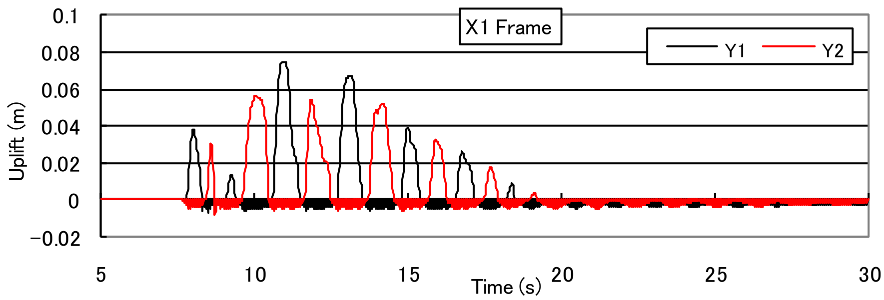


Figure 15. Rotation response on roof floor of R model

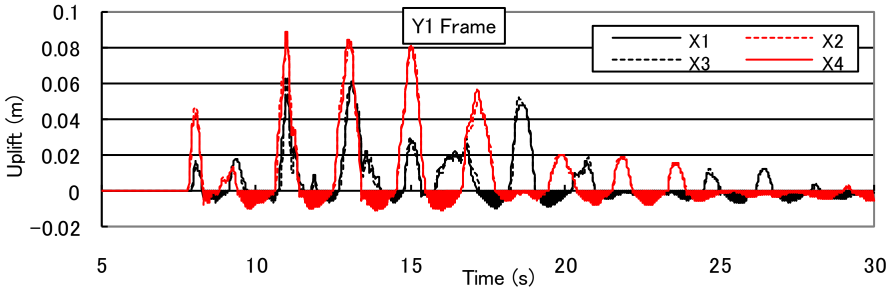


(a) Multi-dimensional inputs (NS, EW & UD)

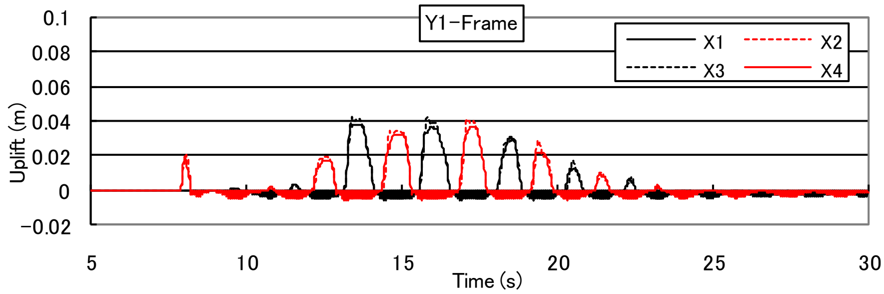


(b) One-dimensional input (only in y direction, NS)

Figure 16. Uplift responses in X1 frame



(a) Multi-dimensional inputs (NS, EW & UD)

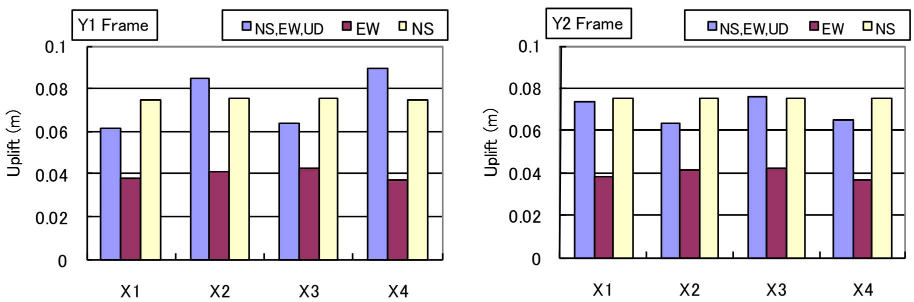


(b) One-dimensional input (only in x direction, EW)

Figure 17. Uplift responses in Y1 frame

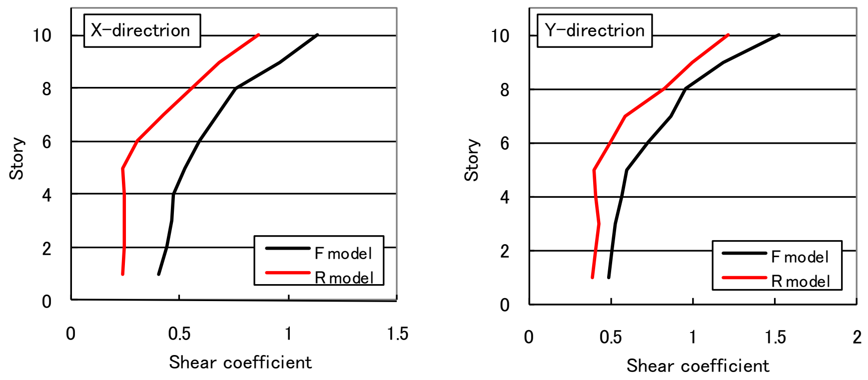
Figures 16 and 17 show uplift responses on uplift devices of X1 frame and Y1 frame, respectively. In each figure, responses against multi-dimensional inputs are compared with those of one-dimensional input. We can see that uplift response is predominant in the y direction during the former part of earthquake. On the other hand, during the latter part of earthquake, uplift response is predominant in the x direction. In Figure 18, maximum uplifts against multi-dimensional inputs are compared with those against one-dimensional input. The uplift responses against multi-dimensional inputs tend to become larger than those against one-dimensional input on some uplift devices. However these graphs show that we can approximately estimate maximum uplift against multi-dimensional inputs from the corresponding one against one-dimensional input.

Figure 19 shows maximum shear forces of each story of R model, comparing with those of F model. Analysis results clear that story shear forces of F model can be reduced by applying R model.



Y1 Frame Y2 Frame

Figure 18. Maximum Uplift against multi-dimensional inputs and one-dimensional input



X direction Y direction

Figure 19. Comparison between shear coefficients of R model and those of F model

3. CONCLUSIONS

The self-centering system using uplift mechanism was proposed to reduce seismic damage of steel buildings. This system is allowed to uplift and realize a self-centering system using effect of building's self weight.

Seismic performance and dynamic behavior of the proposed system against multi-dimensional inputs were examined by executing seismic response analyses to a case study model. When a building structural model to which is applied the proposed system (R model) starts uplifting, rotation response occurs. And the rotation response tends to amplify uplift response on some part of the R model. However this effect was not serious in the case of this study.

And the analysis results cleared story shear forces of a fixed base model (F model) can be reduced by applying the proposed system. On the other hand, roof displacements of R model became larger than those of F model. When we apply the proposed system to buildings, we need to pay attention to displacement responses and to control uplift by using appropriate uplift devices.

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