DEVELOPMENT OF A PASSIVE VARIABLE FRICTION DAMPER WITH DISPLACEMENT-DEPENDENT DAMPING FORCE CHARACTERISTICS

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ABSTRACT

The aseismic performance of some existing skyscraper buildings in Japan should be adequately improved in order to allow these buildings to withstand the long-period earthquake ground motions that are expected to occur in the near future. For this purpose, mounting new dampers in existing structures is generally an effective approach. However, one problem associated with this approach is that conventional dampers give rise to an increase in the stress on existing structural members such as beams, columns, and foundations.

In the present study, in order to overcome this problem, a passive variable friction damper (VFD) with displacement-dependent damping force characteristics has been developed. The VFD is designed to decrease the frictional force when its displacement exceeds a predetermined value. This makes the VFD ideal for aseismic retrofitting of existing skyscraper buildings. Dynamic loading tests on a brace-type VFD mounted in a full-scale steel frame were carried out in order to verify the performance of the proposed damper. The results indicated that the VFD satisfied the required performance requirements, exhibiting stable operation and high endurance under cyclic loading.

Keywords: Passive variable damper, Variable friction damper, Vibration control, Skyscraper building, Long-period ground motion.

1. INTRODUCTION

The aseismic performance of some existing skyscraper buildings in Japan needs to be adequately improved in order to allow these buildings to withstand the long-period earthquake ground motions that are expected to occur in the near future. For this purpose, mounting new dampers in existing structures is generally an effective approach. However, one problem associated with this approach is that conventional dampers increase the stress on existing structural members such as beams, columns, and foundations. In order to overcome this problem, a passive variable oil damper has been developed and applied to an actual high-rise building (Kimura et al. 2008; Kimura et al. 2009).

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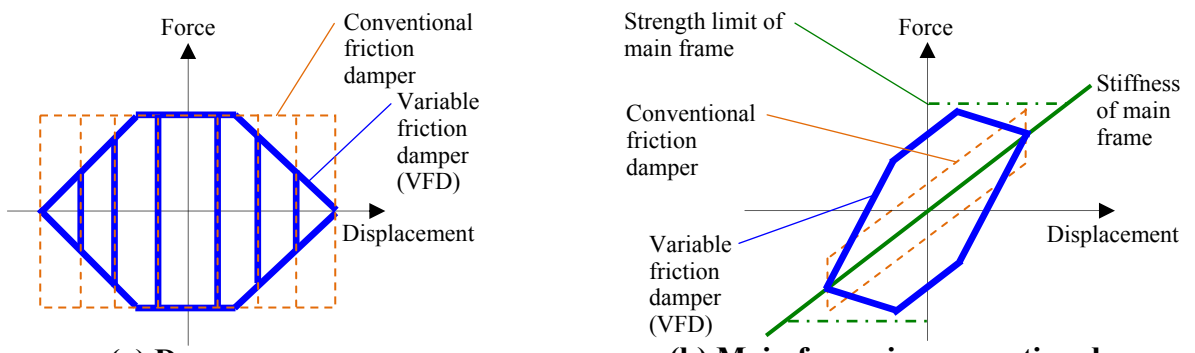
In the present study, as an alternative approach, we have developed a passive variable friction damper (VFD) with displacement-dependent damping force characteristics. The VFD is designed to decrease the frictional force when its displacement exceeds a predetermined value. This makes the VFD ideal for aseismic retrofitting of existing skyscraper buildings. Dynamic loading tests on a brace-type VFD mounted in a full-scale steel frame were carried out in order to verify the performance of the proposed damper.

2. OUTLINE OF THE VARIABLE FRICTION DAMPER

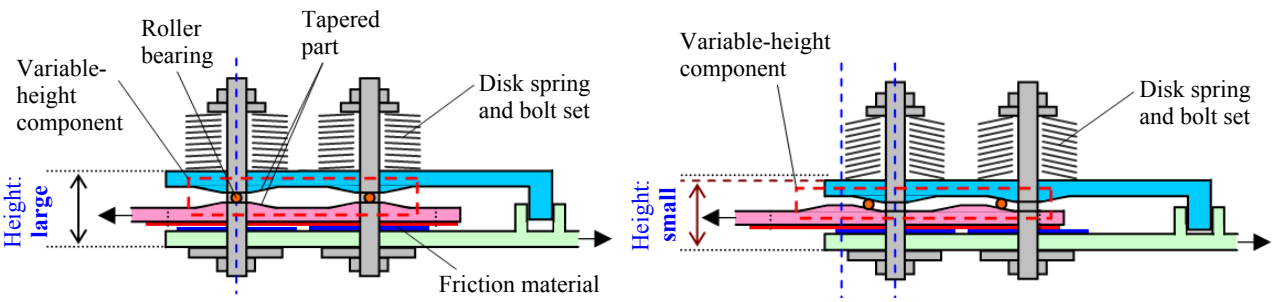
This section describes the main features of the VFD. Figure 1 shows conceptual diagrams of the VFD (Shirai et al. 2012) compared with a conventional friction damper (Sano et al. 2003). As shown in Figure 1(a), the VFD is designed to produce a decreased frictional force when its displacement exceeds a predetermined value. Therefore, as shown in Figure 1(b), the VFD provides the main frame with relatively large amount of damping that depends on the strength limit of the main frame, in contrast to the conventional friction damper. This makes the VFD ideal for aseismic retrofitting of existing skyscraper buildings.



(a) Damper **(b) Main frame incorporating damper**

Figure 1: Conceptual diagrams of VFD (force-displacement relationships)

Figure 2 shows the mechanism of the VFD. Similar to a conventional friction damper (Sano et al. 2003), the VFD contains friction materials and disk spring and bolt sets. In addition, the VFD has variable-height components, which consist of tapered parts and roller bearings.



(a) At the neutral position **(b) At the time of deformation**

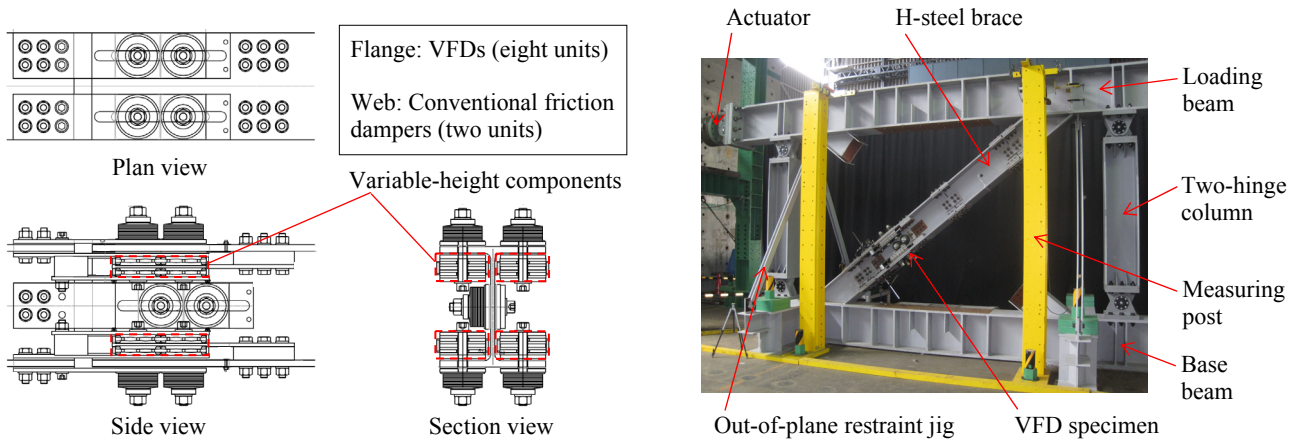
Figure 2: Mechanism of VFD

As shown in Figure 2(a), when the VFD is in the neutral position, the height of the variable-height components remains large. In contrast, as shown in Figure 2(b), when the deformation of the VFD

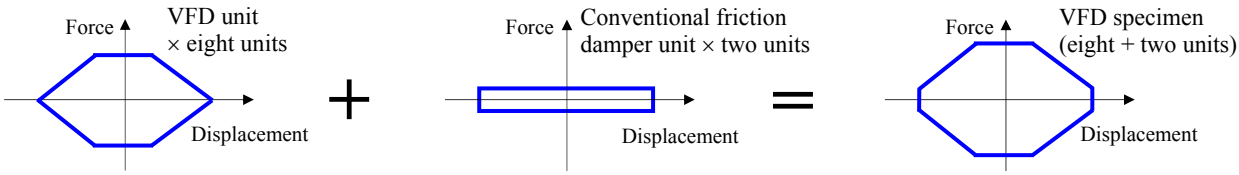
becomes large, the height of the variable-height components becomes smaller, thereby decreasing the frictional force.

3. DYNAMIC LOADING TESTS

This section describes dynamic loading tests on a brace-type VFD specimen incorporated into a full-scale steel frame. Schematic diagrams of the VFD specimen are shown in Figure 3(a), and the target damper force-displacement relationships of the specimen are shown in Figure 3(b). The section size of the H-steel of the VFD specimen was H-400×362 mm. Each VFD unit and conventional friction damper unit was designed and adjusted so as to have a maximum damper force of approximately 80 kN per unit. The total number of friction surfaces was two. The target installation tension for each disk spring and bolt set was 120 kN. The predetermined displacement of each VFD unit, for which the frictional force begins to decrease, was designed to be 10 mm. The number of VFD specimens was one. The loading system is shown in Figure 3(c). A dynamic 1,000-kN actuator was used for horizontal one-directional loadings. The height from the base beam center line to the loading beam center line was 3,170 mm, and the span between both two-hinge columns was 5,000 mm. The installation angle between the horizontal axis and the H-steel brace axis was 38.4 degrees.



(a) Schematic diagram of VFD specimen **(c) Loading system**



(b) Target damper force-displacement relationships of specimen

Figure 3: VFD specimen and loading system

Table 1 shows the loading programs. Runs 1 through 7 and 10 were sine wave loadings. Runs 8 and 9 were simulated earthquake response waves, which were computed by time history response analyses using an MDOF model by assuming a fictional high-rise building, the 1st and 2nd natural periods of which were 4.3 s and 1.7 s, respectively. Run 10 was cyclic loading of 100 cycles.

Table 1: Loading programs

Run	Type of wave	Period of sine wave [s]	Target damper displacement [mm]	Steady cycle number
1	Sine wave	100	10	2
2	Sine wave	4.3	10	10
3	Sine wave	4.3	20	10
4	Sine wave	4.3	30	10
5	Sine wave	4.3	40	10
6	Sine wave	1.7	10	10
7	Sine wave	1.7	20	10
8	Simulated earthquake response wave (Kokuji-ha, Kobe NS phase)			
9	Simulated earthquake response wave (1978 Tohoku University NS)			
10	Sine wave	4.3	40	100

4. RESULTS OF DYNAMIC LOADING TESTS

This section describes the results obtained during the tests. Figure 4 shows the damper force with respect to the damper displacement (damper axis direction, Runs 3 through 5). Here, the horizontal axis shows the measured displacement of the VFD specimen in the direction of the H-steel brace axis, and the vertical axis shows the calculated damper force based on the measured load at the actuator and the installation angle of the H-steel brace axis. Figure 4 indicates that the VFD specimen exhibited on-target displacement-dependent variable characteristics and corresponded approximately to the required performance shown in Figure 3(b).

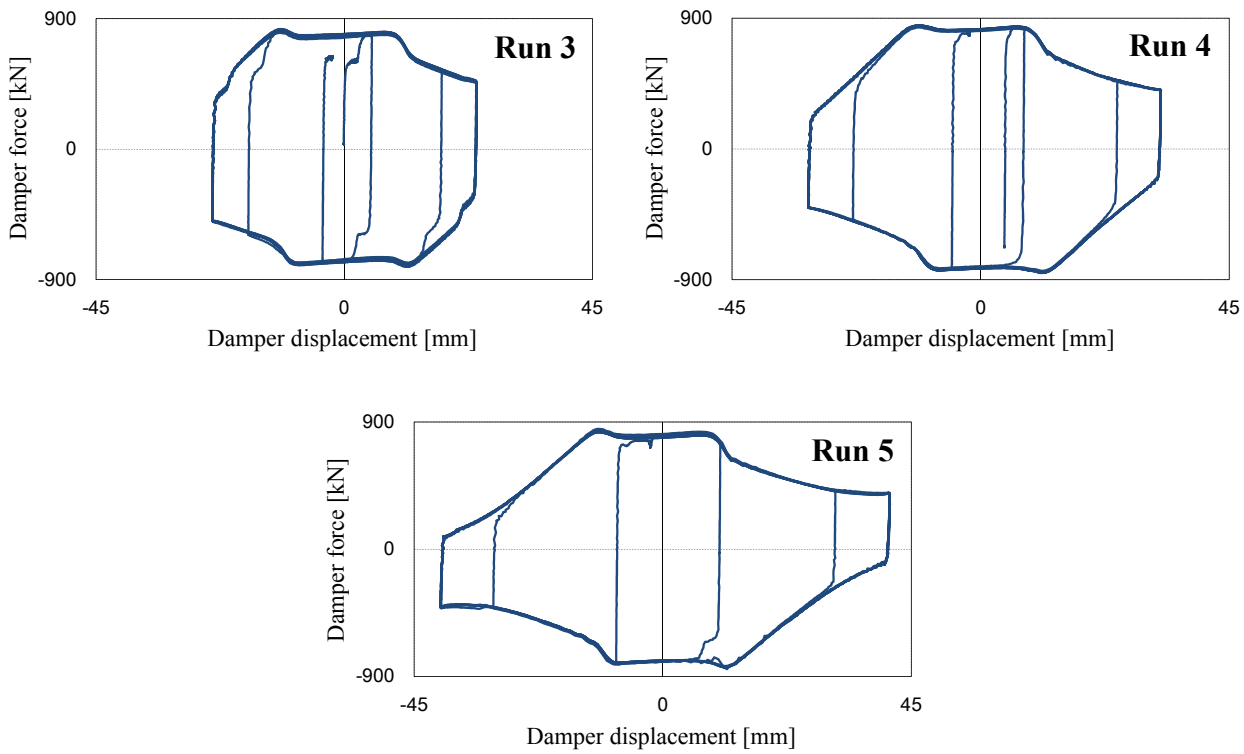


Figure 4: Damper force-displacement relationships (damper axis direction, Runs 3 to 5)

Figure 5 shows the friction coefficients obtained during the sine wave loading tests (per one surface, Runs 1 through 7). Here, the horizontal axis shows the number of sine wave loading cycles, and the vertical axis shows the friction coefficient calculated from the damper force at the zero damper displacement point for each cycle divided by the total target installation tension at each disk spring and bolt set (= 120 kN × 10 units) divided by the number of friction surfaces (= 2). Figure 5 indicates that the friction coefficients were stably distributed between approximately 0.30 and 0.34.

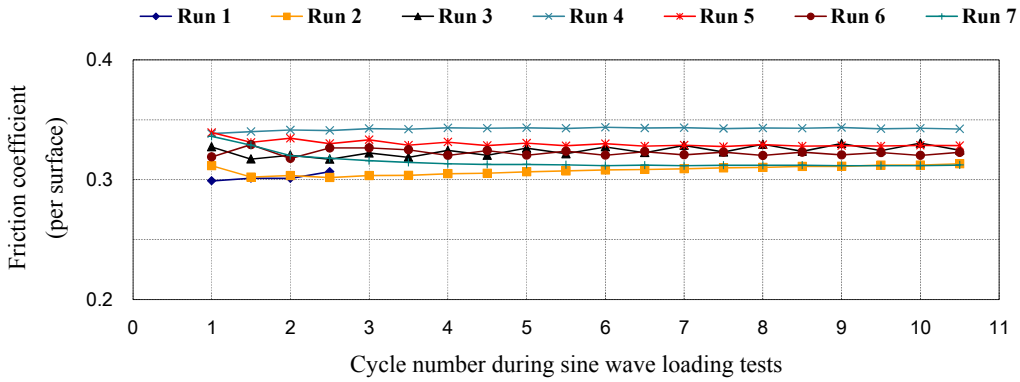


Figure 5: Friction coefficients (per one surface, Runs 1 to 7)

Figure 6 shows the results of the simulated earthquake response loading tests (Runs 8 and 9). The VFD specimen exhibited stable operations under random dynamic loads.

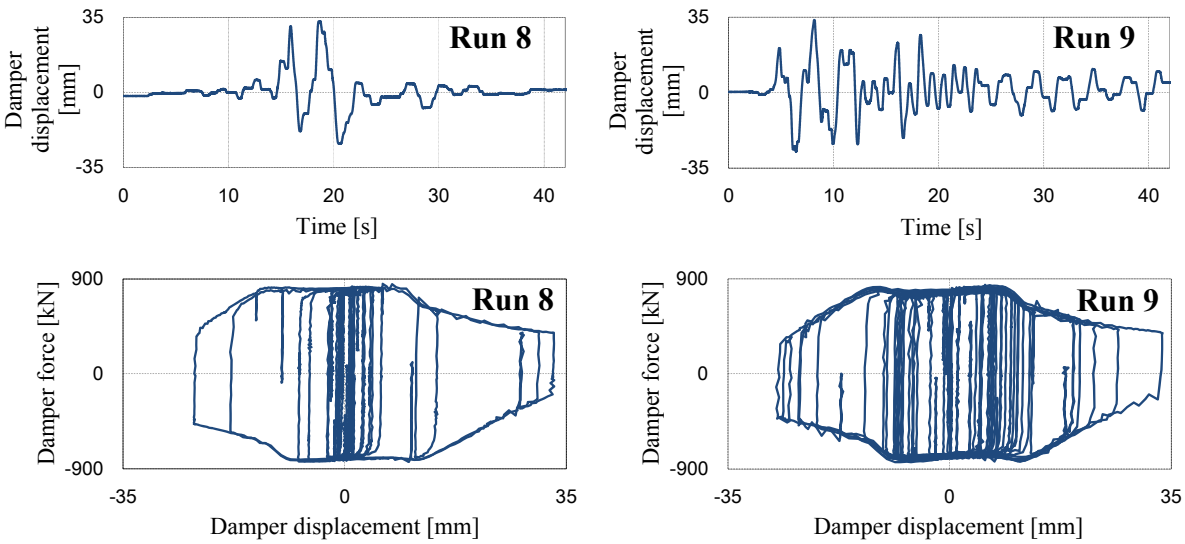


Figure 6: Simulated earthquake response loadings (damper axis direction, Runs 8, 9)

Figure 7 shows the damper force time history for Run 10 (100-cycle loading test). Each peak in the damper force has approximately the same value. The VFD specimen exhibited high endurance under cyclic loading.

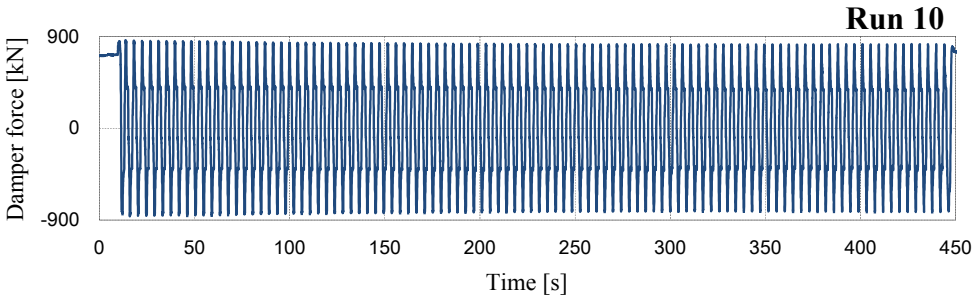


Figure 7: Damper force under cyclic loading (damper axis direction, Run 10)

5. CONCLUSIONS

A passive variable friction damper (VFD) with displacement-dependent damping force characteristics has been developed. The VFD is designed to decrease the frictional force when its displacement exceeds a predetermined value. This makes it ideal for aseismic retrofitting of existing skyscraper buildings.

Dynamic loading tests on a brace-type VFD specimen incorporated into a full-scale steel frame were carried out in order to verify the performance of the VFD. The results indicated that the VFD satisfied the performance requirements, providing stable operation and high endurance under sine wave, random, and cyclic loading.

6. ACKNOWLEDGMENTS

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