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ADVANTAGES OF SEISMIC DESIGN FOR WAREHOUSE BUILDINGS USING SLIDING LOADS

K. Yamagishi(1), T. Imada(2)

(1) *Professor, Kanazawa Institute of Technology, kuniaki@neptune.kanazawa-it.ac.jp*
(2) *Graduate student, Kanazawa Institute of Technology, b6801717@planet.kanazawa-it.ac.jp*

Abstract

Global warehousing and distribution systems have expanded in earthquake-prone countries, reducing logistical costs, including warehouse construction costs, and it is an ongoing issue for enterprises. Warehouses in earthquake-prone countries require both logistics optimization and load maintenance during earthquakes. In traditional seismic-proof warehouses, the response of the warehouse increases as the number of floors rises, and the risk of over-turning increases. Therefore, large-scale warehouses with seismic isolation have been developed. However, the initial cost of seismically isolated warehouses is higher than that of traditional warehouses, and the adoption of the former is limited. Through experiments and analyses, it was found that allowing loads with small friction coefficients to slide during an earthquake reduces not only the acceleration response of the load but also the displacement response of the frame. That is, sliding loads can substantially reduce the risk of overturning without seismic isolation being adopted. Furthermore, because the structural response is reduced, the design load during an earthquake and the cross-sections of the frame members can be reduced. We refer to these two advantages as the "slide effect." [1]

Imada and Yamagishi [2] discussed the variation of the maximum inter-story drift in three-story buildings with load sliding, which was less than that with fixed loads. However, Imada and Yamagishi conducted the earthquake response analysis using up to five input seismic motions but the limited number of input seismic motions were insufficient to accurately discuss the variation in response. Therefore, an earthquake response analysis was conducted for the same type of warehouse that was previously investigated using 100 different artificial seismic motions with the same target spectrum. This study focused on the variation of the maximum response and the absorbed energy at each floor and the associated inter-story drift. As a result, the variation of the maximum response will depend on the superstructure condition. For example, the variation of the maximum acceleration in the case of fixed loads is almost equal to that in case of sliding loads when the frame is in an elastic state, and the variation in the sliding load is much more significant than the fixed load when the frame is in an elastoplastic state. The variation of the maximum inter-story drift in the case of sliding loads is less than that in case of fixed loads when the frame is elastic, and its tendency when the frame is in the elastoplastic state is much higher. In particular, the latter assertion may be valuable to plastic design. On the other hand, the variance of the hysteresis energy of the frame with sliding loads is less than that with the fixed loads.

Thus, a variation reduction effect was found for some responses. This is the third consequence of the slide effect.

Keywords: Warehouse; Slide effect; Coefficient of Variation; Artificial seismic motion; Maximum seismic response; Hysteresis energy

1. Introduction

Owing to the development of distribution networks and the increase in retail distribution through e-commerce, demand for warehouses has increased worldwide. The construction of large warehouses with rampways to support these networks is increasing. Japan is an earthquake-prone country, and the disruption of logistics due to earthquakes leads to a reduction in economic activity. In response to growing business continuity planning, warehouses with seismic isolation structures have recently been constructed. Seismic isolation structures have a high initial cost, such as those associated with building a double foundation and installing expensive seismic isolation devices. In response to the increasing costs, low-cost seismic isolation systems have been developed.

However, seismic isolation structures may not be capable of withstanding massive tsunami waves such as those caused by the 2011 Tohoku-Pacific Ocean Earthquake, and the application of seismic isolation structures is a suboptimal way to preserve such structures.

It is well known that when a slidable weight is placed on a slab, the weight slides during an earthquake, reducing the acceleration response of the weight, and consequently, reduces the response of the frame supporting the slab. Ogawa [3] and Gao and Takanashi [4] conducted a shaking table test on a three-story steel frame with a slidable weight and found that the response of the frame was significantly reduced as compared to a frame with fixed weights. When the weight of the slidable load is relatively large as compared to the weight of the frame, the effect of the reduction in the response of the frame was increased. Therefore, Sasaki and Yamagishi [5] investigated the effect of reducing the response of the frame by means of a sliding load from the viewpoint of energy conservation for a warehouse subjected to a heavy load. Sasaki and Yamagishi [5] termed such a reduction in response of the slide effect.

On the other hand, Imada and Yamagishi [6] attempted to evaluate this response reduction effect as an equivalent damping ratio, assuming that additional damping was added to the structural damping of ordinary structures. The equivalent damping added to the structural damping of a general building is referred to as an additional equivalent damping ratio, h_{ae}. Imada and Yamagishi [6] examined the additional equivalent damping factor of a three-story warehouse with reinforced concrete (RC) columns and steel (S) beam structures (referred to as RCS structures), with parameters such as capacity reduction coefficient and seismic motion input magnification. As a result, it was clarified that h_{ae} is approximately 5 % for buildings that conform to the Building Standard Law of Japan (BSLJ) considering the slide effect. This implies that allowing a load to slide brings about a response reduction effect equivalent to that of a seismically-controlled structure. Thus, it can be said that the slide effect comprises two effects: the response acceleration of the load is reduced, and the sliding load reduces the response of the frame. However, Imada and Yamagishi [2] found that applying five artificial seismic motions to the three-story warehouse, not only reduced the variation of the frame response but also confirmed that the variation in the maximum inter-story drift was reduced. This fact, if confirmed, could be considered the third consequence of the slide effect.

Therefore, in this study, a seismic response analysis was conducted using input magnification and duration of the seismic motion as parameters for the warehouses of two- to six-story buildings comprising RCS structures, and the maximum response variation was then analyzed. Then, the variation of the maximum responses were also calculated, for example, the inter-story drift variation of each layer, comparing the variation with and without the sliding of the load. In addition, the effect of dispersing the hysteresis energy, using the sliding load, by calculating the variation of the hysteresis energy of each story is also discussed.

2. Outline of the analysis model and input seismic motion

2.1 Analysis model

The standard floor plan of the warehouse building used in this study is shown in Fig. 1. The vertical cross-section of the warehouse is shown in Fig. 2, and an outline of the building is listed in Table 1. The warehouse under consideration is a RCS structure, and the analysis models vary from two - to six-story buildings with end-bearing piles. This warehouse is considered to be ordinary and used for pallet storage. In addition, it is assumed that this large warehouse building has a standard floor height of 6 m and is 100 m × 115 m in length and width, respectively. The area of the warehouse is 10,000 $m^{2,}$ and the live load for slab design is assumed to be 15 kN / m^2.

The analysis model is shown in Fig. 3. A multi-degree of freedom equivalent shear-spring model is used for the structural frame as the primary system. Single degree-of-freedom models for each floor are used for the load system on each floor. The structural masses of each floor are assumed to be lumped masses, calculated from the sum of the dead load of the columns, beams, slabs, and other structural elements. The loads on each floor are assumed to be lumped masses calculated by the sum of the loads.

The skeleton curves for each story of the frame are replaced with trilinear models. The maximum stiffness, initial stiffness, and yield point displacements of the trilinear model are set as follows: First, it is assumed that the initial stiffness distribution of each story is proportional to the maximum capacity of each story. The maximum capacity of each story is the demand lateral strength provided in the BSLJ for a massive earthquake. The demand lateral strength varies depending on the ductility of the building. In this study, the capacity reduction coefficient, $C_{R,}$ was used to set the strength. C_R is a reduction coefficient multiplied by the shear force equivalent to a 1 G inertial force, and C_R is set to 0.4, assuming that the structure is a traditional building. For comparison, a model with $C_R = \infty$, that is, an elastic model is also set.

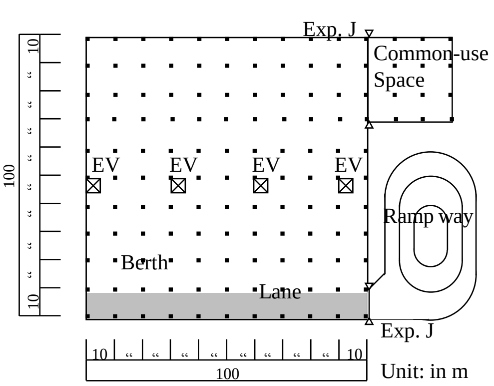


Fig. 1 – Standard floor plan

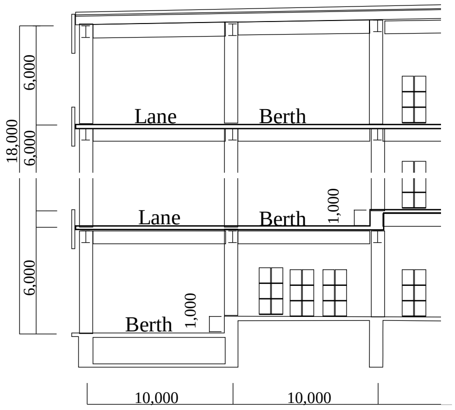
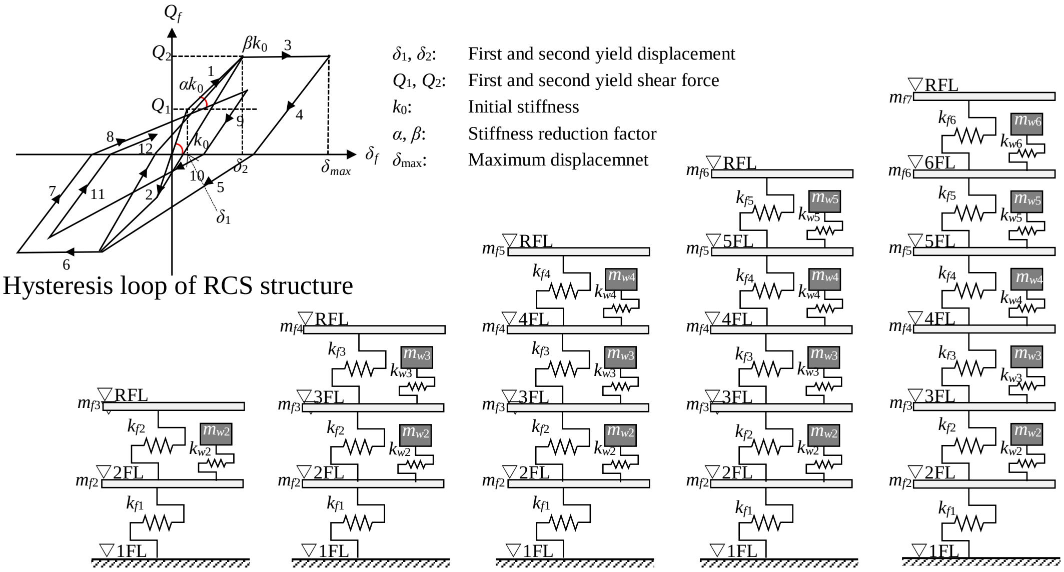


Fig. 2 – Partial sectional view

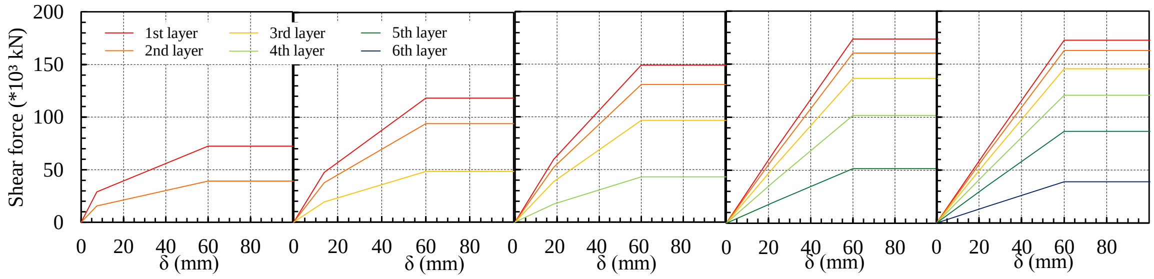
Table 1 – Outline of the warehouse for analysis

Item	Values
Structural Classification	RC-Column and S-beam S hybrid structure
Overall length × width	100 × 100 m
Standard floor height	6 m
Floor area	10,000 m^2
Number of floor	From 2 to 6
Structure height	18 m
Type of warehouse	Ordinary warehouse



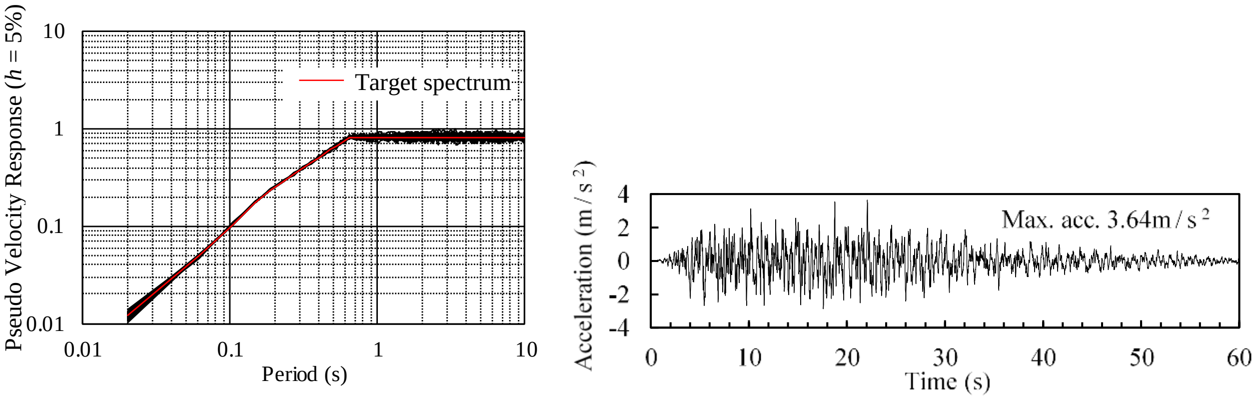
(a) 2F model (b) 3F model (c) 4F model (d) 5F model (6) 6F model

Fig. 3 – Analysis models



(a) 2F model (b) 3F model (c) 4F model (d) 5F model (6) 6F model

Fig. 4 – Skeleton curves



(a) Pseudo-velocity response spectra (h = 0.05) (b) Sample waveforms of input seismic motion

Fig. 5 – Input ground motion

Second, the initial stiffness is determined by defining the natural period of the structure. The natural period, T_s of the RCS structure is assumed to be 0.026H, where H is the height from the ground level to the surface of the roof slab. This simplified formula is suggested by Iizuka et al. [7] for a commercial building with an 8 m span and 4 m story height. Because the spans and story heights of general warehouses are longer than those of commercial buildings, the natural period of warehouses is 1.5 times longer than the period calculated using 0.026H. The initial stiffness is determined by conducting a convergence calculation by multiplying the stiffness of each floor by the same multiplier so that the natural period calculated by eigenvalue analysis coincides with the above-mentioned natural period.

Finally, the yield point displacement is described. The second yield displacement for each story, that is, the displacement that reaches the maximum capacity for the first time, is set such that the inter-story drift angles are uniformly 1 / 100. Then, the first yield point displacements are set at a shear force equivalent to 1 / 2.5 of the maximum capacity. Fig. 4 shows the skeleton curves of the second to sixth-floor models, as determined by the method described above.

The maximum displacement-oriented degrading trilinear model shown in Fig. 3 is used as the restoring force characteristics of the RCS structure based on the experimental results [8].

On the other hand, the skeleton curve of the sliding load system is a bilinear model. The initial stiffness of the load system was set such that the natural period of the system was 0.3 s, and the system yielded a dynamic friction coefficient μ_d = 0.15. The stiffness reduction rate after the yield was 1.0×10^{-4}. The reason why the natural period of the load system is set to 0.3 s is based on the fact that the natural period of the three-tiered rack is approximately 0.3 s when the author shakes it. Yamagishi [9] shows that the slide effect is obtained when the dynamic friction coefficient μ_d ranges from 0.1 to 0.2 by means of seismic response analysis. Therefore, the dynamic friction coefficient, μ_d, is set at an intermediate value of 0.15. The assumption of μ_d = 0.15 is much smaller than that of μ_d between a general floor and a general pallet. A base isolation pallet sold in Japan for seismic proofing is adopted as the pallet in this study. However, changes in the load system due to deformation or collapse, and collisions between loads or between the load and the frame are not taken into account.

2.2 Input ground motion

The input ground motions are artificial ground motions that fit the acceleration response spectrum (damping ratio h = 0.05) defined by the BSLJ (shown in Fig. 5). One hundred types of seismic motions with different random phase-angle characteristics and duration times (10 s, 30 s, 60 s) were created by employing a sinusoidal wave synthesizing method.

3. Reduction of variation due to the slide effect

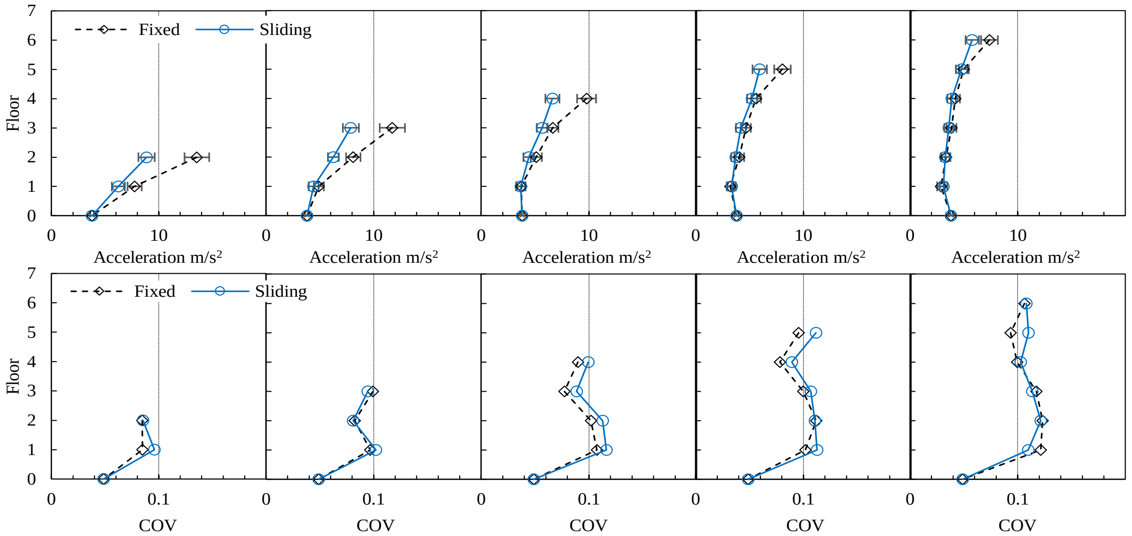
3.1 Variation of maximum response value of each floor

First, the response result of the frame, when the restoring force characteristic of the frame is elastic, is compared in cases where the load does and does not slide. The maximum acceleration, maximum shear force coefficient, and maximum inter-story drift are shown as the representative response results. The upper row of each response result shows the average value, m of each maximum response with its standard deviation ($m \pm \sigma$), and the lower row shows the coefficient of variation (COV) of the maximum response value. The average value of the maximum acceleration (Fig. 6 (a) upper) is smaller when the loads are slidable (sliding load) than when the loads are fixed (fixed load). However, the COV (Fig. 6 (a) lower) shows little difference in the two cases. The average value of the maximum shear force coefficient (Fig. 6 (b) upper) is significantly smaller for the sliding load case than for the fixed load case for buildings of any height. Although the COV (Fig. 6 (b) lower) is smaller for the sliding load than for the fixed load when considering six-story buildings, almost all COVs are the same for buildings of different heights. The average value of the maximum inter-story drift (Fig. 6 (c) upper) is significantly smaller for sliding loads than fixed loads for buildings of different heights, and the slide effect is remarkable. However, the COV (Fig. 6 (c) lower) is the same (Fig. 6 (b) lower) because the frame is elastic. Although the average of the maximum response is smaller for the sliding load than for the fixed load, there is almost no difference between their COVs. However, these results are response results when the frame is elastic. An inter-story yielding occurs like in the case of a simple moment-resisting frame structure. Therefore, Fig. 7 shows the same result when the capacity reduction coefficient is set to C_R = 0.4.

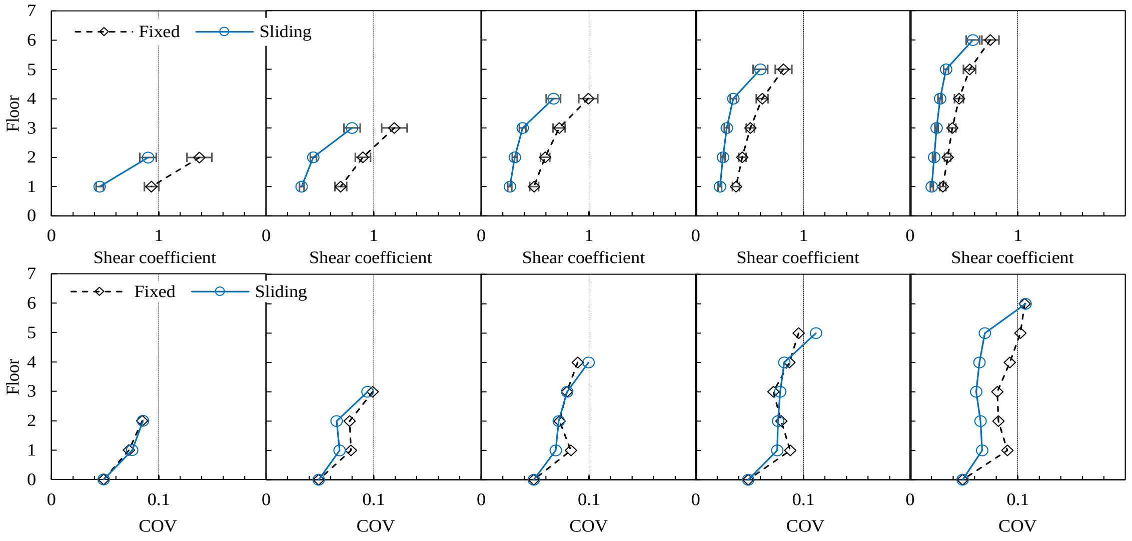
On the contrary, the average value of the maximum acceleration (Fig. 7 (a) upper) is smaller for the fixed load than for the sliding load, and the tendency is remarkable for the COV (Fig. 7 (a) lower). The average value of the maximum shear force coefficient (Fig. 7 (b) upper) is lower in the case of the sliding load than it is for the fixed load, as in the case of elasticity. However, because the story yielding saturates the shear force of each story, the shear force coefficient difference between the sliding load case and fixed load case is reduced. Therefore, the COV is significantly smaller for the fixed load than the sliding load case. In the case of the fixed load, because the shear force of almost all layers, except the top layer, exceeds the yield shear force, the dispersion of the maximum shear force itself decreases. The average value of the maximum inter-story drift (Fig. 7 (c) upper) is significantly smaller for the sliding load than it is for the fixed load for buildings of all heights under consideration for this study, as in the case of elastic response. However, the COV (Fig. 7 (c) lower), except for the top story, in the sliding load case, is significantly lower than in the fixed load case. This tendency is mainly remarkable for six-story buildings. In the case of fixed loads, the variation in inter-story drift increases because of the plasticization of the story. In contrast, in the case of sliding loads, the variation in response decreases because the average value of the maximum inter-story drift is less than the yield displacement due to the slide effect. Therefore, it is considered that there was a significant difference in the COV between the two models.

3.2 Variation of each floor response in the vertical direction

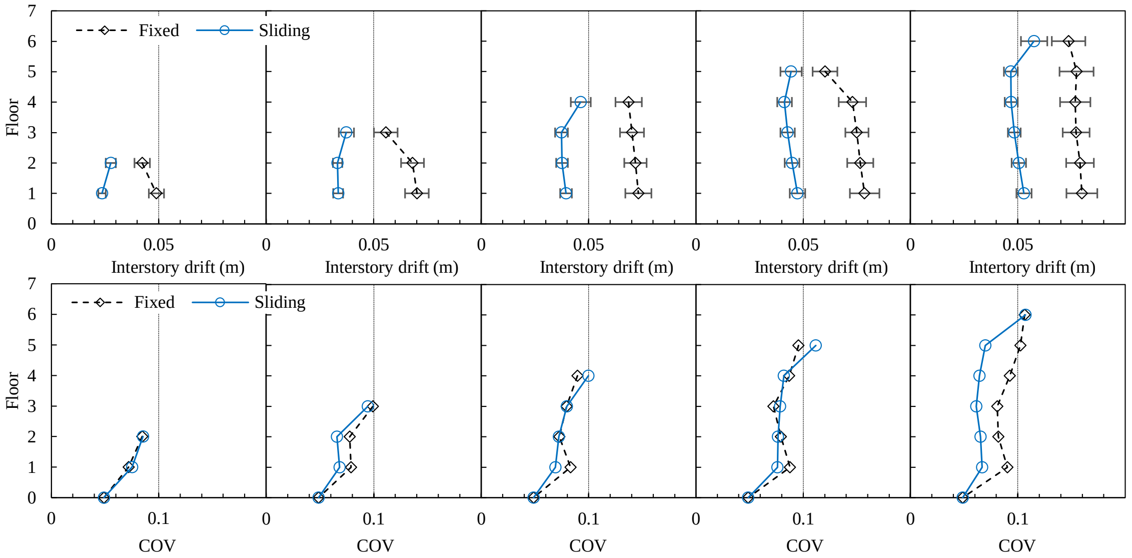
Although the slide effect, in which the maximum shear force and maximum inter-story drift decrease when the load slides are confirmed, the variation (COV) of each story is not always smaller in the sliding load case than



(a) Maximum acceleration (upper row: $m \pm \sigma$, lower row: COV)

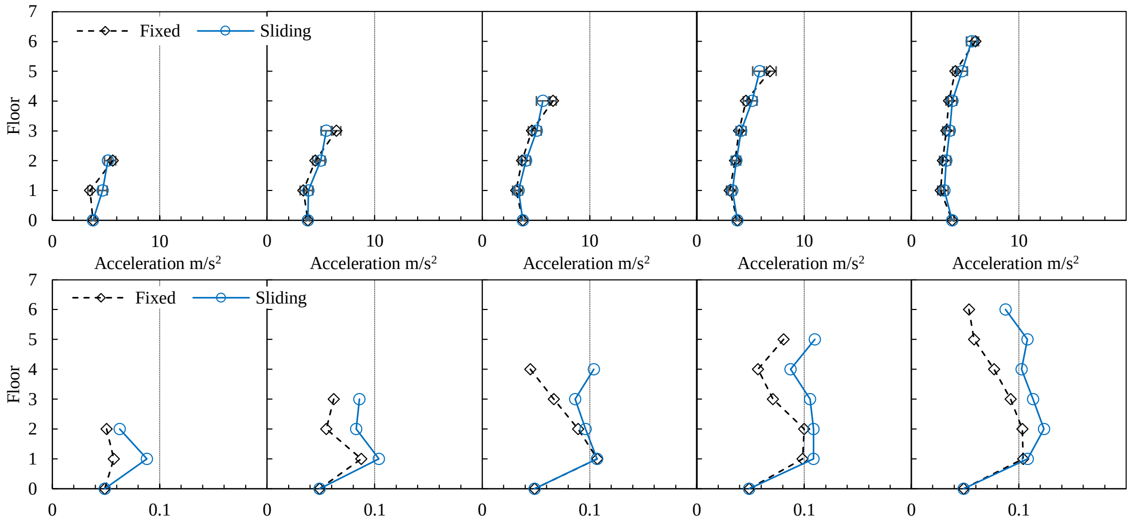


(b) Maximum shear force coefficient (upper row: $m \pm \sigma$, lower row: COV)

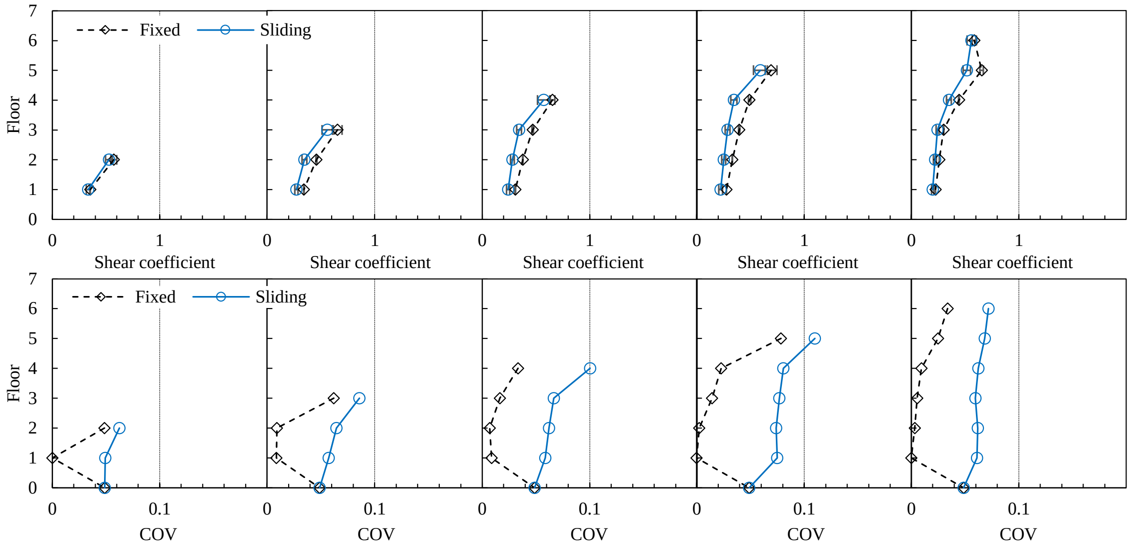


(c) Maximum inter-story drift (upper row: $m \pm \sigma$, lower row: COV)

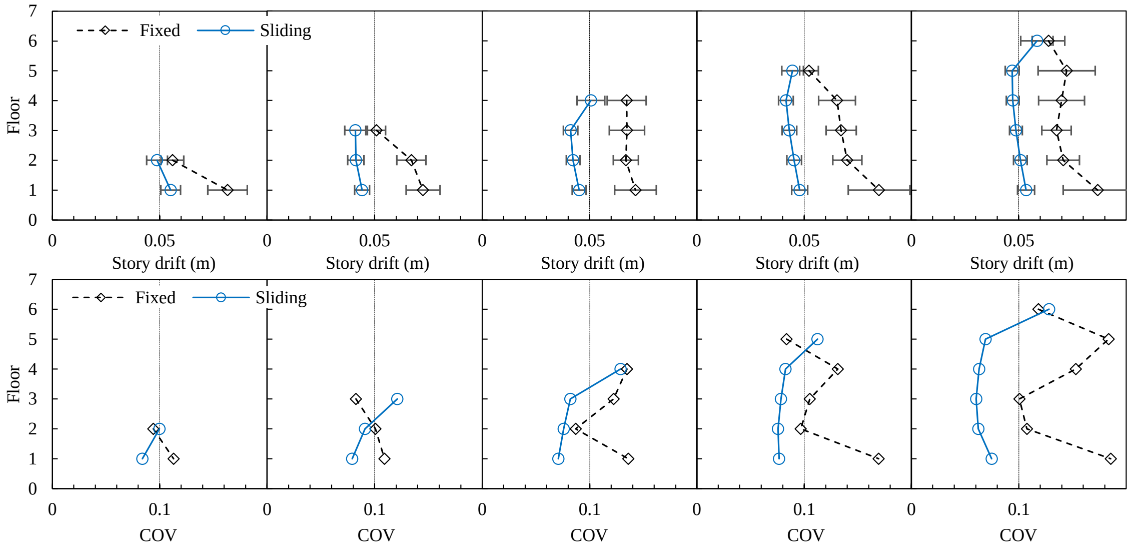
Fig. 6 – Average and COV of maximum response when $C_R = \infty$



(a) Maximum acceleration (upper row: $m \pm \sigma$, lower row: COV)

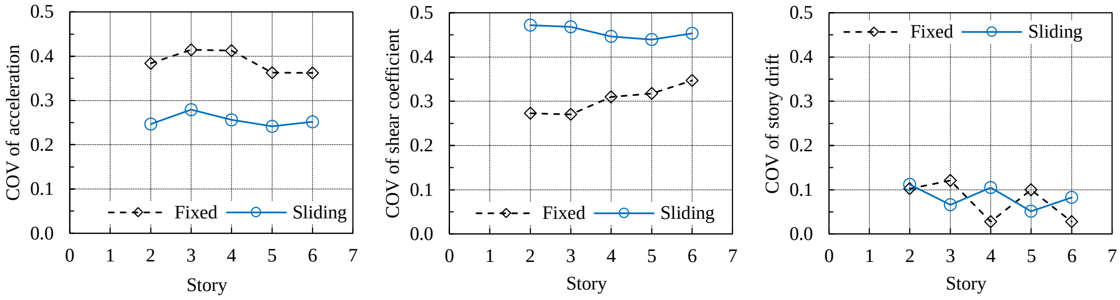


(b) Maximum shear force coefficient (upper row: $m \pm \sigma$, lower row: COV)

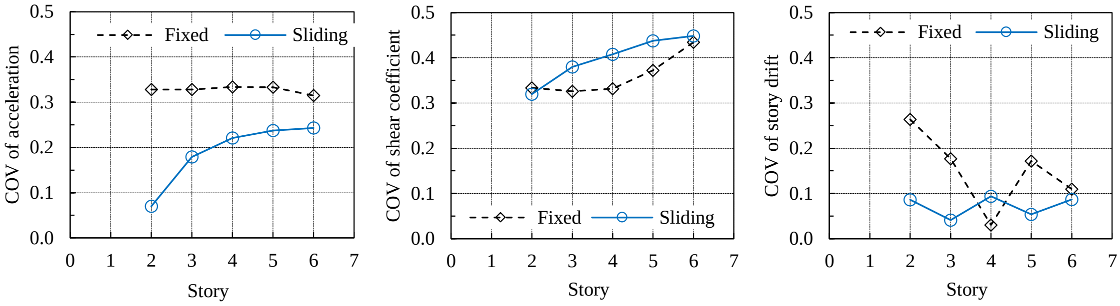


(c) Maximum inter-story drift (upper row: $m \pm \sigma$, lower row: COV)

Fig. 7 – Average and COV of maximum response when $C_R = 0.4$



(a) $C_R = \infty$



(b) $C_R = 0.4$

Fig. 8 – COV of maximum responses between stories

it is in the fixed load case. As can be seen from the average value of the maximum inter-story drift in the upper row of Fig. 7 (c), the difference between the inter-story drift of each story seems to be smaller in the sliding load cases than it is in the fixed load case. Therefore, the variation between stories is discussed. Fig. 8 shows the maximum response variation (COV) between stories. When the frame is elastic, the maximum acceleration is smaller for the sliding load case, and the maximum shear force coefficient is smaller in the fixed load case for buildings with any number of floors. Regarding the maximum inter-story drift, the values in the case of the sliding loads are smaller for 3, 5-story buildings, whereas the value for the fixed load case is more extensive for buildings with other story heights. On the other hand, when the capacity reduction coefficient $C_R = 0.4$, the maximum acceleration and maximum inter-story drift show the same tendency as the elastic model, whereas the maximum story displacement is smaller for the sliding load case except for a four-story building. In particular, this tendency is remarkable for low-rise buildings. Imada and Yamagishi [2] noted that the maximum inter-story drift of a three-story warehouse had less variability between stories. However, it was found that the variation may be similarly reduced in buildings with other numbers of floors. However, there are exceptions, such as four-story buildings. In this study, the input ground motions were generated from the same target response spectrum, and although the phase characteristics were different, ground motions with almost the same amplitude characteristics were used. Therefore, in the case of the fixed condition of the four-story building, it is considered that the maximum story displacement of all stories was accidentally made uniform.

There is a possibility that the difference between stories of the maximum story displacement of buildings with a capacity reduction coefficient of $C_R = 0.4$ (not all buildings) may be small. When an excessive ground motion is applied to a building, not only may it cause an inter-story drift, but it also causes an inter-story collapse. During the 1995 Hyogoken–Nambu Earthquake in Japan, an intermediate story collapse was noticed. In recent years, a method has been proposed to avoid such an intermediate story collapse by installing a continuous high-rigidity member such as a core member in the vertical direction [10]. Although load sliding cannot positively suppress the collapse of a building like such a core member, it may help to suppress the collapse of the building in the sense of dispersing the maximum inter-story drift and hysteresis energy in the vertical direction.

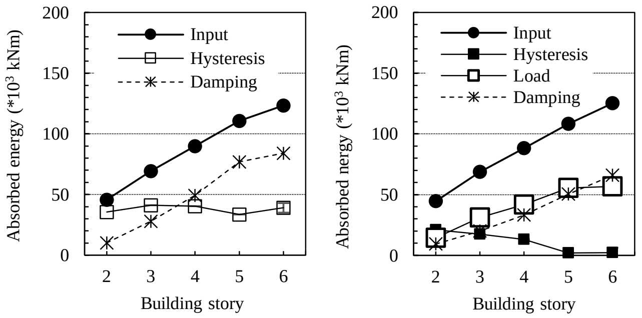


Fig. 9 – Absorbed energy for building story

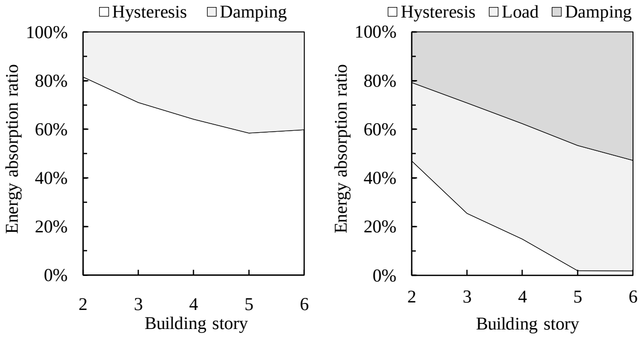


Fig .10 – Energy absorption ratio

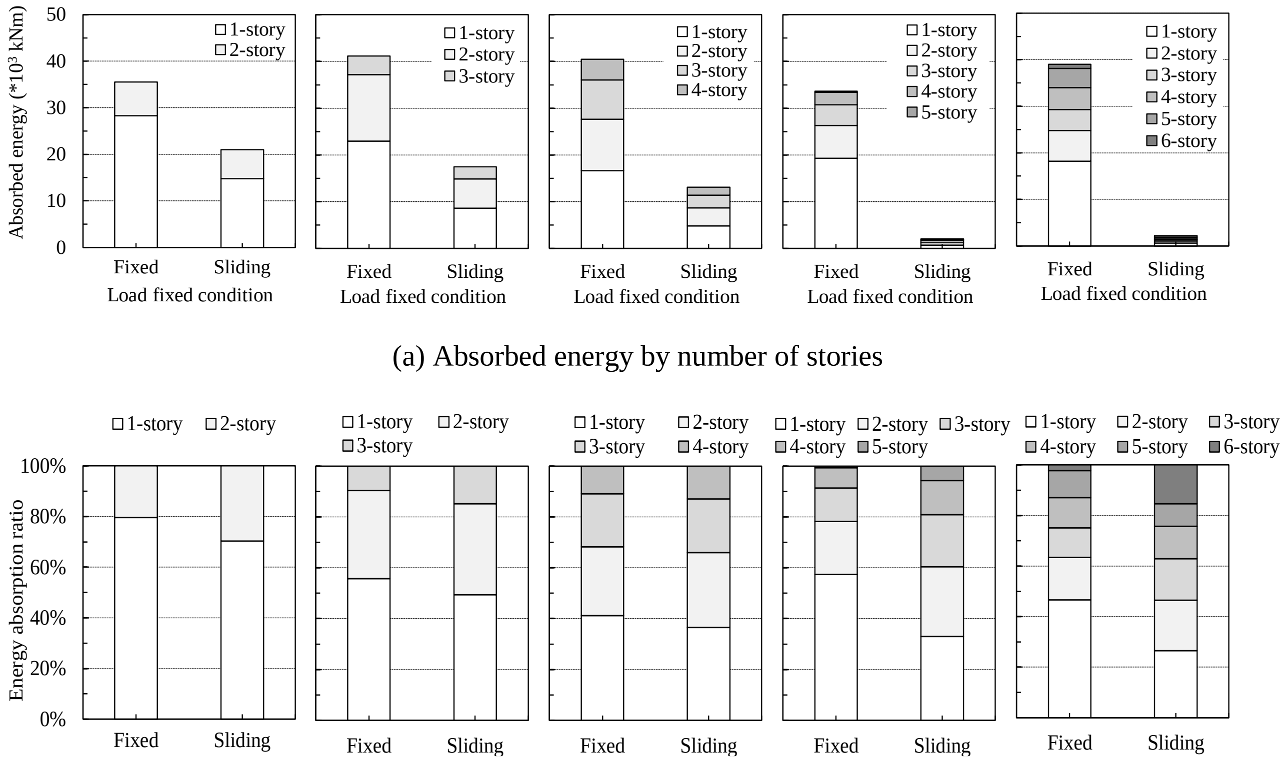
4. Changes in energy variation as a result of the slide effect

4.1. Absorbed energy when the load slides

As seen in the previous section, it was found that sliding the load not only reduced the maximum response but also reduced the variation in the maximum response. The decrease in these responses is because (1) part of the seismic input energy is converted into the friction energy between the load and the slab, and (2) the apparent mass of a floor that is the sum of the dead load mass and live load multiplied by the dynamic friction coefficient is less than the simple sum of the dead load mass and live load mass. Section 4.1 focuses on energy absorption, and the energy balance and energy dispersion of the system are discussed.

Fig. 9 (a) shows the relationship between the number of floors and energy absorbed when the load is fixed. These results are the average of the amount of energy from 100 input seismic waves with a duration of 60 s. As the number of floors increases, the seismic input energy (Fig. 9 (a) Input) increases because of the increase in vibration energy in accordance with the increase in mass. On the other hand, the fluctuation of the hysteresis energy (Fig. 9 (a) hysteresis) of each story is small, with the difference in the number of floors. This is attributed to the fact that the hysteresis energy does not increase owing to the decrease in the ductility factor as the number of floors of the building increases. The damping energy of the frame increases as the number of floors in the building increases. On the other hand, Fig. 9 (b) shows the energy when the load slides. It can be seen that the seismic input energy (Fig. 9 (b) Input) is almost the same as when the load is fixed. On the other hand, the damping energy and hysteresis energy of the frame is reduced as compared to the result obtained during the fixed load condition, and the reduction of the hysteresis energy of the frame is particularly remarkable (Fig. 9 (b) Hysteresis).

Instead, the friction energy is increased; for example, in the case of a six-story building, it is larger than the hysteresis energy of the frame in the case of fixed loads. As described above, because part of the seismic energy is converted into the friction energy of the load, the response of the frame is reduced, and its hysteresis energy is also reduced. As the majority of the seismic input energy is converted into hysteresis, damping, and friction energy, that is, the absorbed energy (the kinetic and elastic energies at the end of seismic duration time are small and negligible), the distribution of these energies is of interest. Fig. 10 shows the ratio of absorbed energy when the load is fixed and when the load slides, respectively. It can be seen that the higher the number of stories, the larger the damping and friction energy.



(a) Absorbed energy by number of stories

(b) Absorbed energy ratio by number of stories

Fig. 11 – Energy absorption by number of stories

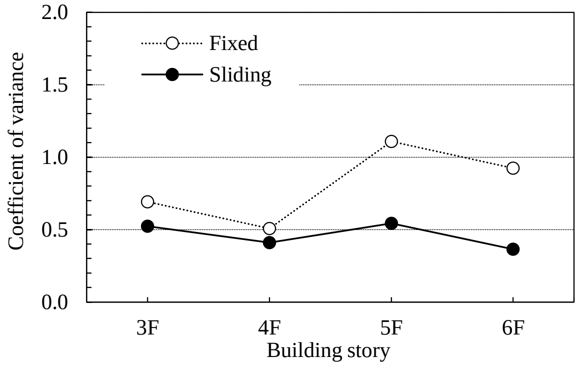
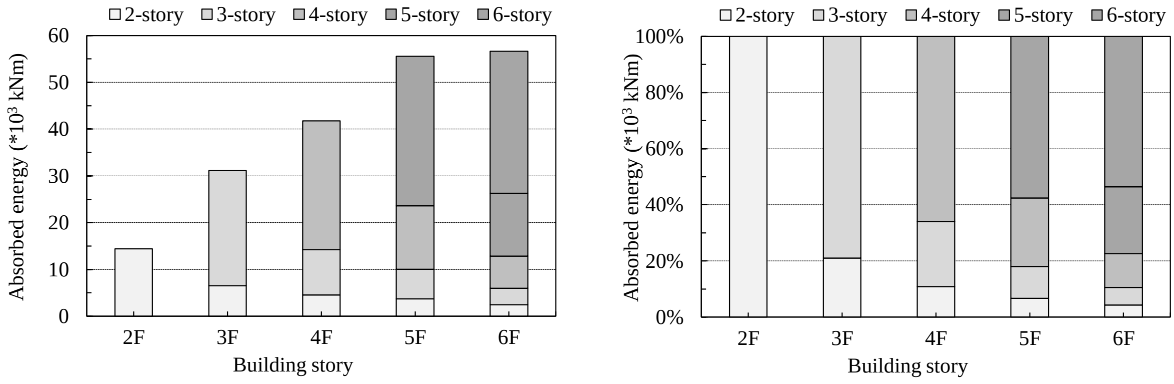


Fig. 12 – COV of hysteresis energies between stories

4.2 Variation of floor energy in the vertical direction

In the previous section, the absorbed energy of the entire system was described. In Section 4.2, the absorbed energy of each layer and its variation is described. Fig. 11 (a) shows the absorbed energy (history energy) of the frame in each layer. In both the fixed and sliding load case, it can be seen that the energy absorption of one-story structures is the largest, and then decreases as the number of stories increase. Fig. 11 (b) shows the percentage of each energy. Sliding loads disperses the energy of each story. That is, the sliding of the load may avoid the concentration of the hysteresis energy at any one story of the frame.



(a) Accumulation of friction energy (b) Friction energy ratio

Fig. 13 – Friction energy between the load and the slab by number of stories

Fig. 12 shows the coefficient of variation COV of the hysteresis energy at each story. The COVs of three - and four-story buildings are smaller than those of five - and six-story buildings. Those in the case of sliding loads are smaller than in the case of fixed loads, especially the difference between the sliding load and fixed load case is significant for five - and six-story buildings. The slide effect reduces not only the variance of the maximum response but also the variance of the energy between stories. The dissipation of the hysteresis energy in a building may be more critical for usability after an earthquake owing to the reduced damage sustained by the frame.

Although the variation of the frame was discussed, the amount of friction energy and its variance is of interest. Fig. 13 (a) shows the accumulation of friction energy at each floor for buildings with different story heights. As the number of floors increases, the total amount of energy increases. However, it seems that the total energy saturates in the case of a six-story building. The ratio of the friction energy at each story to the total friction energy increases as the number of stories rise. That is, the increase in the sliding displacement of the load on the upper floor, with the inertial force generally increasing, is reflected in the energy ratio. Although the higher the friction energy, the higher the slide effect, which may result in a complication in the form of an increase in the sliding displacement of the load.

5. Conclusion

The slide effect has the following two effects: (1) Because the load slides when the inertial force of the load exceeds the frictional force generated between the load and the floor, the acceleration response of the load decreases when the loads are allowed to slide. (2) The displacement response of the frame is reduced by converting a part of the hysteresis energy of the frame into the friction energy of the load. However, as described in Sections 3 and 4, the slide effect also has the advantage of leveling the variation of the maximum response that occurs on each story and also has the advantage of leveling the hysteresis energy. This is the third effect of the slide effect. The sliding effect obtained by reducing the friction coefficient between the load and the floor does not require the installation of individual devices such as dampers to reduce the displacement and acceleration response, as required in a seismically-controlled structure. Owing to its significant damping characteristics, the seismic control structure can reduce the response of each floor; however, it cannot reduce the response acceleration of the load. Therefore, it should be noted that the slide effect is not universal for any building or seismic motion. The hysteresis characteristic of the frictional force shows a strong nonlinearity that exhibits high stiffness until the external force exceeds the frictional force, and exhibits extremely low stiffness after the external force exceeds the frictional force. If the earthquake motion includes unique phase characteristics, the response of the system is not always reduced. Furthermore, the slide effect cannot be expected for excessive input ground motion. The design incorporating the slide effect should take into consideration the fact that the load does not fall over first, then consider whether the response of the frame can be reduced under the load. From the viewpoint of business continuity, the maintenance and preservation of goods in a warehouse is essential. It is of crucial importance to adopt a base isolation system to protect the building and the goods contained in it completely. Although the goods would potentially shift after the earthquake, the choice of an inexpensive building by applying the slide effect might be a potential option.

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6. References

[1] Sasaki R, Yamagishi K (2017): Fundamental experiment and analytical study of seismic response reduction effect with load sliding of elastoplastic frame -additive damping ratio by load sliding-: *International Conference on Structure in Architecture building Technologies*.

[2] Imada T, Yamagishi K (2019): Additional equivalent damping factor due to sliding of load in warehouse building with column RC beam S structure. *Japan Association for Earthquake Engineering Annual Meeting*, Kyoto, Japan. (in Japanese)

[3] Ogawa N. (1986): Seismic response of frame structures with movable loads. *Journal of Structural and Construction Engineering, Transactions of AIJ*, No.370, 28-39. (in Japanese)

[4] Gao X, Takanashi K (1990): Earthquake responses of structures with sliding floor loads. *Journal of Structural and Construction Engineering*, *Transactions of AIJ*, No.409, 107-113. (in Japanese)

[5] Sasaki R. Yamagishi K (2017): Energy balance of structural system with load sliding. *International Conference on Civil and Structural Engineering*, *ICCSE*-17.

[6] Imada T, Yamagishi K (2019): A study on the Slide effect of loading objects in warehouse building considering variation of friction coefficient. *12th Pacific Structural Steel Conference PSSC*, Tokyo, Japan, 639-642.

[7] Iizuka N, Kasamatsu T, Noguchi H. (1994): Hashira RC Hari S kouzou setsugoubu no kaisekitekikenkyu (Analytical study of column RC beam S structural joint). *Proceedings of the Japan Concrete Institute*, 1235-1240. (in Japanese)

[8] Takeda T, Sagawa T, Yamanobe K, Nishitani T. (2014): Experimental study on structural behavior of composite frame of reinforced concrete column and steel beam with small column/beam depth ratio. *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, Structures III*, 1235-1236. (in Japanese)

[9] Yamagishi K (2015): Analytical study on seismic response reduction effect of buildings by loaded objects. *Proceedings of Annual Research Meeting, Hokuriku Chapter*, Architectural Institute of Japan, Vol. 35, 102-105. (in Japanese)

[10] Takeuchi T, Chen X, Matui R (2015): Seismic performance of controlled spine frames with energy-dissipating member. *Journal of Constructional Steel Research*, Vol. 114, 51-65.