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SEISMIC PERFORMANCE OF FIXED-MOVABLE-FIXED SUPPORTED FOLDED CANTILEVER SHEAR STRUCTURE

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ABSTRACT

The work presented in this study discusses as analytical and experimental models developed of folded cantilever shear structure as a new seismic isolation approach for middle multi-storey building. The previous study of folded cantilever shear structure model was proposed by two parts namely fixed and movable sub-structure, now that structure is developed to acquire symmetrical structural regularity consists of fixed – movable – fixed shear sub-frames and connection sub frame which connects their sub-frames by a rigid connection at the top. The movable sub-frame is supported by roller bearings. Besides, additional viscous damper are attached laterally between beam to improve seismic performance and increase damping ratio. The seismic behavior of the proposed structure is investigated by using analytical and experimental studies. The 16 stories of folded cantilever shear structure model are conducted for experimental study, and also shaking table test is carried out. The observation points are set at top floor and movable bottom floor to investigate the structures responses. The numerical models and time histories analysis are simulated by used spring-mass model and 3D model of commercial software packages called ABAQUS and SAP2000. The seismic responses diagrams of experimental and analytical results are reasonable agreement.

The complex eigenvalues analytical results are clarified that the first natural period of the proposed structure can be extend almost two times longer than ordinary structure with the same number of story and the time history analysis are showed the effectiveness of viscous dampers to reduce the seismic responses of structures.

Keywords: folded cantilever shear structure, viscous damper, seismic performance, damping ratio, shaking table test.

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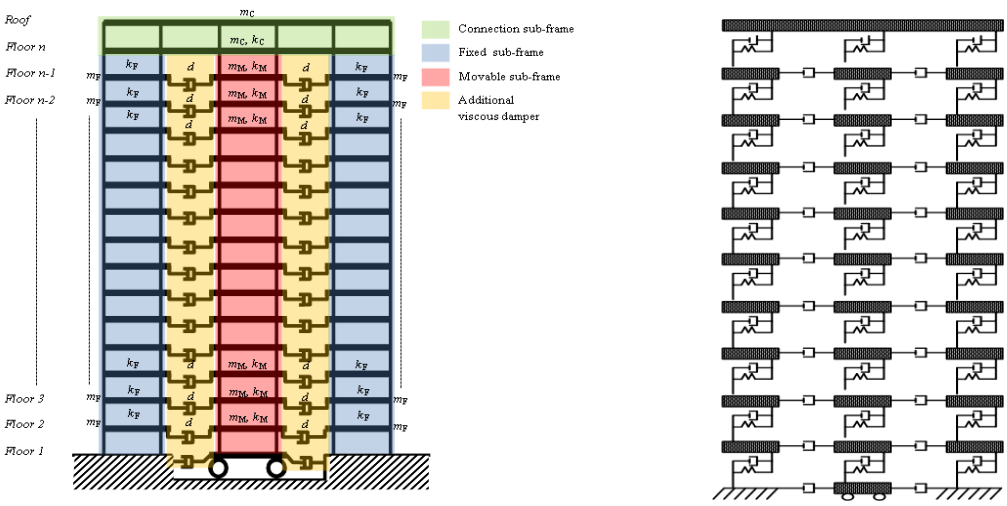
1. INTRODUCTION

In the last decades, many seismic design methods have been developed to resist the impacts of earthquake. Some methods were developed including base isolation and damping device to reduce the seismic response of structure. In the previous study, new approach to improve seismic performance of multistory building was introduced. Previous study was conducted by using folded cantilever shear structure model consisting only fix – movable sub-frames and the results are clarified that the first natural period of proposed structure can be extended almost two times longer than ordinary structure with the same number of stories and the effectiveness of viscous dampers are quite increased (Kaya et al. 2011).

In this study, structural system of proposed structure is modified to acquire symmetrical structural regularity and examined in terms of natural period and damping ratio. Therefore, analytical and experimental studies were conducted in order to compare the seismic performance of propose structural system. The analytical models and time histories analysis are simulated by used spring-mass model and 3D model of commercial software packages called ABAQUS and SAP2000.

2. MODEL OF FOLDED CANTILEVER SHEAR STRUCTURE (FCSS)

The proposed structure consist of four main parts including fix – movable – fixed shear sub-frames and connection sub-frame which connects to each other by a rigid connection beam on the top as shown in Figure 1. Fixed sub-frames are clamped to the ground on both sides and middle part which is movable sub-frame supported by roller bearings to increase flexibility of the structure. Besides, additional viscous dampers are supplemented between beams laterally to connect sub-frames to each other and minimize displacements to be occurred due to seismic movements and increase damping ratio as well.



(a) Description model of FCSS (b) Spring-mass model of FCSS

Figure 1: Folded cantilever shear structure model.

Besides, the column stiffness is represented by letter *k*, mass of beam is *m* and the additional damping coefficient is *d*. According to the main parts, the mass of beam fixed sub-frame, movable sub-frame and connection sub-frame are represented m_F, m_M, m_C, respectively. k_F, k_M, k_C, are column stiffness of fixed sub-frame, movable sub-frame and connection sub-frame, respectively.

3. ANALYTICAL STUDY OF FOLDED CANTILEVER SHEAR STRUCTURE

The first study was conducted to investigate of proposed structure behavior analytically. The specified parameter of proposed building and ordinary building are summarized in Table 1.

Table 1: Structural parameters of FCSS and OCSS models

Parameters	*Proposed Building (FCSS)*	*Ordinary Building (OCSS)*
Total height, H	38.5 m	38.5 m
Number of stories, n	11	11
Story height, h	3.5 m	3.5 m
Story mass (kg)	m_F : 125,000 m_M : 250,000 m_C : 500,000	500,000
Total mass	6,000,000	5,500,000

To examine the proposed structure, a set of numerical analyses including eigenvalue and dynamic response analysis were performed through two models, OCSS also FCSS with and without damper.

Based on the eigenvalue analysis, the first natural period of proposed structure is obtained around 2.57 second, while the ordinary structure has around 1.16 second. The natural period of proposed structure is almost two times longer than ordinary structure. As an ordinary structure, OCSS model has 0.02 of structural damping ratio, whereas the FCSS model with additional damper has 0.22 of damping ratio.

The dynamic analysis was conducted to investigate the seismic behavior of numerical models due to El Centro 1940, Taft 1952, and Hachinohe 1968. The acceleration and displacement responses histories shown in Figure 2, the FCSS proposed structure can reduce the structure responses.

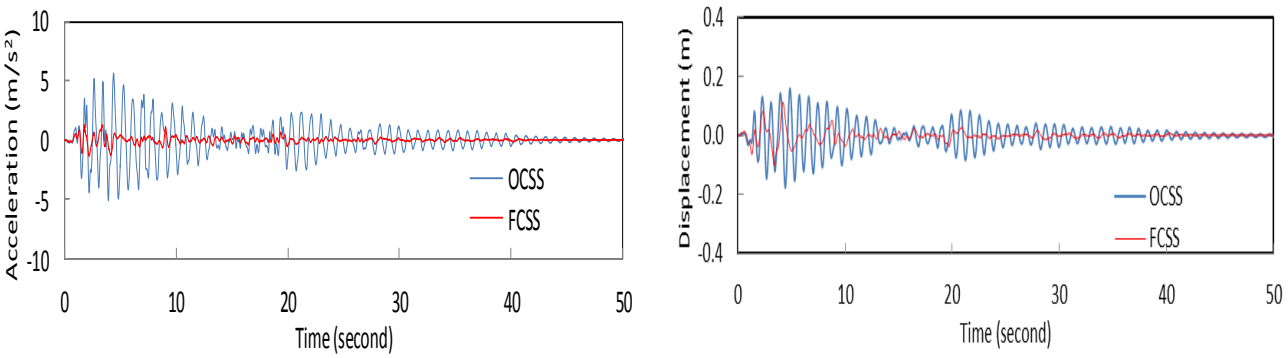
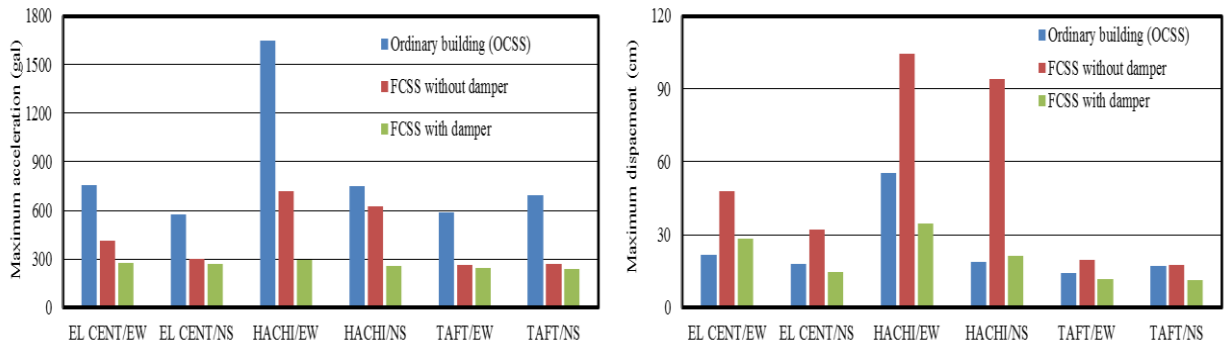


Figure 2: Acceleration and displacement responses history of OCSS and FCSS models at the most upper floor due to El Centro NS earthquake wave.

The maximum responses for each earthquake wave are summarized graphically of bar chart; it can be seen in Figure 3. As compared, the proposed structure can reduce the acceleration of the ordinary structure around 20%-50% and 40%-80%, without damper and with damper respectively.

Figure 3 also shows the proposed structure without damper give the biggest displacement response. It increase 1.4 to 5 times of ordinary structure, it was caused decreasing the horizontal stiffness of the structure. When the additional damping device is attached, it can reduce the displacement response than ordinary structure generally.



(a) Maximum acceleration resnponses (b) Maximum displacement resnponses

Figure 3: Maximum responses of OCSS, FCSS with and without damper models at the most upper floor for each earthquake wave.

4. EXPERIMENTAL STUDY OF FCSS MODEL

4.1. Experimental test model

Study of 16-story of the proposed model was tested through shaking table as shown in Figure 4. Aluminum alloy rectangular plates are used as beam and continue polycarbonate screws are used as column. The total height of model is 1.470m.

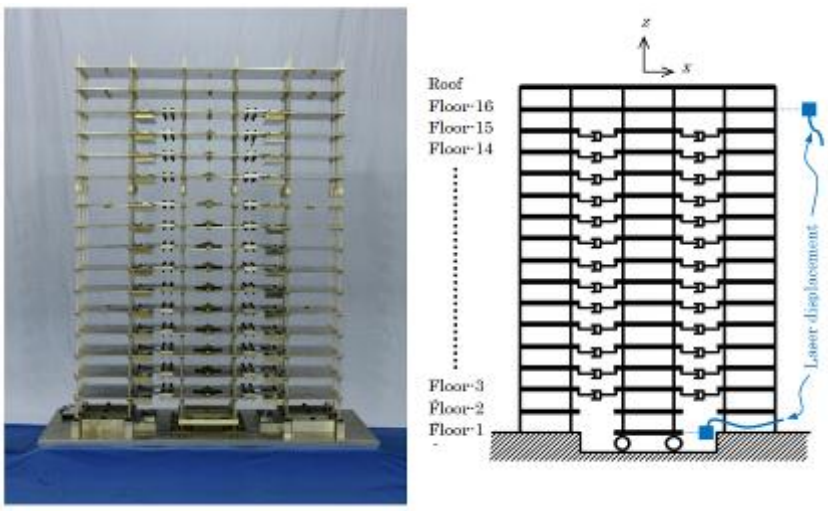
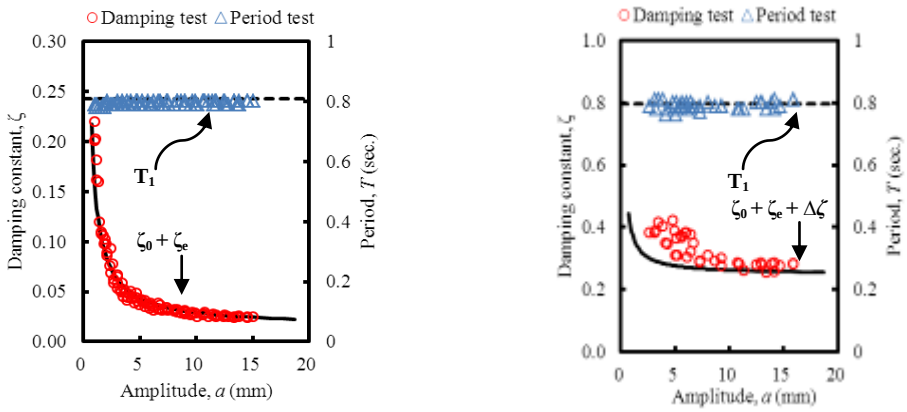


Figure 4: Experimental model of proposed FCSS.

4.1.1. Free vibration test

The free vibration test is carried out for FCSS without and with additional damper, the period and damping constant are obtained as shown in Figure 5, respectively. First period of the FCSS without damper system is around, T_1 = 0.808 sec. and the FCSS with damper is T_1 = 0.796 sec.



(a) Without additional damper (b) With additional damper

Figure 5: The damping constant and period of proposed FCSS model

As shown above, ζ_0 is constant structural damping; ζ_e is equivalent damping constant due to frictional force obtained from Eq. (1), $\Delta\zeta$ is additional viscous damping constant and a is displacement amplitude.

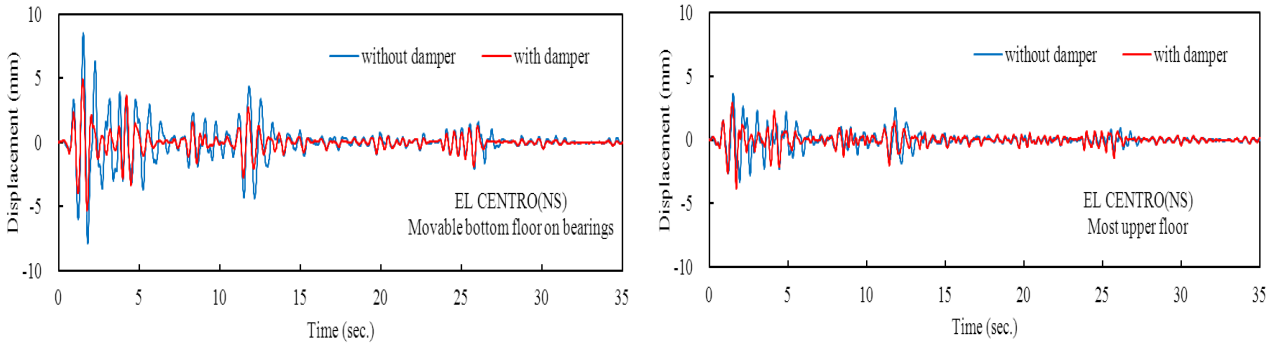
$$\zeta_e = \frac{2 f_b |\phi_b|}{\pi\theta\omega} x \frac{|\phi_i|}{a_i} \tag{1}$$

where, f_b is friction force of the roller bearing, ϕ_b is the amplitude of natural vibration mode at movable base , ϕ_i is the amplitude of natural vibration mode at observation point, θ is frequency during a steady state motion , ω is natural frequency , a_i is displacement amplitude of observation point (Katayama et al. 2008).

4.1.2. Shaking table test

The shaking table experimental analysis is carried out for El Centro, Taft, Hachinohe earthquakes respectively and then the displacement responses of the experimental test model for each of these earthquakes are obtained. To set an example, only displacement responses due to El Centro NS earthquake are given in Figure 6. Then the response value results of the others are summarized graphically of bar chart in Figure 7.

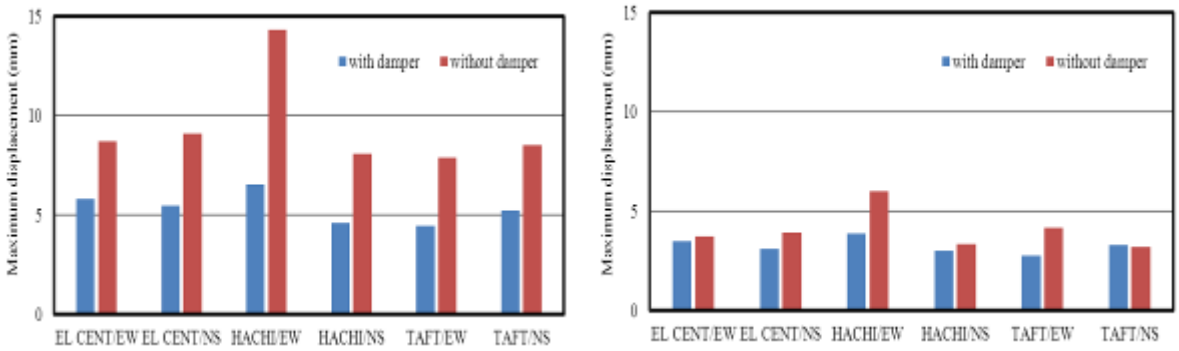
Figure 6 show the displacement responses of proposed FCSS model at the bottom floor. In here, the displacement responses decrease significantly when the additional damper is attached in structure. In the other side, at the most upper floor, the effect of additional damper is not significant than at the bottom, however it still can reduce the displacement responses.



(a) Movable bottom floor (b) Most upper floor

Figure 6: Displacement responses of FCSS model with and without damper.

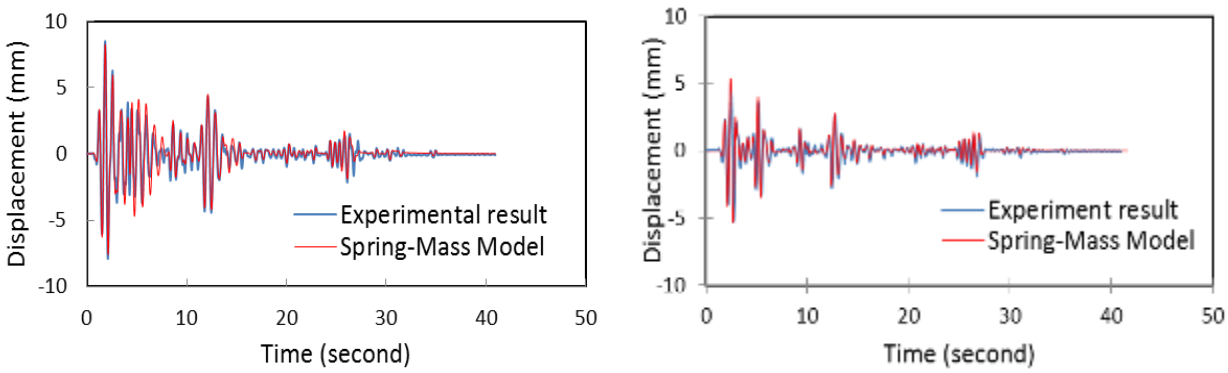
Figure 7 show maximum displacement responses for all earthquake data waves. As mentioned above, the additional damper gives effect significantly to reduce the maximum displacement at the bottom floor than the most upper floor. It is shown when the additional damper attached in model, the maximum displacement is decrease, generally.

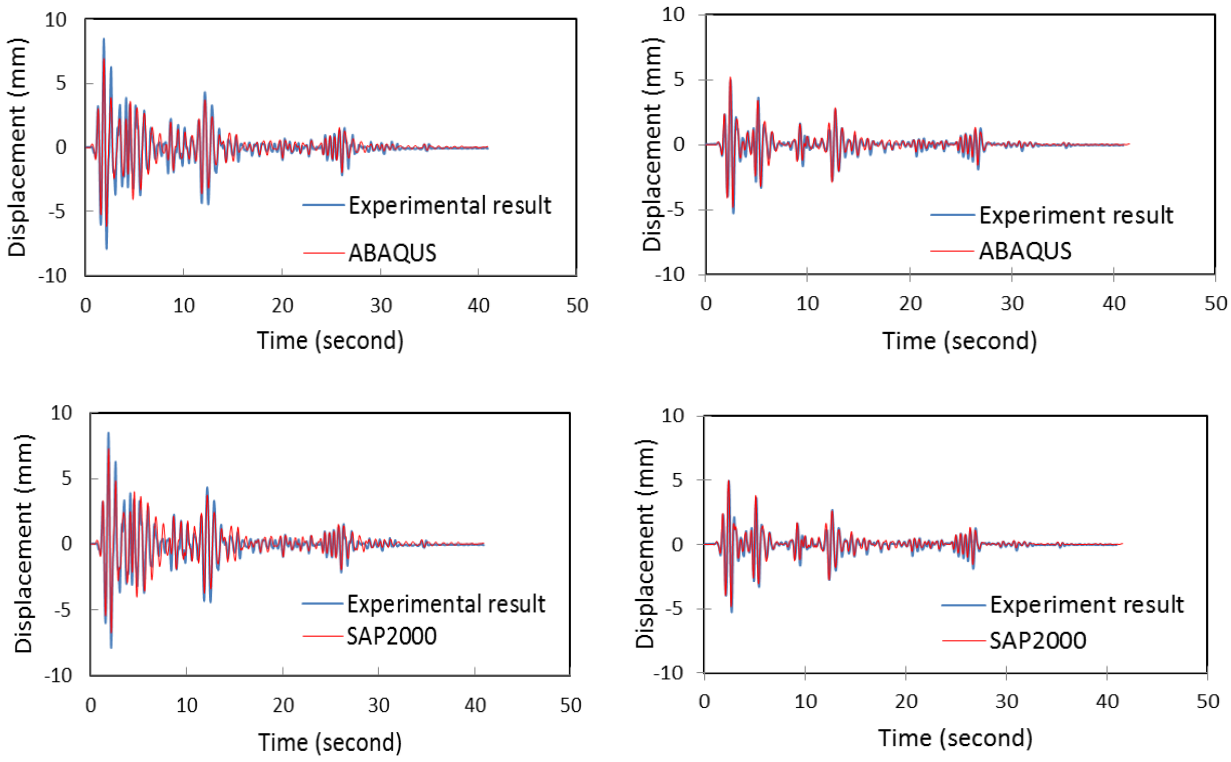


(a) Movable bottom floor (b) Most upper floor

Figure 7: Maximum displacement responses of proposed FCSS model

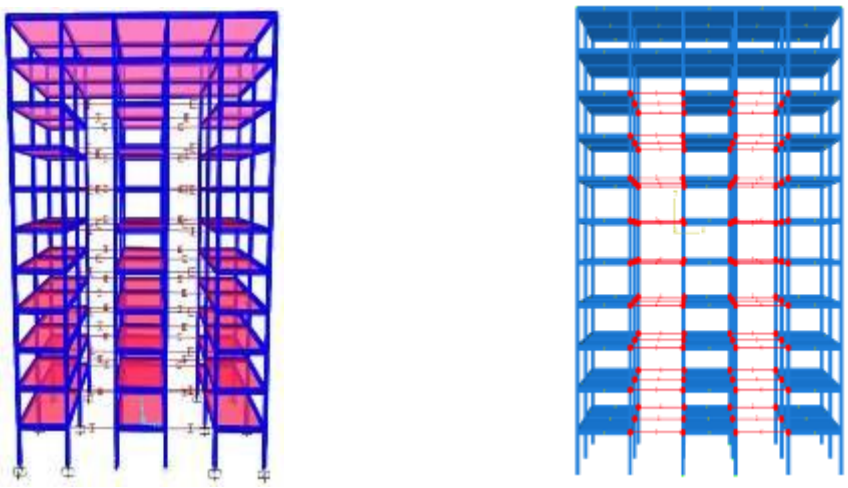
Besides, to confirm the experimental results of model, it also investigated by numerical analysis. The experimental model was simulated by used spring-mass model and 3D model of commercial software packages called ABAQUS and SAP2000. The comparisons results are plotted in Figure 8.





(a) Without additional damper (b) With additional damper

Figure 8: Comparisons of FCSS model displacement responses at bottom movable floor between experiment and spring-mass model, ABAQUS, SAP2000 for El Centro NS earthquake.



(a) FCSS model in SAP2000 (b) FCSS model in ABAQUS

Figure 9: Simulation of FCSS experimental model.

5. CONCLUSIONS

In this study, the modification of proposed FCSS from the previous study model was investigated by used analytical study and experimental study. It is aimed to observe the proposed model can increase the natural period and damping ratio, and decrease the seismic response. According to the seismic behavior of analytical and experimental study due to some earthquake data wave, it is clarified that modification of proposed FCSS model can improve seismic performance with long natural period and high damping ratio and decrease seismic response than ordinary structure. Furthermore, a good agreement between the results of shaking table testing and those of numerical analysis was obtained.

6. ACKNOWLEDGMENTS

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