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Control of Vibration in Steel Structures by Base-isolation System Using Friction Dampers

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ABSTRACT

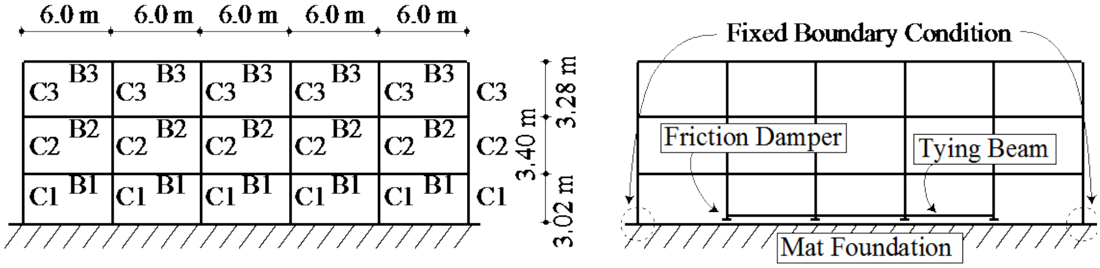
This study examined a vibration control system that is based on passive friction dampers installed at the base of a steel structure. The main advantage of this vibration control system is that the conventional base-isolation pit can be omitted during building construction. Instead, the first story of the structure takes on the base-isolation role. This is achieved by installing passive friction dampers at the bottom of some of the columns of the first story. This paper describes the behaviour of a frame with the vibration control system, by drawing on the results of previous studies. The columns of the first story are divided into two groups. The first group consists of normal columns, and the second group is fitted with the passive friction dampers. The latter are installed side-by-side with the columns, at the bottom of the columns, and play the important role of gravity columns. As such, the first story can act as a base-isolation system that causes the natural period of the frame to increase. Several numerical simulations were conducted to investigate the contribution of the system to the performance of the entire frame, in terms of the reduction in the shear force, inter-story drift angle, and seismic energy transfer when the frame is subjected to earth tremors. The frame with the passive friction dampers exhibited less deformation.

1. INTRODUCTION

The authors previously investigated the effect of installing friction dampers at the bottom of a frame without column base connections [1]. The sliding of the friction dampers reduces the amount of seismic energy being transmitted to a building. A base-isolation system can be realized by adding friction dampers at the base of each column of a frame. Each friction damper has a single degree of freedom in the horizontal direction. However, there are two serious problems with this model of the friction element. The first is that the slip load on each friction damper is subject to different degrees of friction force given the variations in the axial force in a column when it is subject to an earthquake. The other is the issue of residual displacement of the dampers that may lead problems after an earthquake. This system must be improved in order to overcome these problems. To make the slip loads of the different friction dampers almost uniform, each column base should be connected by tie beams. Furthermore, the side columns of the first story should be directly connected to the foundation to prevent excessive drifting of the frame. Therefore, the base of a frame with friction dampers must be capable of springing back to its original position. An index that can be used to determine the seismic response of the frame and friction dampers is the inter-story drift angle. The seismic responses of the frame and the friction dampers are examined according to some analytical parameters.

2. ANALYTICAL FRAME

In this section, an outline of the analysis frame shown in Fig. 1 is described by referring to previously designed steel frames [2]. A five-bay, three-story steel frame was designed according to Japanese building codes, and then subjected to a series of numerical analyses. The original, undamped frame and the frame with the friction dampers are shown in Fig. 1.



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

Figure 1. Analytical frame

The columns and beams are hollow steel sections and wide-flange steel sections, respectively. The friction dampers are represented by special mechanical elements. The hysteresis behaviours of the columns and the beams exhibit isotropic and kinematic hardening. The cross-sectional size and material properties of each member are summarized in Tables 1 and 2, respectively.

Table 1. Cross sections of members

Column	C1	C2	C3
	RHS-300 × 300 × 19	RHS-300 × 300 × 16	RHS-300 × 300 × 12
Beam	B1	B2	B3
	H-500 × 200 × 10 × 16	H-496 × 199 × 9 × 14	H-446 × 199 × 8 × 12

Table 2. Material properties

Young's modulus	Strain hardening factor	Yield strength
205,000 N/mm^2	0.005	258.72 N/mm^2

The side columns of the first story have a fixed boundary condition because they are not fitted with friction dampers. The other columns have friction dampers and are rigidly connected by tie beams. The cross sections of the tie beams are the same as those of the beams of the second floor.

3. FRICTION DAMPER

This section introduces the analytical model of the friction dampers incorporated into the frame. The analytical model and mechanical system of the friction damper while sliding are shown in Fig. 2.

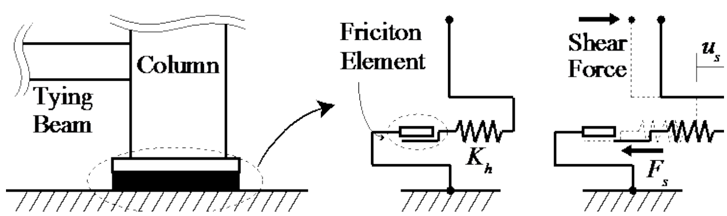


Figure 2. Analytical model of friction damper

Here, K_h is the stiffness of the friction damper. The friction dampers are assumed to be infinitely stiff. The hysteresis behaviour of the friction dampers is based on Coulomb friction, as expressed by Eq. (1).

$$F_S = \mu \cdot W \tag{1}$$

Here, F_S is the slip load, μ is the coefficient of friction, and W is the contact force of the friction dampers. When the frictional force becomes equal to the slip load, the friction damper starts to slide. There must be a close relationship between the characteristics of sliding of the friction damper and its deterioration under a dynamic load. However, for the analyses performed as part of this research, it was assumed that the surface of the friction damper does not exhibit any deterioration.

4. EIGENVALUE ANALYSIS

Isolation damping is applied to the frame because the natural period of a frame with friction dampers is longer than that of an undamped frame. The natural period of the undamped frame is as long as only one of the frames with the friction dampers, which does not slide under the influence of an earthquake. Therefore, eigenvalue analysis was conducted, and the resulting natural periods of the frame with friction dampers, both when they slide and do not slide, are listed in Table 3.

Table 3. Natural periods of frame

Mode	Without sliding (original frame)	With sliding
1st	0.553 s	0.759 s
2nd	0.193 s	0.248 s
3rd	0.121 s	0.134 s

The first natural period of the frame at sliding is approximately 37% longer than that when there is no sliding.

5. DYNAMIC ANALYSIS

5.1. Dynamic analysis

The contact force of the friction damper, which is the total weight of the frame, remains roughly constant through the analysis, as mentioned above. The slip load changes with the coefficient of friction. Therefore, calculations were conducted using the coefficient of friction as an analytical parameter. The coefficient of friction varied over a wide range, from 0.1 to 0.6. The direction of ground motion applied to the frame was assumed to be in the X-direction for each of the analyses. Ground motion data for the El Centro (1940) NS wave was used for the analyses. For this research, it is important to obtain analysis results for a range of earthquake magnitudes. Therefore, the maximum velocity of the ground motion was set to 0.25, 0.50, and 0.75 m/s, which represent small-, medium-, and large-intensity earthquakes, respectively. The step time of the numeric integration of the seismic response analysis was 0.002 s. The duration of the analyses was 30.0 s.

5.2. Time history of inter-story drift angle

The time history of the inter-story drift angle in each story (R_i) for a coefficient of friction of 0.1 and a maximum velocity of 0.75 m/s is shown in Fig. 3. 'Original' in the graph legends refers to the dynamic behaviour of the original, undamped frame, and 'Friction' in Fig. 3 refers to the dynamic behaviour of the frame with the friction dampers. The vibration period of the frame with the friction dampers is longer than that of the original, undamped frame. Furthermore, the inter-story drift angle in the second and third story of the frame with friction dampers is smaller than that of the original, undamped frame. This is caused by the input seismic energy being reduced by the effect of the isolation damping, which increases the vibration period of the frame length and the amount of energy dissipated by the friction dampers.

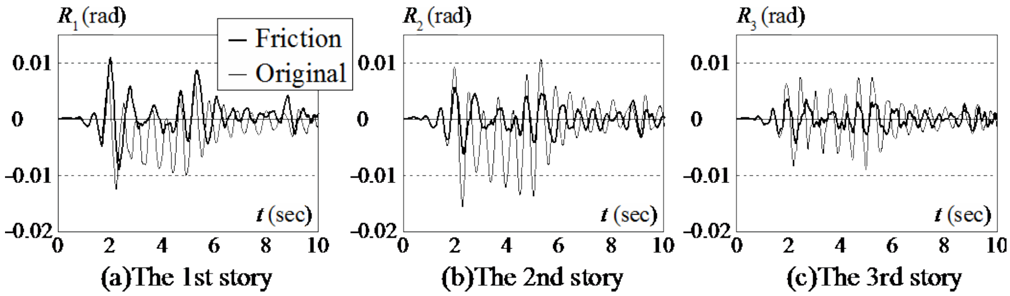


Figure 3. Time history of inter-story drift angle

5.3. Maximum inter-story drift angle

The maximum inter-story drift angle ($R_{i\,\mathrm{max}}$) in each story is shown in Fig. 4. 'Original' in the graph legends refers to the original, undamped frame. $R_{i\,max}$ of the frame with the friction dampers is smaller than that of the original, undamped frame from the second story upwards. When the value of the coefficient of friction is 0.10, $R_{i\,max}$ in the second and third stories falls by approximately 50% relative to the value for the original, undamped frame. On the other hand, as the coefficient of friction increases, the vibration control becomes less effective. For this reason, the sliding displacement of the friction dampers is lower when the coefficient of friction is large.

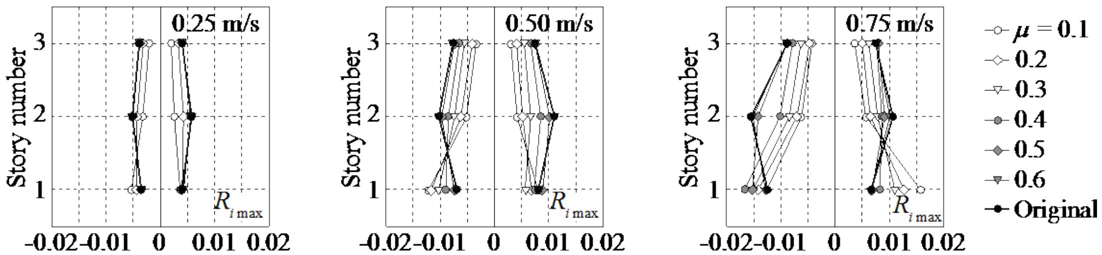


Figure 4. Maximum inter-story drift angle

6. CONCLUSION

The incorporation of friction dampers into the bottom of a frame, combined with the connection of the side columns of the first story to the foundation, provides an effective means of reducing a building's dynamic response. The tendency, as obtained by numerical analyses, is for $R_{i\,\mathrm{max}}$ of the frame to fall by approximately 50% relative to that of the original, undamped frame when the coefficient of friction is 0.10.

7. REFERENCES

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