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Cyclic behavior of seesaw energy dissipation system with steel slit dampers

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ABSTRACT

This paper presents an investigation into the cyclic behavior of a passive vibration control system in which steel slit dampers are applied to a seesaw energy dissipation system. The fundamental concept of the seesaw system is the quasi-linear motion mechanism, which enables the bracing members to remain in tension during vibration. The lateral stiffness and strength formulae of the frame with this system are derived first. Six cyclic loading tests were conducted to reveal that the proposed system has a stable hysteretic property and a large energy dissipation capacity. For all specimens, the slit dampers yielded at early stages of the tests around a story rotation angle of 0.001 rad. This property is preferred for energy dissipation properties to reduce story drift in building structures under seismic loads. The important seesaw system characteristic of the bracing members remaining tensile was also observed. The tri-linear hysteretic model is introduced to model the cyclic behavior of the proposed damping system. A comparison of the hysteretic loops and the energy dissipation amount between the model and test results reveals the adaptability of the tri-linear model to the hysteretic behavior of the proposed system. The validity of the stiffness and strength prediction is also shown from the test results.

1. Introduction

During a severe earthquake, the significant amount of energy input to a structure can cause structural damage. For earthquake risk mitigation in structures, extensive studies of passive energy dissipation methods have been conducted [1]. Some of the input seismic energy can be diverted into energy dissipation devices installed within a structure. Among such devices, a steel damper dissipates seismic energy through the yield deformation of steel materials. Therefore, this is categorized as a so-called hysteretic damper [2]. For example, the buckling-restrained braces dissipate seismic energy through the axial yielding of steel core members [3–7]. The steel shear panels dissipate seismic energy through shear yielding [8]. In addition, the TADAS [9], the U-shaped dampers [10,11], slit dampers [12], and pipe dampers [13] dissipate seismic energy through flexural yielding. Slit dampers are used, for example, at brace members [14] and at beam-to-column connections [15,16].

A previous study [11] investigated an energy dissipation system based on a quasi-linear motion mechanism realized by three link members called a Chebyshev linkage, as presented in Fig. 1(a–c). Multiple dampers placed at both ends of a rotatable member dissipate energy by compression and tension deformation, as presented in Fig. 1(b). This energy dissipation system is designated as a seesaw system because the rotatable member moves similarly to that of a seesaw [17]. One benefit of this system is that it enables the usage of steel rods or cables as bracing because the bracing members with pretension retain their tension during vibration. Various kinds of dampers are available for this system. First, U-shaped steel dampers were adopted and investigated through static cyclic loading tests [11]. In subsequent studies, velocity-dependent dampers such as viscoelastic dampers [17] and fluid viscous dampers [18] were also adopted for the seismic response analyses of building frames. A recent study [19] examined friction dampers for a case in which a seesaw member was installed vertically, as presented in Fig. 1(d).

Some cyclic loading tests conducted for the seesaw system with U-dampers showed the stable hysteresis loops and large ductility of the damping system [11]. The results showed, however, that the lateral stiffness of the damping system was rather low, which resulted from the low bending stiffness of the U-dampers. For that reason, late damper yielding occurred when the story rotation angle reached about 0.005 rad. This property is not preferred from the perspective of energy dissipation properties to reduce the story drift of structures under seismic loads.

This study investigates the application of steel slit dampers to the seesaw system for increasing the damper stiffness and improving the energy dissipation property. In this paper, the lateral story stiffness and strength formulae are first derived for the seesaw system with slit dampers. The energy dissipation property of the proposed system is revealed from the results of six cyclic loading tests. Finally, a tri-linear hysteretic model is introduced to represent the cyclic behavior

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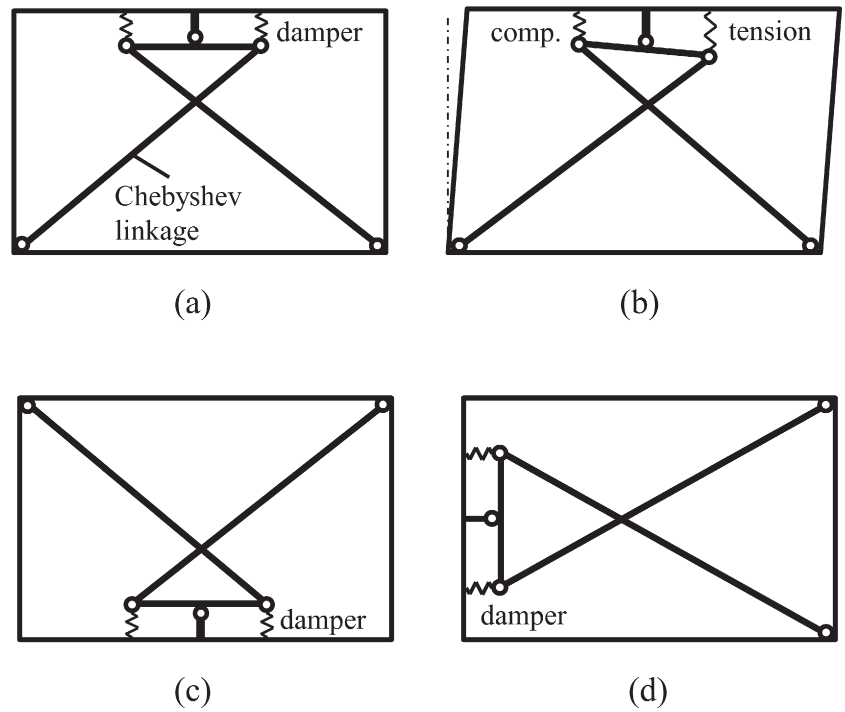

Fig. 1. Concept of seesaw energy dissipation system: (a) initial configuration, (b) deformed configuration, (c) bottom installation type, (d) vertical installation type.

of the proposed system in a simple manner. The validity of the stiffness and strength prediction and the adaptability of the hysteretic model are examined by comparing the cyclic loading test results.

2. Lateral stiffness and strength evaluation

2.1. Outline of seesaw system with steel slit dampers

Fig. 2 presents the seesaw energy dissipation system with steel slit dampers. Multiple slit dampers are installed under the seesaw member. When a lateral force F acts on the frame, the brace's tensile force acts on the seesaw member edge. The frame lateral displacement is denoted by δ as shown in Fig. 2(b). The seesaw member rotation around the pin forces the slit dampers to deform as presented in Fig. 2(b). The slit dampers exhibit plastic deformation and dissipate energy. By providing pre-tension force to the bracing members, it is expected that the tensile axial force remains in both bracing members during the frame deformation [11].

2.2. Slit damper stiffness and strength

The shape and dimensions of a steel slit damper are presented in Fig. 3. It is assumed that one side of the damper is fixed and the other side is roller supported. The relationship between the shear force f_D and displacement u_D is expressed as.

$$f_D = k_D u_D. \tag{1}$$

In Eq. (1), k_D denoting the damper stiffness is obtained by.

$$k_D = 1/\left(\frac{h'}{3Gtb} + \frac{h'^3}{3Etb^3}\right), \tag{2}$$

where G signifies the shear modulus, E represents the Young's modulus, and t denotes the steel plate thickness. Also, h' is the equivalent strut length [14,15] as presented in Fig. 4.

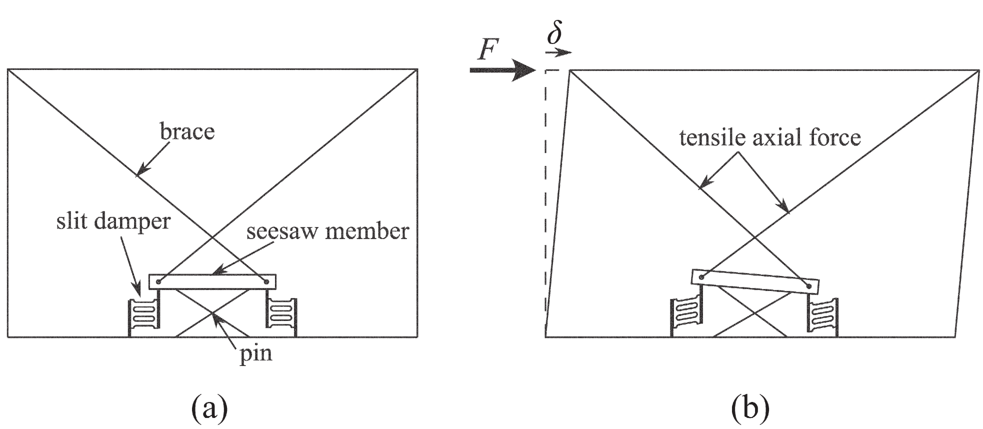

Fig. 2. Seesaw system with steel slit dampers: (a) initial configuration and (b) deformed configuration.