Development of double slit dampers for seismic retrofit of structures

J. Kim(1), M. M. Javidan(2)

(1) *Professor, Sungkyunkwan University, jkim12@skku.edu*
(2) *Ph.D. Student, Sungkyunkwan University,*
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Abstract

This research proposed a new displacement-dependent energy dissipation device for seismic protection of framed structures. The double-slit damper is developed by combining weak and strong steel slit dampers in series. It has two stages of energy dissipation with different yielding forces and stiffnesses: for low to medium earthquakes, the weak-slit damper yields and dissipate seismic energy. For stronger earthquakes, further deformation in the weak slit damper is restrained and the strong-slit damper begins to dissipate the energy. Cyclic loading test of a prototype damper is carried out to evaluate the seismic energy dissipation capacity. A simplified numerical model of is developed in the framework of commercially available structural analysis software. To verify the applicability of the dampers in practice, the dampers are installed in a 2-story full scale RC frame structure and are tested under cyclic loading. The experimental and analysis results show that the double slit dampers are effective in reducing seismic response of framed structures.

Keywords: seismic retrofit, slit dampers, seismic design

1. Introduction

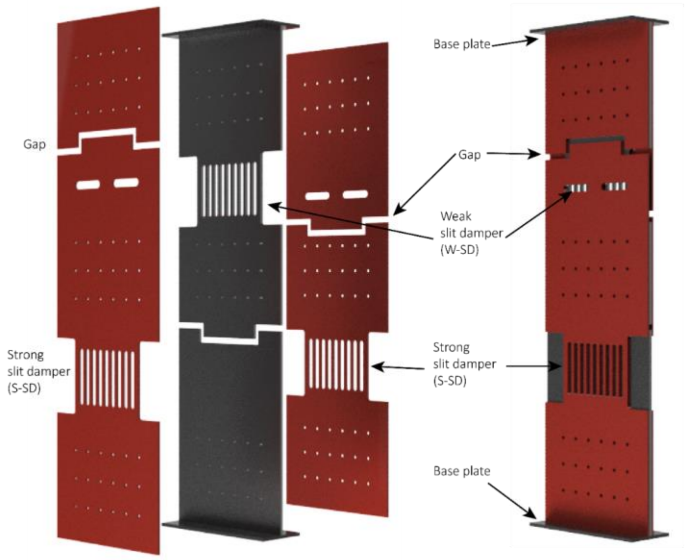
Steel slit dampers are considered as an efficient seismic protection device for structures in the field of earthquake engineering. Lee and Kim [1] developed hybrid damping devices by combining steel slit and rotational friction dampers connected in parallel, and showed that the hybrid dampers are especially effective in reducing seismic responses for small to medium earthquakes, compared with slit or friction dampers with the same yield strength. Kim and Shin [2] studied the seismic loss assessment of a structure retrofitted with slit-friction dampers through test and analysis. The seismic performance of a self-centering hybrid slit damper with shape memory alloy bars was investigated by Naeem et al. [3, 4]. The hybrid slit dissipation device turned out to be effective in reducing both the earthquake-induced maximum and residual displacements of a structure.

Even though slit dampers are effective seismic energy dissipation devices, their energy dissipation capacity is completely lost when the slit columns are fractured at large displacement. This study aims to develop a double-slit damper in which weak and strong slit dampers are connected in series. The proposed damper consists of steel slit dampers with two different stiffnesses and yield strengths. During low to medium earthquakes, the weak slit damper is activated while the strong slit damper remains elastic. For severe earthquakes, both the weak and strong dampers act together to dissipate large seismic energy. When the displacement of the weak slit damper reaches near the fracture point, further displacement is prevented by a stopper and the force is transferred to the strong slit damper. A simplified analytical model of the proposed damping devices is developed, verified, and calibrated by cyclic loading test and detailed finite element analysis. The applicability and effectiveness of the proposed damper are investigated by comparing the seismic performance of a 5-story RC ordinary moment frame before and after retrofit.

2. Double-slit dampers

The double-slit damper developed in this study is composed of story-high steel plates combined together using high-strength bolts as shown in Fig. 1. The center plate with the weak slit damper is sandwiched between the two side plates with strong slit damper. The three steel plates are connected to each other by bolts at upper, middle, and lower parts, and only the center plate is fixed to the beams of the loading frame at the top and bottom. Each side plate is divided into the upper and lower part by the $\prod$-shaped gap which is used as a stopper to deactivate the weak slit damper located in the center plate and as a load transmitter to activate the two strong slit dampers in the side plates when a certain displacement is reached. As the lateral displacement further increases, even the gap in the center plate is closed and the strong slit dampers are also deactivated to prevent fracture. At this stage, the double slit damper works like a steel plate shear wall.

The in-plane stiffness of the slit damper subjected to horizontal shear force can be obtained based on the assumption that the ends of the narrow strips are fully restrained from rotation. The force-displacement relationship of the double slit damper is presented in Asad and Kim [5]. Based on the stiffness of the combined mechanism of the double slit damper, typical hysteresis curve with two distinct yield points is shown in Fig. 2.



Exploded view

Perspective view

Fig. 1. Exploded view of the multi-slit damper

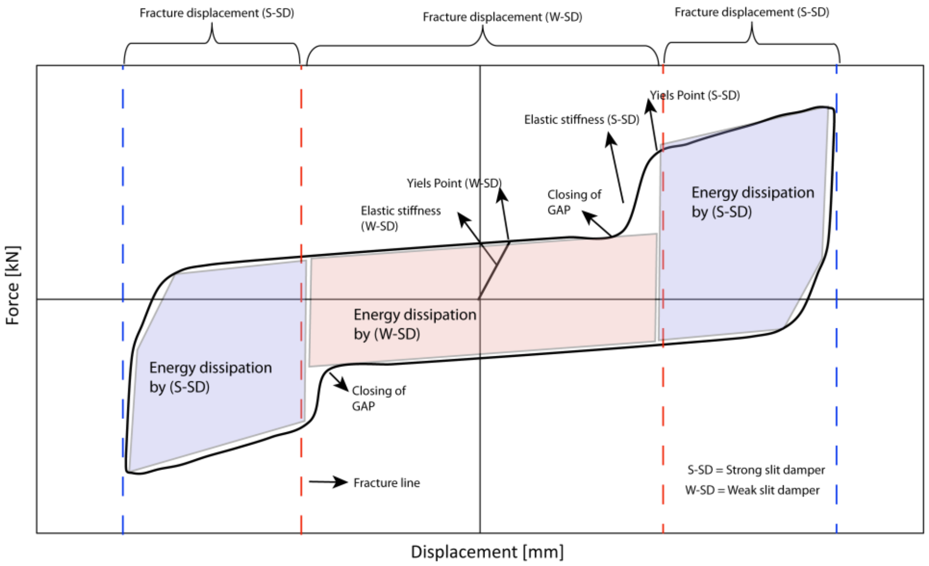


Fig. 2 Hysteresis curve of the multi-slit damper

3. Cyclic loading test

To investigate the hysteric behavior of the proposed damper, displacement-controlled cyclic loading test of the double slit damper was carried out using 1,000 kN hydraulic servo actuator as shown in Fig. 3. The damper was installed in the steel frame with the pinned joints at the top and bottom of the columns for test. The height and span of the steel frame are 3,200 mm and 4,400 mm, respectively.

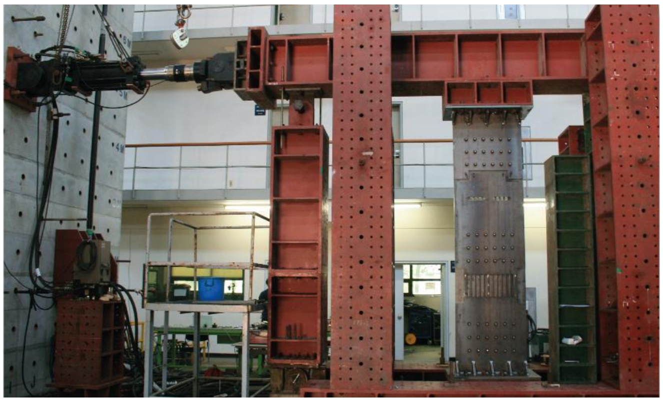


Fig. 3. Test setup for cyclic loading test of the MSD

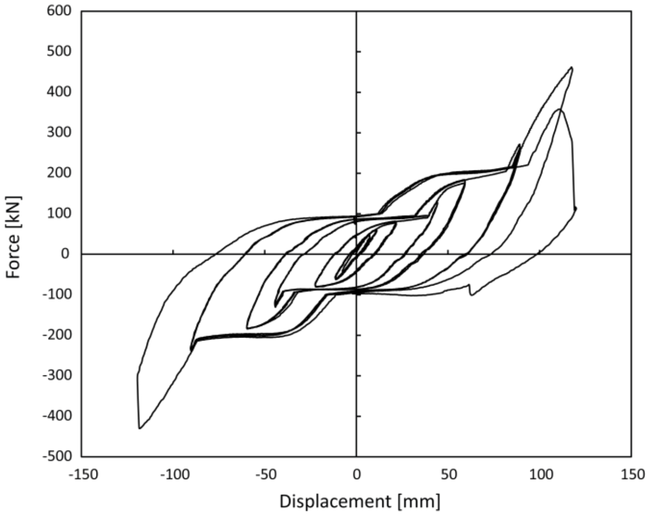


Fig. 4 Hystersis of double slit damper obtained from the loading test

Figure 4 shows the force-displacement relationship of the test specimen obtained from the cyclic loading test. The weak slit damper yield first while the strong slit dampers remain elastic. Once the displacement of the weak slit damper reaches 30mm, which is slightly smaller than the fracture displacement, the gaps between the top and bottom side plates are closed, and the load is transferred to the strong slit dampers at the bottom side plates while the weak slit damper is prevented from further deformation. In this way, the slit dampers are prevented from being fractured and remain functional throughout earthquake excitations. It is observed that the weak slit part yield first at the displacement of 5.3 mm and the load increases again until the strong slit parts yield at the displacement of 38 mm. Fig. 5 shows that the dissipated energy, which is the area included in the hysteresis curve, increases with the increase in the displacement because both slit dampers are activated. The hysteresis curves are nearly symmetrical in both directions. It was observed during the first cycle of 1.5% drift that the side plate gaps were closed at the displacement of 30 mm, but due to reasons such as slip of bolted connections, local deformation, and slight twist of the steel plates during the previous loading steps, the gap was closed at larger displacement in the subsequent cycles. Similarly, at the final stages of the test, the center plate gap was closed at the displacement of 80 mm increased from the initial value of 60 mm. At the displacement larger than 60~80 mm the load increased significantly due to the fact that the deformation of all slit dampers was stopped by the closing of all gaps and the steel plates acted like a steel plate shear wall.

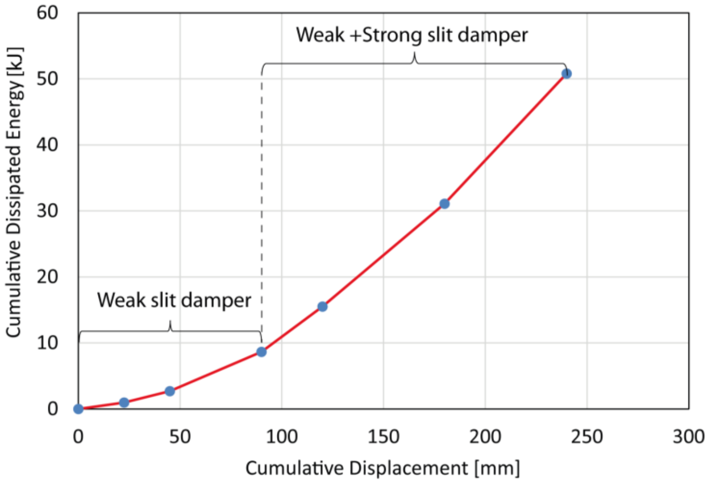
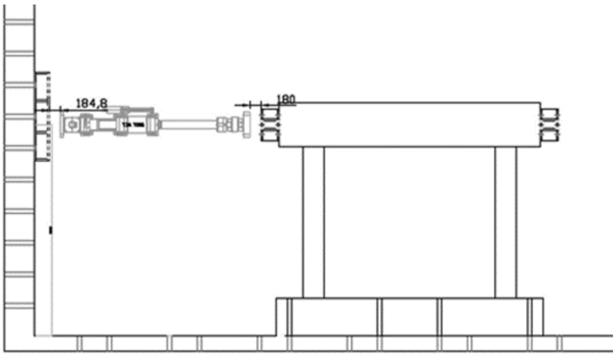


Fig. 5 Accumulated energy dissipation obtained from the cyclic loading test

4. Test of a RC frame with the double slit damper

The double slit damper was installed in the middle of the one bay single story reinforced concrete frame, as shown in Fig. 6, and tested using cyclic loading. Fig. 7 depicts the hysteresis curves of the structure before and after the retrofit, where it was observed that in both cased the structure failed by shear fracture at the upper column. It was found that after the seismic retrofit the overall strength increased by 1.27 times. Fig. 8 shows the accumulated dissipated energy estimated in the structure during the test. It was observed that the energy dissipation increased by 3.25 times after the seismic retrofit using the double slit damper.



(a) Test setup for unreinforced frame

(b) Test setup for reinforced frame

Fig. 6 Test of double slit damper installed in a RC frame

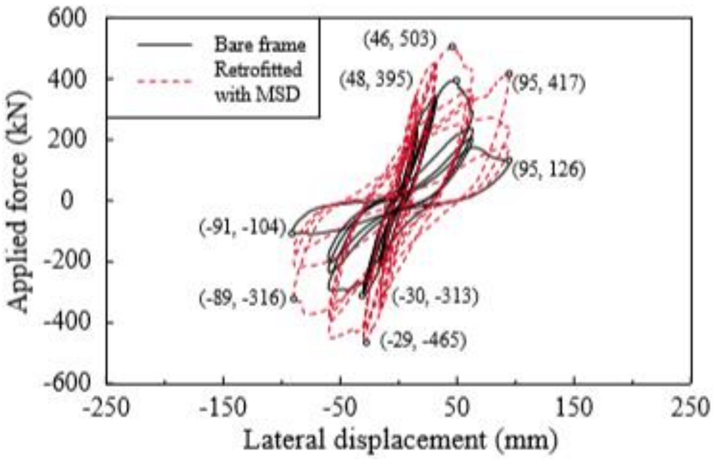


Fig. 7 Hysteresis curve of the RC frame with and without retrofit using the multi-slit damper

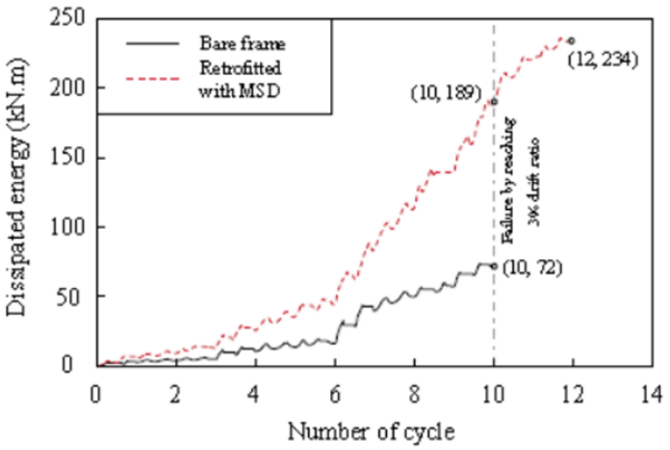


Fig. 8 Accumulated energy dissipation measured in the cyclic loading tests

5. Summary

This paper proposed a new steel slit damper composed of story-high steel plates with weak and strong slit parts connected in series. It was observed in the cyclic loading test that two distinct yield points existed as designed and that the damper showed stable hysteretic behavior at the lateral displacement larger than 4% of the story height. It was observed in the single story RC test that after the seismic retrofit the overall strength increased by 1.27 times, and the accumulated energy dissipation was increased by 3.25 times. Based on the experimental results, it was concluded that the double slit damper is an effective seismic protection system for framed structures.

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