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Experimental and Numerical Study of Hybrid Friction Damper

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ABSTRACT: In this study, a new hybrid energy dissipation device was developed by combining two friction dampers (auxiliary and main fuse) in series to be used for seismic control of two different earthquake intensities. Compared with the conventional friction dampers, the new hybrid damper has an advantage in which only auxiliary fuse (with low sliding force) is activated for moderate earthquakes and both fuses work simultaneously for strong earthquakes. Cyclic loading tests of the combined hybrid dampers were carried out in order to evaluate their seismic energy dissipation capability. The obtained experimental force-displacement indicated proper details of the new damper to create two performance level. Finite element analyses of the test specimens were also carried out for comparison, which had good agreement with the test results. Force displacement characteristics, Energy dissipation and equivalent viscous damping were also derived and good agreement has been found with code requirement for displacement dependent dampers. Also, it was demonstrated that engaging the main fuse with non-loaded pretention bolts, strength losses of the hybrid damper in subsequent cycles were limited compared to the common friction dampers which can be called "resurrection-type" behavior of the main fuse in the main shocks.

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1. INTRODUCTION

Response control of structures is one of the reliable approaches to increase the safety and stability of structures against wind and earthquake excitation. Passive, active and semi-active controls are the main classification of structural control systems. The passive systems are also known as passive energy dissipation devices, do not require an external source of power so they have been considered an effective and common way to decrease earthquake effect on structures. In passive control systems, input energy supplied by wind and/or earthquake can be dissipated within energy dissipative devices by yielding or friction [1,2].

Some researchers investigated the simultaneous application of multiple devices to maximize the energy dissipation mechanism of dampers during severe and moderate excitations. The combined dampers mitigated the seismic effect by means of minimizing the shortcomings of individual dampers [3-5]. Combination of friction and yielding dampers [6] buckling resistant braces with viscoelastic dampers [7] multiple steel pipes [8] and dual TADAS plates [9] improved some aspects of structural response providing benefits for multiple damage measures.

The purpose of this study is the development of a hybrid friction damper which works for both major and minor earthquakes numerically and experimentally. It seems that the proposed damper despite its simplicity, applicability and relatively low cost, demonstrates good performance and is acceptable in reducing the seismic vibrations of structures.

The hybrid damper developed in this study consists of two friction damper named hereby main and auxiliary fuse to resist strong earthquakes and small earthquakes respectively. Auxiliary and main fuse are connected through a displacement gap (horizontal holes) in series as shown in Figure 1. The auxiliary friction part consists of friction damper with low pretention force on bolts and the main one is provided by high pretention force which it is designed base on severe earthquakes.

The introduced hybrid friction damper is basically a displacement-dependent device which dissipates seismic energy by a slip of friction pads in two stages (friction dampers). The slip of friction pads in an auxiliary part occurs at small displacement, which makes it effective in resisting small earthquakes. The main par in dampers remain elastic during small earthquakes and are activated at only major earthquakes after reaching the predefined displacement gap. As the imposed displacement increases, high tension bolts attach on the end of horizontal slotted holes and transfer the force to the main part of the damper with large pretention

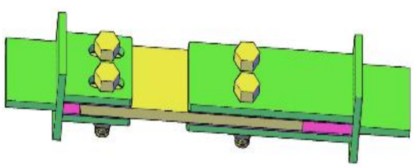

Fig. 1. Hybrid friction damper

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Fig. 2. The test set up in universal actuator

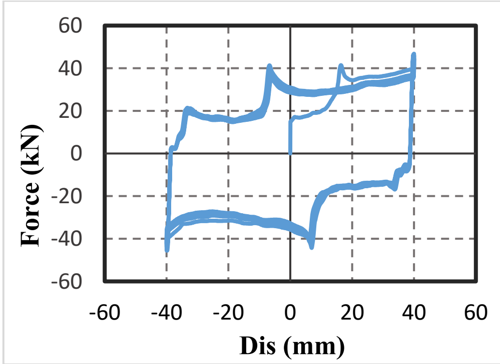

Fig. 3. Load- displacement results for sample A

specimen	P_{S1} (kN)	P_{S2} (kN)	P_{s2}/P_{s1}	δ_{max} (mm)
A	15	28	1.9	50
B	36	104	2.9	40
C	60	180	3	60
D	87.5	237.8	2.7	60

Table 1. Clamping forces in the experimented specimen

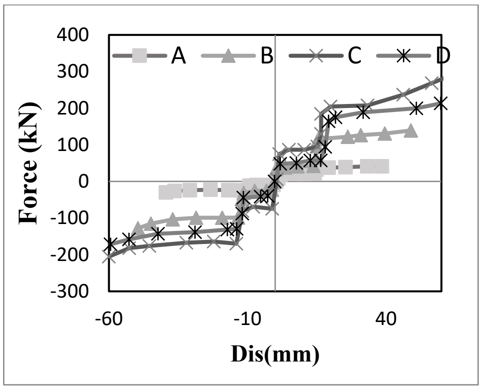

Fig. 4. Backbone curves of experimented samples

force on bolts in the main part.

2. METHODOLOGY

For evaluating the seismic performance of the hybrid damper, displacement-controlled cyclic tests of the specimens were carried out using a 300 kN universal electronic servo actuator. Figure 2 shows the photographs of the hybrid damper test set up.

In the experimental program of the hybrid friction damper, 20 cycles of harmonic displacement loading were applied with constant amplitude in such a way that the maximum displacement of 60 mm is reached at each loading cycle. This amplitude of imposed displacement corresponds to 2% of the story height in structures.

According to Table 1, four samples were experimented by changing their clamping forces in both parts of hybrid damper. The friction coefficient of the friction pads used in the hybrid damper was determined to be 0.3 based on a series of preliminary tests measuring slip force of the friction pad subjected to various clamping forces induced by a torque ranch.

3. RESULTS AND DISCUSSION

The relevant test results were used to plot hysteresis curves for the hybrid friction damper; one of the results is shown in Figures 3 for sample A. The increase in forces associated with gap displacement was evident in the hysteresis loops. Also, the maximum applied displacement amplitude was chosen greater than the displacement gap in order to show the effects of adding the main fuse to the energy absorption system.

Force-displacement multi liner curve has been extracted from all test results and they are depicted in Figure 4. These simplified curves are derived from average slip force at corresponding displacement amplitudes. As can be seen, slip forces of specimens were increased due to the increase of clamping forces in A to D samples.

Base on the requirement of ASCE/SEI41-06 [10], slip force reduction in each cycle should not be greater than %15 compared with average slip load in all cycles. Slip force of all experiment samples has shown that the value of recorded force is not fluctuating diversely and confirmed with the code requirements. Equivalent damping ratio and dissipated energy of tested sampled have been determined by using the area under the force-displacement curve in each cycle. Results demonstrated that dissipated energy grow quickly after gap displacement and equivalent damping ratios vary approximately about 0.55.

In order to describe the multi-phase hysteretic behavior of the hybrid damper, numerical analysis was performed with Open Sees software [11]. In formulating an analytical model, elastoplastic material is considered to idealize a rectangular loop of friction damper in each part of damper and gap-hook material are used to model the displacement gap between two fuses. Defined materials are combined in series and have been

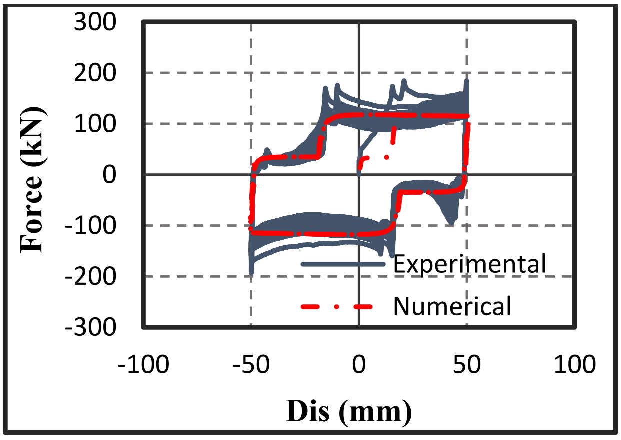

Fig. 5. Verification of numerical model with the experimental result

Table 2. Numerical model properties

model	P_{S1} (kN)	P_{S2} (kN)	P_{s2}/P_{s1}
a	93	172	1.85
b	74	165	2.23
c	70	200	2.86
d	55	230	4.18
e	45	268	5.6
f	35	297	8.5
g	93	345	3.7
h	70	270	3.86
i	50	185	3.7
j	35	143	4.1

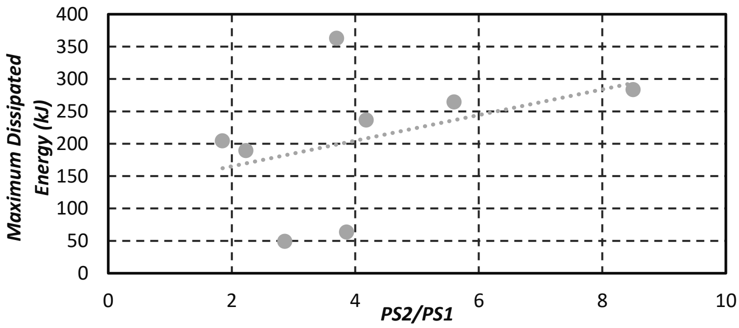

Fig. 6. Effect of *Ps2/Ps1* on maximum cumulative energy

modeled as a zero-length element in Open Sees software. Good agreement was observed between numerical analysis and experimental results for sample A (as illustrated in Figure 5).

Numerical models were developed in order to define the effect of the ratio of different slip force values in both fuses according to Table 2. Dissipated energy of all models was calculated and the relation of *Ps2/Ps1* and amount of cumulative energy dissipation have been investigated. As shown in Figure 6, increases in *Ps2/Ps1* led to ascending energy dissipation while it seems the advanced analysis of structures equipped by hybrid friction damper is necessary to determine the optimum ratio of slip forces.

4. CONCLUSIONS

The obtained experimental force-displacement indicated proper details of the new damper to create two performance level. Finite element analyses of the test specimens were also carried out for comparison, which had good agreement with the test results. Force displacement characteristics, Energy dissipation and equivalent viscous damping were also determined and compared to code requirements. It was found that results are in the allowable range of code requirements. Also, it was demonstrated that engaging the main fuse with non-loaded pretention bolts, strength losses of the hybrid damper in subsequent cycles were limited compared to the common friction dampers which can be called “resurrection-type” behavior of the main fuse in the main shocks.

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