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OPTIMUM PLACEMENT DESIGN OF NEW LLINKAGE SYSTEM SEISMICALLY CONTROLLED MULTI-STORY STEEL FRAME

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Abstract

This paper describes basic characteristics of a vibration control performance of a new link mechanism with rotational friction dampers in a steel frame. The damping system prevents the frame from damage of the main structural members and reduces the response of the superstructure by incorporating the device that absorbs seismic energy under strong earthquake. A similar rectangular link mechanism with rotational friction dampers have been proposed previously by the authors. Although, the structural system is rather complicated in erection because it consists of many parts. A new linkage system was proposed in this paper, that reduces complexity of erection at site. The identification of the geometric relationship followed by confirmation of consistency by static analysis was carried out. Eventually, the geometrical relationship, the existing mechanism was able to secure seven times the rotation amount of the new mechanism, while the rotation amount of the rotary friction damper was five times the deformation of the frame. An analytical study was conducted in order to obtain the information with respect to the overall response of the frame and the rotating behavior of the friction damper, the energy dissipation out of seismic energy input to the superstructure through the dynamic analysis.

The slip moment index as new parameter was defined. The slip moment index shows how much force the rotating friction damper receives when it receives a force against a strong earthquake. It is supposed that an amount of energy input to the rotational friction damper incorporated in the structure depends on the amount of rotational angle of the damper due to the deformation of the frame under the lateral force. In other word, the energy dissipation of seismic energy can keep enough for the vibration control design under suitable adjusting the sliding moment of the rotating friction damper. Forthermore, the paper describes the seismic design of multi-storied steel frames a new link mechanism with rotational friction dampers to obtain adjusting the sliding moment of the rotating friction damper and arrangement problem.

The 3-bay, 8-story steel planer frame was prepared for dynamic analysis. The result of the analysis suggestis that the damping effect of the rotational friction damper with the new type of link mechanism is enough as well as the old type. The inter-story drift angle of the frame with the new friction damper is much less than that of the basic frame. The response of the frame is distributed in thefirst story, therefre the new link mechanism reduce the response of the superstructure by incorporating a device absorbing. Consequently, the energy dissipation of seismic energy in the first story, the damper obtained very well. On the ather hand, the dampers in the midle and high stories do not obtain well. The energy of the whole frame is affected by the value of the sliding moment of the rotational friction damper. And also, it is possible that lateral shear of the frame can be reduced much by a suitable adjusting the sliding moment of the rotating friction.

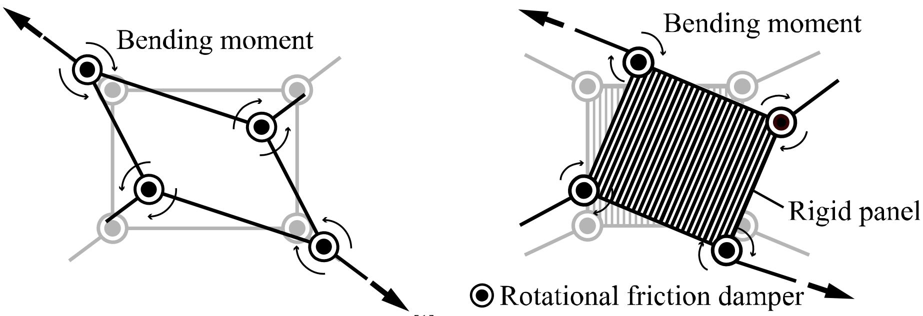
Keywords: Steel Frame; Rotational Friction Damper; Link Mechanism; Vibration Control.

1. Introduction

Damping structures prevent damage to the main frame and reduce the response of the superstructure by incorporating a device absorb energy in the superstructure. Among the developed damping device, there is a friction damper. In particular, the friction damper of the rotary type, it is easy to secure the friction surface, it can be stable slip proof stress obtained. In previous studies, an old-model link mechanism with the friction dampers [1] as shown in Fig.1(a) has been studied. Previous researches have proposed a rectangular link mechanism with rotational friction dampers at the corners of the rectangle. In this mechanism, the rotational friction dampers are connected to the column-to-beam connections with the steel braces. Since the members deform under tensile or compressive axial force, Eventually, the original rectangle changes its shape with rotation of the dampers, so that the dampers dissipate the energy entered in the main frame. Having this mechanism, the rotational friction dampers can follow the large lateral drift of the frame expecting dissipation of much energy. However the linkage system has a weak point that assembling work becomes complicated because of jointing with multiple parts[2], [3].

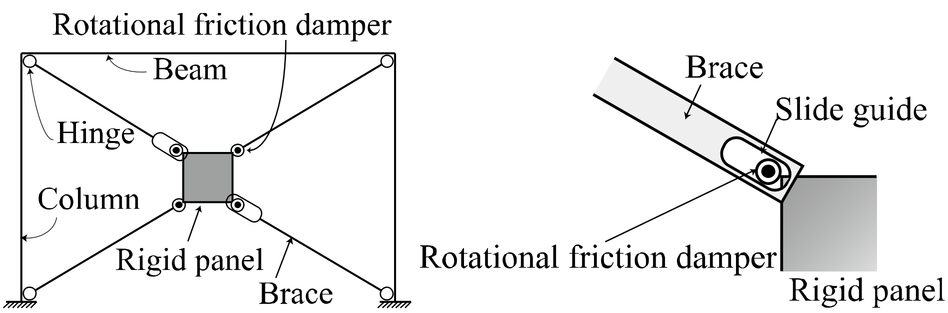
Consequently, a newly proposed linkage system in Fig.1(b) reduces complexity of erection at site. The rectangle portion shall be replaced by a square rigid panel for ease of assembling. The rotational friction dampers in the linkage system are incorporated into four hinges as same as an old-model link. As the square panel rotates without its deformation, a couple of braces have the sliding mechanism. It is possible to obtain the amount of rotation at four nodes. Thus, it can be expected much dissipation of energy as well as old system.

This research is a basic research that deals with a problem on how the link mechanism with the rotational friction dampers can earn the amount of rotation of the rotational friction damper and how much obtain the energy dissipation of the rotational friction dampers efficient. It leads to the amount of rotation of the rotational friction damper for an inter story drift angle of the frame from geometric relationship. The damping effect of a rotational friction damper with a link mechanism on dynamic behavior of the planer frame is examined through a series of numerical simulations.



(a) Old-model link mechanism [1] (b) New link mechanism

Fig. 1 – Model of link mechanism with rotational friction damper



(a) Frame with new link mechanism (b) Slide mechanism

Fig. 2 – Model of mechanism

2. Modeling of analytical frame

2.1 Analysis model of rotational friction damper

The behavior of the rotational friction damper in this research is to be based on Coulomb's friction law. A rotational friction damper in the analysis constitutes a rotational spring. The behavior of the rotational spring is similar to that of a perfectly rigid-plastic element. Therefore, a very large value of elastic stiffness of the element was used for expression of the rigid-plastic behavior in a numerical calculation. The behavior of a rotational friction damper is expressed with a slip moment M_s, and the hysteretic loops is drawn as shown in Fig.3.

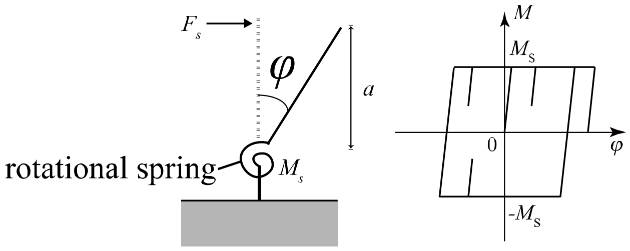


Figure 3. Rotational spring model and hysteresis damper model.

2.2 Analytical frame

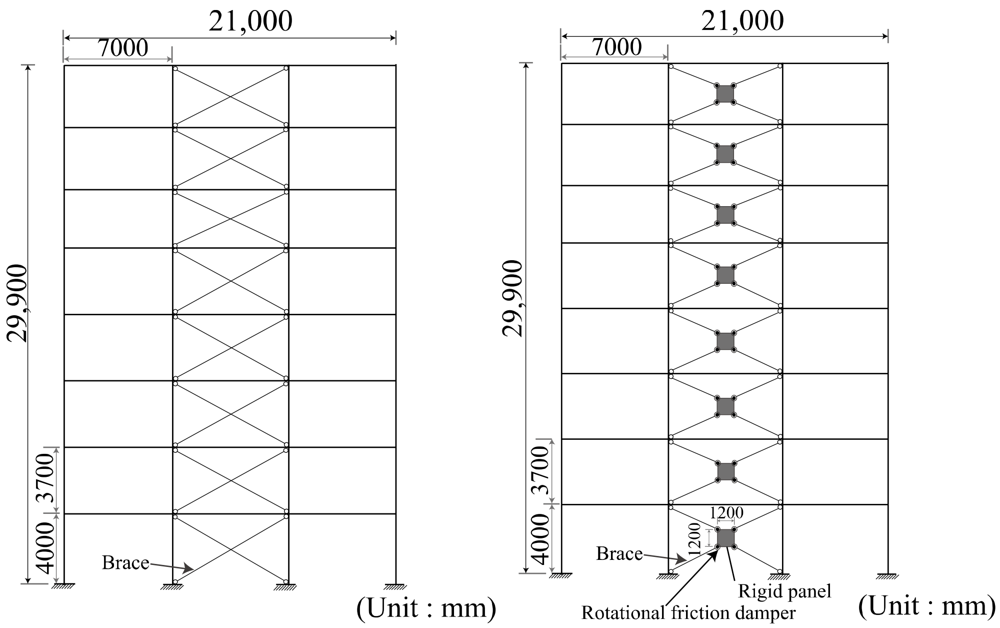
The frame for the analysis is a 3bay-8story planer steel frame that was designed based on Japanese building code. Incorporating the rotational friction damper with the new link mechanism in the analytical frame is shown in Fig.4. The length of a panel is 1200mm to consider practical use at site. The columns and the beams are elastic-plastic steel sections and the both ends of the members have simple plastic hinges after yielding. The braces are assumed to be elastic memebers. The sections of the braces are designed so that the contribution to the lateral shear force in a story becames 60%, 70% and 80% of each stories. The total number of models is six. It is assumed that the column member has an isotropic hardening model and the beam member has a restoring force characteristic of the kinematic hardening model. The strain hardening coefficients are both 0.02. the section of members and the materials properties are shown in Table 1 and 2 respectively. The masses for the seismic response analysis were concentrated at the column-to-beam nodal points, and each one is 25.3tonf.

Table1.material properties

Member	Young's modulus (N/mm^2)	Yield strength (N/mm^2)	Strain hardening coefficient (%)
Clumn		325	2.0
Beam	205000	235	2.0
Brace			

Table2.material sections

Story	Column	Beam	Brace (60%)	Brace (70%)	Brace (80%)
8	□350x350x12	H450x200x12x16	□150x150x5	□150x150x6	□200x200x14
7	□350x350x12	H450x200x12x16	□150x150x5	□150x150x6	□200x200x8
6	□350x350x12	H450x200x12x16	□150x150x5	□150x150x9	□200x200x16
5	□400x400x16	H450x250x12x22	□150x150x6	□150x150x9	□200x200x14
4	□400x400x16	H450x250x12x22	□150x150x6	□150x150x9	□200x200x8
3	□400x400x16	H450x250x12x22	□150x150x9	□150x150x9	□200x200x8
2	□450x450x22	H500x300x16x25	□150x150x9	□200x200x8	□200x200x14
1	□450x450x22	H500x300x16x25	□150x150x9	□200x200x8	□200x200x16



(a) Original braced frame (b) Frame with dampers

Fig. 4 – Analytical frame

2.3 Analytical parameter

The slip moment index (A_s) as a design parameter is defined by Eq.1 (1).

$$A_S = \frac{M_{S1} - M_{S01}}{M_{S02} - M_{S01}} \quad (1)$$

The slip moment index as new parameter was defined. The slip moment index shows how much force the rotating friction damper receives when it receives a force against a large earthquake that is supposed.

M_{s1} are sliding moment of the damper. M_{s01} and M_{s02} means sliding moment of the damper acted horizontal force of first and second respectively. when the horizontal force of first acted on the frame, value of A_s is 0. when the horizontal force of second acted on the frame, value of A_s is 1,0. A_s value was changed by 0.2 chopping fine from 0.0 to 1.2.

2.4 Condition of analysis

Seismic response analysis of the frame was conducted by using the structural inelastic dynamic analysis program OpenSees. The ground motions for input to the frame are the two kinds of seismic waves shown in Table 3 that are very strong earthquake. The ground acceleration was adjusted for that the peak ground velocity takes 0.75m/s. Newmark-β method (β =1/4) was adopted for the numerical integration in the seismic response analysis. The damping characteristics of the frame are Rayleigh type that the first and the second damping constants are 0.02. The incremental time of calculation is 0.002s. The duration of the seismic motion is 20.0s.

Table 3. Input seismic wave.

Input seismic wave	Maximum acceleration (m/s^2)	Duration (s)
El Centro NS	3.35	20
Taft NS	1.52	

3. Push-over analysis

Fig.5 shows the results obtained from the push-over analysis. The relationships between the lateral shear force and the inter-story drift angle are shown in the top of Fig.5. In order to evaluate the performance of the rotational friction damper, the cumulative dissipated energy of the rotational friction damper attention is paid. The relationships between the total cumulative energy in the frame and A_s are shown in Fig.5. E_f is the cumulative dissipated energy of the rotational friction dampers, and E_p is the cumulative plastic strain energy of the main frame.

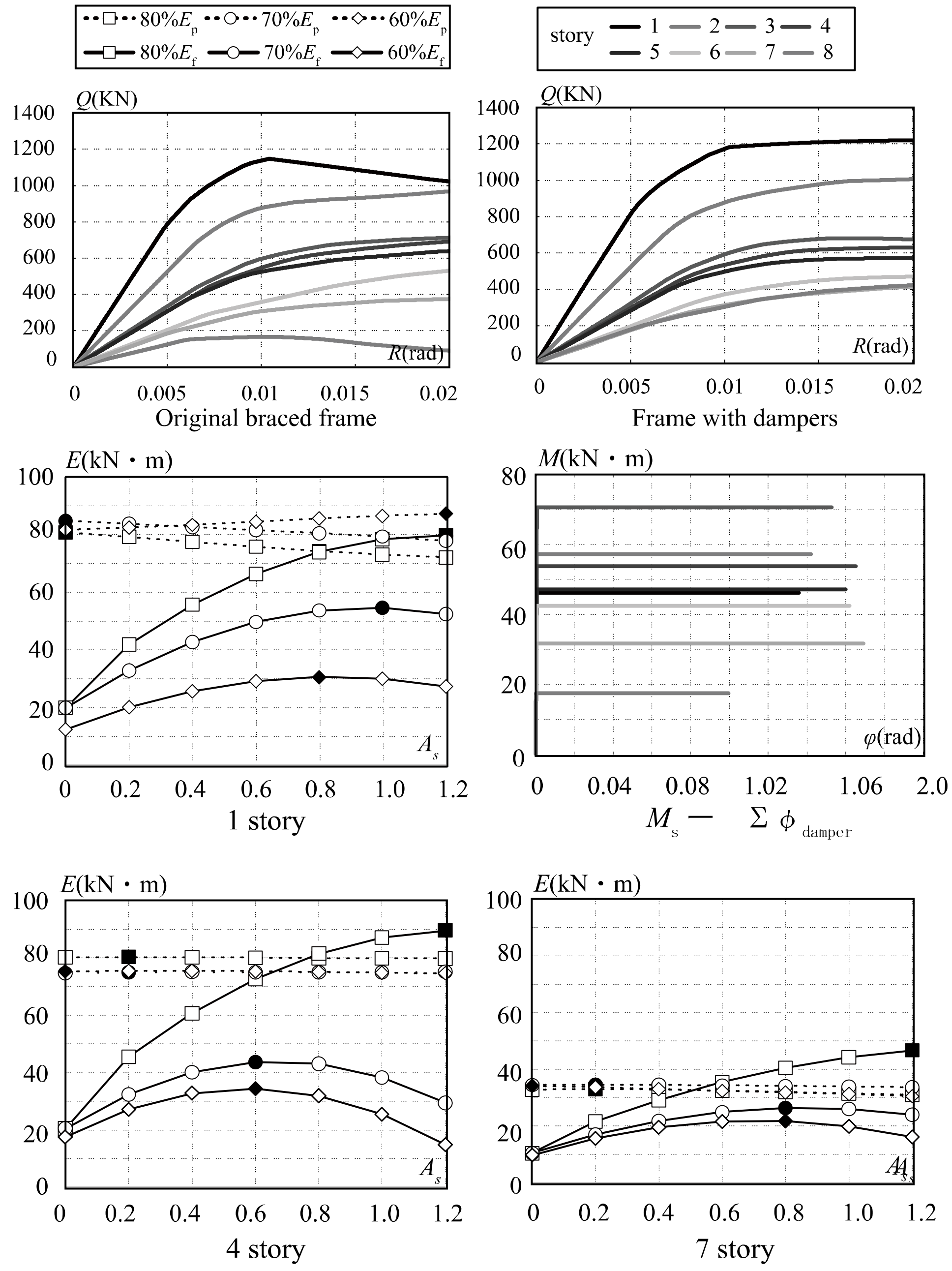


Fig. 5 – Force - deformation curve and relationship between response energy and As

4. Dynamic analysis

4.1 Response of the frame

The maximum inter-story drift angle R_{max} is used as an indicator of the deformation of the frame. R_{max} in each story is shown in Fig.6. The damping effect of the rotational friction damper with a new type of link mechanism are expressed. Existing of the rotational friction damper with the new link mechanism makes R_{max} much less than that of basic frame. The values of R_{max} in case that the link mechanism distributed in lower stories reduces the response of the superstructure because the devices dissipate seismic energy in the superstructure.

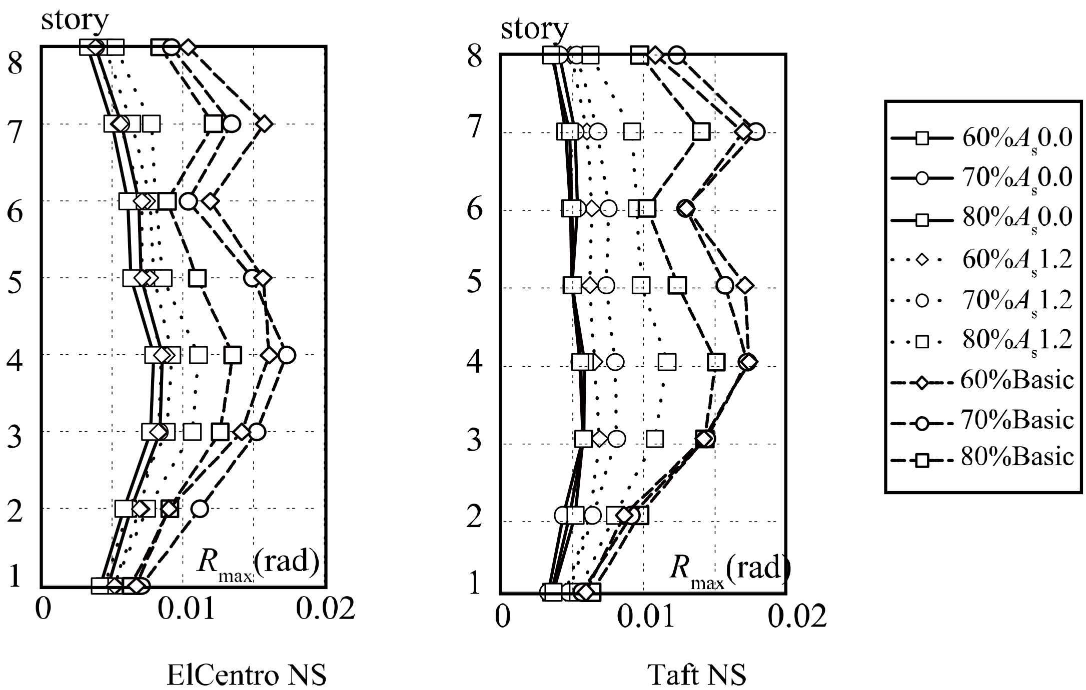


Fig. 6 – Maxima inter-story drift angle

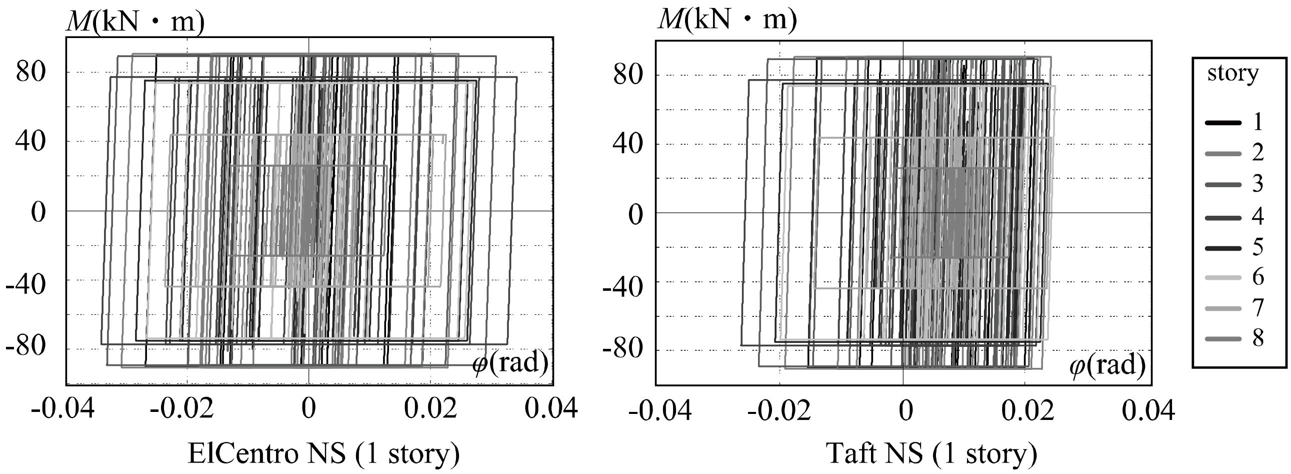
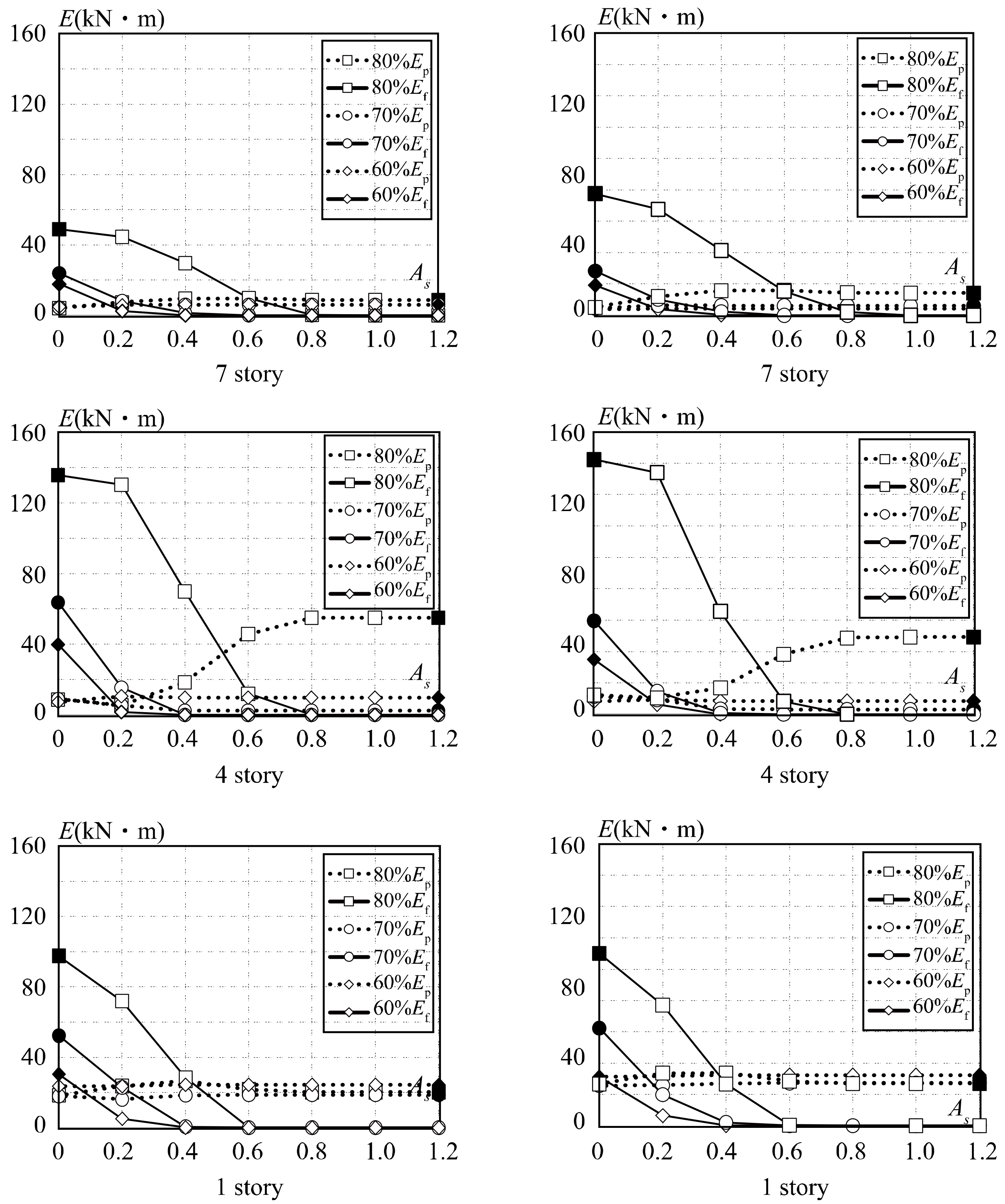


Fig. 7 – Slip moment and slip rotational angle



(a)ELcentro NS (b)Taft NS

Fig. 8 – Relationship between A_s and response energy

4.2 Consideration of the response energy

Relationship between A_s and response energy is shown in Fig.8. Generally, when A_s decreases, the percentage of energy that a rotary friction damper disperses increases. In opposite, the increase of A_s withdraws difficulty of rotating of the friction damper. It turns out that the energy dissipation ability of the friction dampers is related not only to the slip moment but also the rigidity of the frame. It is easy to get an effect with dampers at the lower stories in the frame.

5 Conclusion

In this research, the static analysis was carried out for obtaining the basic information such as the inter-story drift angle and the relationship between A_s and the dissipated energy. The value of E_p hardly changes, when the rotational friction dampers are set in upper stories of the frame. On the other hand, the dampers exist in lower stories dissipate seismic energy effectively. It is supposed that an amount of energy input to the rotational friction damper incorporated in the structure depends on the amount of the rotational angle of the damper due to the deformation of the frame under the lateral force. Consequently, the energy dissipation of seismic energy can keep enough for the vibration control design under suitable adjusting the sliding moment of the rotating friction damper.

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