DYNAMIC PERFORMANCE EVALIATION OF 200kN MAGNETO-RHEOLOGICAL DAMPER

by

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ABSTRACT

Magneto-rheological damper (MR damper) has been expected to control the response of civil and building structures in recent years, because of its large force capacity and controllable force characteristics. Recent study is to the application of controllable dampers for reducing earthquake response of buildings and/or wind induced sway. The dynamic characteristics of the MR damper have to be clarified, in order to install and activate MR damper to the structure for controlling the response. In this paper, the design of MR damper with bypass flow portion and its dynamic analytical model are outlined. The dynamic characteristics of the damper were examined by dynamic excitation tests comparing with two types of magneto-rheological fluids. From the experimental and analytical results, the effectiveness and validity of MR damper are discussed in this paper.

Keywords: Magneto-rheological fluid
MR damper
Performance evaluation
Experimental test
Analytical formulation

1. INTRODUCTION

Until now, various kinds of semi-active control devices have been developed. A series of studies with viscous damper has been carried out and they were found to have good characteristics and efficient control system properties, Kurita et al. (1998). Well, magneto-rheological (MR) and electro-rheological (ER) fluid dampers attracted significant attention. The damping properties of these types of dampers are changed by changing the magnetic/electrical field applied to each fluid, Kawashima et al. (1995), Gavin et al. (1998), Hidaka et al. (1998), Fukukita et al. (1995), Spencer Jr. et al. (1997), Johnson et al. (1998), Dyke et al. (1998), Spencer Jr. et al. (1998).

Research on semi-active control of building structures using controllable fluid dampers is being conducted in the U.S.-Japan cooperative research and development project of "Smart Materials and Structural Systems." launched in 1998 by NSF and Building Research Institute, Japan Ministry of Construction, Otani et al. (2000). Two kinds of Magneto-rheological damper (MR damper) have been designed and manufactured. One has a nominal capacity of developed. Furthermore, two types of MR fluids are applied to the MR damper. One is MRF-132LD produced by Lord Corporation and the other is trial product #104 made on an experimental basis by Bando Chemical Industries. A series of experimental tests were performed. The damping force and the force-displacement relationship were evaluated. Furthermore, two types of analytical models are proposed to simulate the behavior of the MR dampers, and simulation and experimental results are compared in case of MRF-132LD. This paper outlines the results of experimental tests and simulations of MR dampers.

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2. DESIGN OF MRF DAMPER

The MR damper developed in this study (Photo 1, Table 1) has the nominal capacity of 200kN that is an appropriate size for vibration control systems of full-scale building structures. A new magnetizing system is adopted for this MR fluid damper (Figures 1 and 2). In this system, the electromagnet is attached at the bypass flow portion, which is connected to the cylinder. The bypass flow portion has the orifice to magnetize the fluid effectively. The uniform magnetic field is applied perpendicularly to the MR fluid flow at the orifice that has the annular cross section. The bypass system brings some advantages that the electromagnet can be designed more flexible, e.g. dwarfing of the electromagnet. It is also expected that the manufacturing process of the device and maintenance work is simplified. Two different kinds of MR fluids were tested on the MR damper. One was MRF-132LD and the other was trial product #104 made on an experimental basis by Bando Chemical Industries.

Photo 1: 200kN MR Damper

Table 1: Design Specifications of MR

	MR Damper - 200 kN	
Max. Force (Nominal)	200 kN	
Stroke	± 80 mm	
Cylinder Bore	200 mm	
Bypass Portion (Annular Orifice)	Outer Diameter : 70 mm	
	Inner Diameter : 66 mm	
	Length of Magnetic Field : 10 mm x10 Stages	
MR fluid	a. LORD Corp. : MRF-132LD	
	b. Trial Product #104	
Electromagnet	Coil	0.8 mm, 2200 turns
	Inductance	0.11 henries
	Resistance	10.5 ohms
Max. Current	5 A	

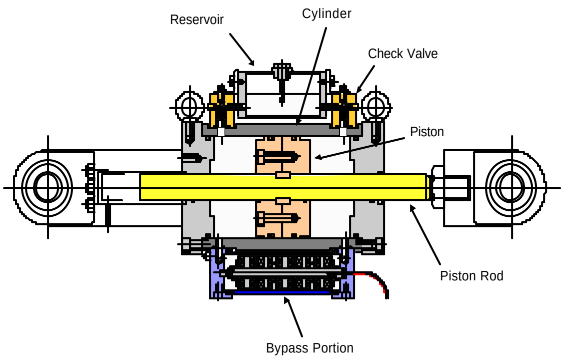


Figure 1: Hydraulic Circuit of Bypass Type 200kN MR Damper

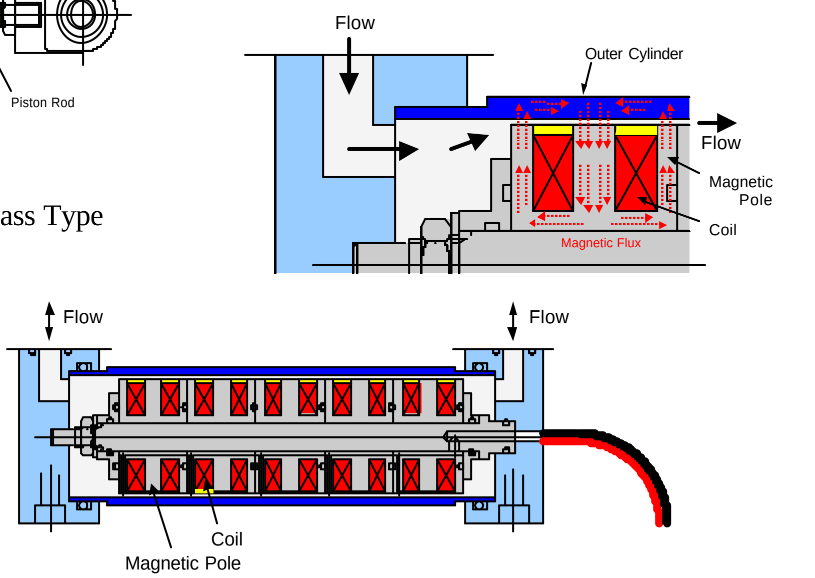


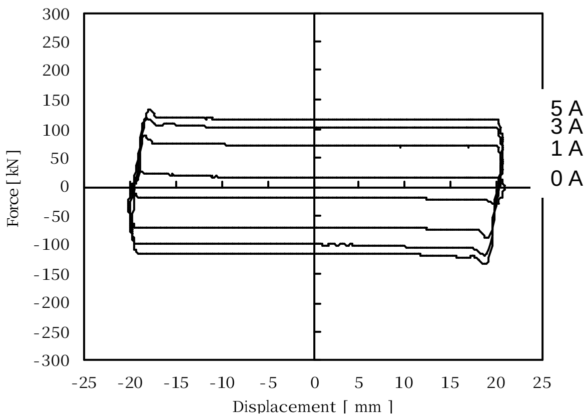
Figure 2: Section of Bypass of 200kN MR Damper

3. EXPERIMENT

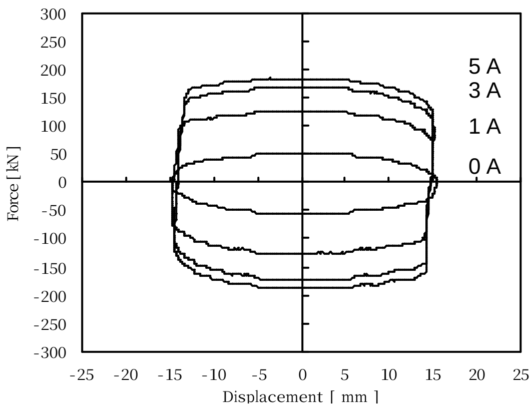
Dynamic loading tests have been carried out using of the vibration-testing machine to verify the damping characteristics of the developed MR damper. Various sinusoidal and triangular displacements are applied to the MR damper and the generated damping forces are measured by a load-cell on the opposite side of the actuator. The input electric current applied to the electromagnet is selected as the one of the test parameters and is maintained to a constant value during the dynamic loading test. The damping force and the force-displacement relationship were evaluated.

Figures 3-1, 3-2, 3-3 show the measured force-displacement relationships for the sinusoidal loading and figure 4 shows one for triangular loading. The left hand side of every figure show the test results using MRF-132LD and the right hand side show the test results using trial product #104 made on an experimental basis by Bando Chemical Industries. The dynamic loading tests were performed under input electric currents of 0A, 1A, 3A and 5A. It was verified that the maximum damping force was controllable by adjusting the magnetic field. The MR damper using trial product #104 generated the comparatively larger forces, because the viscosity of the fluid was higher than MRF-132LD.

Figure 5 shows the force-velocity relationships. The increase rate of damping force of the MR damper using trial product #104 is higher than that of the MR damper using MRF-132LD. The MR damper using trial product #104 seems to be suitable for the structure that responses in comparatively lower velocity. The MR damper using MRF-132LD seems to be suitable when the structure is needed to be controlled in wide response velocity range.

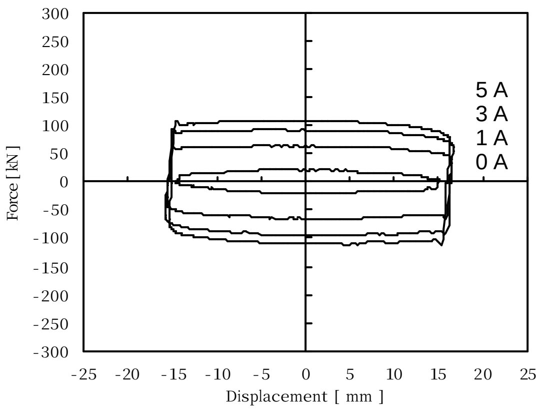


(a) MRF-132LD

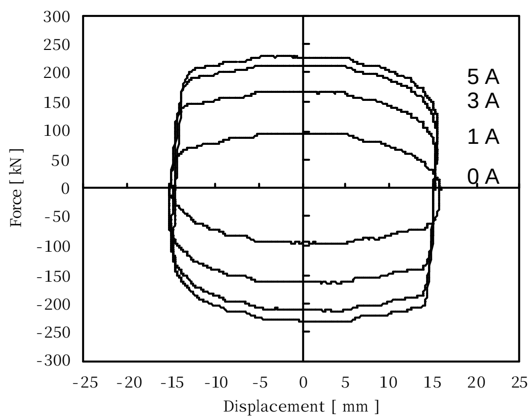


(b) Trial Product #104

Figure 3-1: Force-displacement relationship at maximum velocity 2.5 cm/s (Sinusoidal)

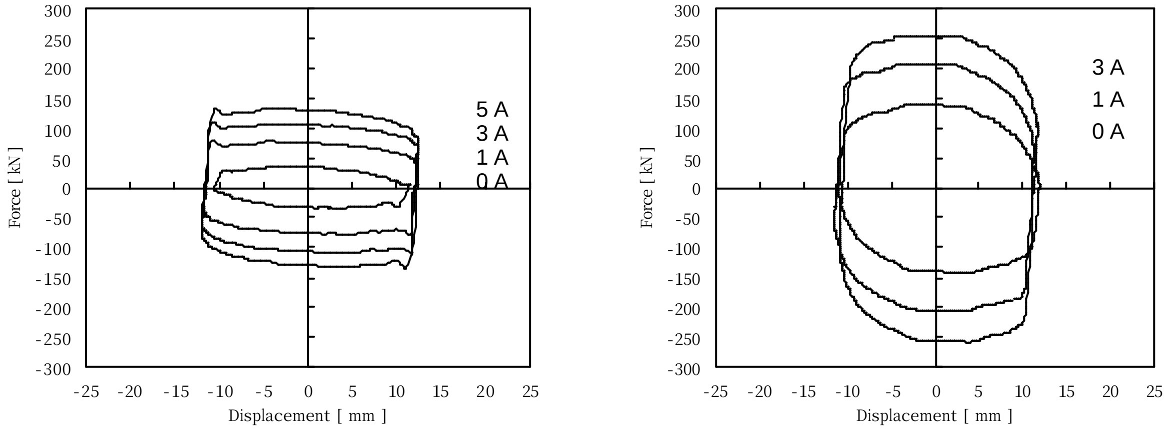


(a) MRF-132LD



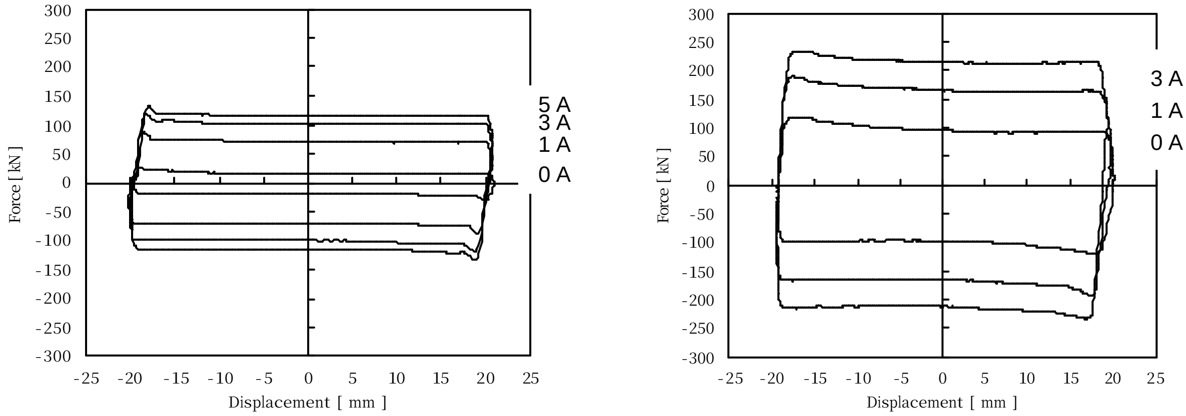
(b) Trial Product #104

Figure 3-2: Force-displacement relationship at maximum velocity 5.0 cm/s (Sinusoidal)



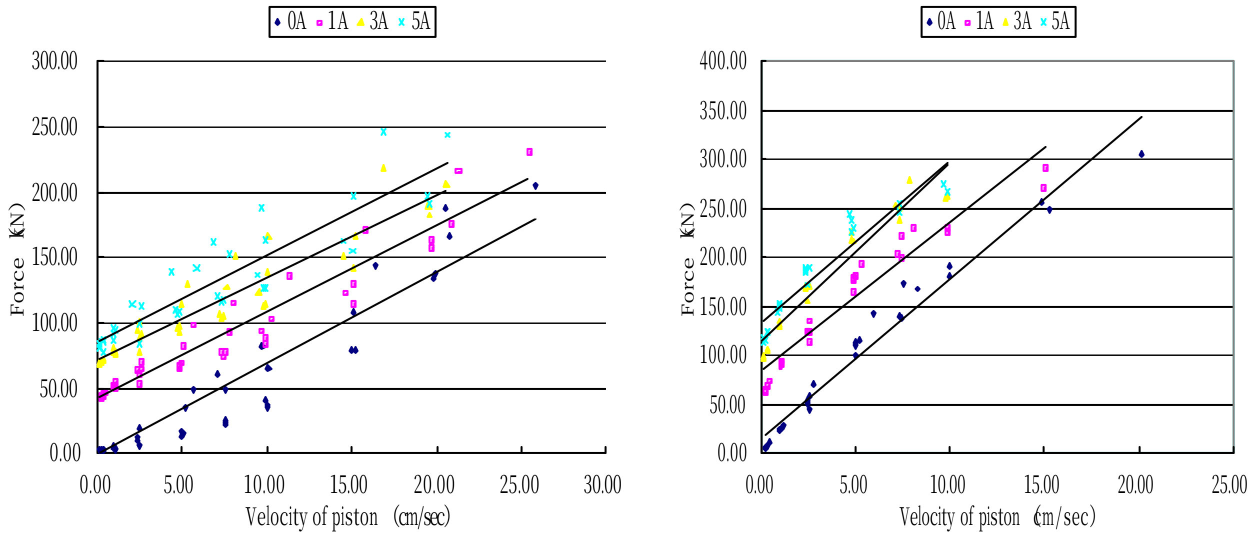
(a) MRF-132LD (b) Trial Product #104

Figure 3-2: Force-displacement relationship at maximum velocity 7.5 cm/s (Sinusoidal)



(a) MRF-132LD (b) Trial Product #104

Figure 4: Force-displacement relationship at maximum velocity 7.5 cm/s (Triangular)



(a) MRF-132LD (b) Trial Product #104

Figure 5: Force-maximum velocity relationship

4. ANALYTICAL MODEL FORMULATION

Until now, a lot of types of analytical models for MR (ER) fluid dampers have been proposed. Some of those consisting of complicated mechanical models can precisely simulate the behavior of MR dampers, especially relationships of both force-displacement and force-velocity, Spencer Jr. et al. (1997) and Snyder et al. (2000). In this paper, in contrast to those complicated models, authors aim at simulating the behavior of the MR dampers with simple analytical models. Two models are considered. One is the Bingham visco-plastic model, in which a couple comprising a dashpot (C_b) and a friction slider (P) are connected in parallel. This Bingham visco-plastic model has been used to simulate the behavior of MR (ER) dampers in some studies, and it is known that it can predict the force-displacement relationship well instead of its simplicity. In this study, an additional mass is considered in the Bingham model in order to consider the effect of the inertia of the MR damper (Figure 6). The other is the involution model, Sunakoda et al. (2000), in which the velocity-force relationship is expressed by:

$$F=C_i\ V^a \qquad (1)$$

where F is the damping force, C_i is a constant independent of the frequency; V is the velocity of the piston and a is an exponent such that $0.0 \leq a$. This expression has often been used to simulate viscous fluid dampers, and is available to simulate the behavior of MR (ER) dampers because the damping force remains within the specified bound under the condition that a is close to zero. Though these two models cannot simulate the relationship between velocities and force exactly, to use these models facilitate both modeling and response analysis.

In this paper, the modeling of the MR damper with MRF-132LD was attempted. The values of identified parameters of both models are shown in Table 2. In the Bingham visco-plastic model, two parameters (C_b and P) were decided by means of the least square method. In the convolution model, on the other hand, two parameters (C_i and α) were decided by means of the non-linear least square method, in which the Gauss-Newton method was used. Figure 7 shows the comparisons between experimental results and analytically simulated ones in harmonic loading (a. 0.1Hz-1cm/s, b. 1Hz-10cm/s, c. 2Hz-20cm/s). Experimental results show quite rigid-plastic behavior under low speed conditions (0.1Hz-1cm/s). By comparing both models' results in the low speed range, it is confirmed that the Bingham model can predicts the rigid-plastic behavior better than the involution model. In addition, under high velocity conditions (2Hz-20cm/s), it is shown that the involution model cannot simulate the experimental results, especially at 0A. The reason for this phenomenon is that α changes rapidly between 0[A] and 1[A]. To evade this phenomenon, it is necessary to set the value of α carefully. Figure 8 shows the comparison between experimental results and simulated ones in applying triangular displacement to the damper. It is found that, in all cases, the resistance force become constant values under the fixed velocity condition. Comparing both models' results, it is confirmed that the involution model can predict the tendency of the resistance in each current more accurately than the Bingham model.

Through these comparisons, it is shown that both models for MR dampers can predict the behavior of the MR damper well. However, it should be noted that choosing appropriate models suitable for the condition is needed in order to simulate the behavior of the damper exactly.

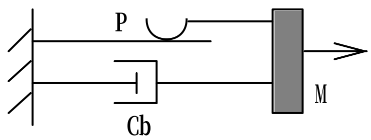
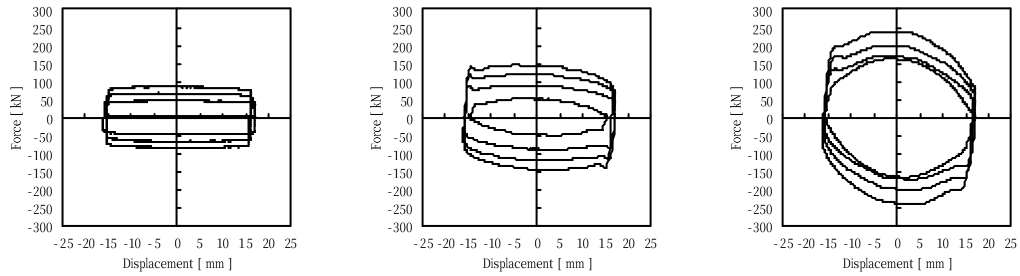


Figure 6: Bingham Visco-Plastic Model with Additional Mass

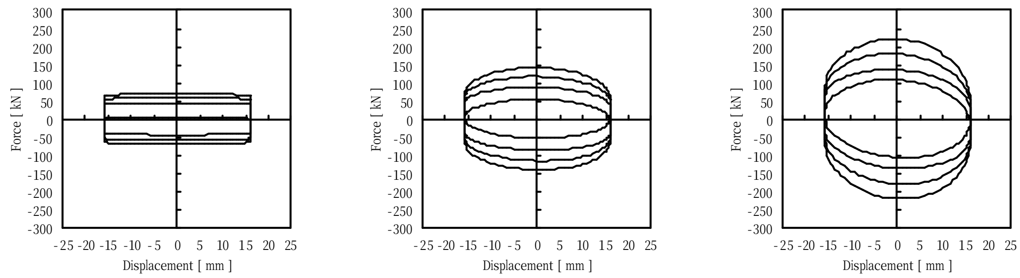
Table 2
Model Parameters

Current [A]	Bingham model			Involution model	
	C_b [KN s/mm]	P[KN]	M[t]	C_I [KN (s/mm)$^{-\alpha}$]	α
0	0.537	0.0	4.44	0.0232	1.65
1	0.487	38.9	4.80	18.9	0.353
3	0.636	53.3	4.48	28.0	0.330
5	0.787	63.0	3.36	32.9	0.334



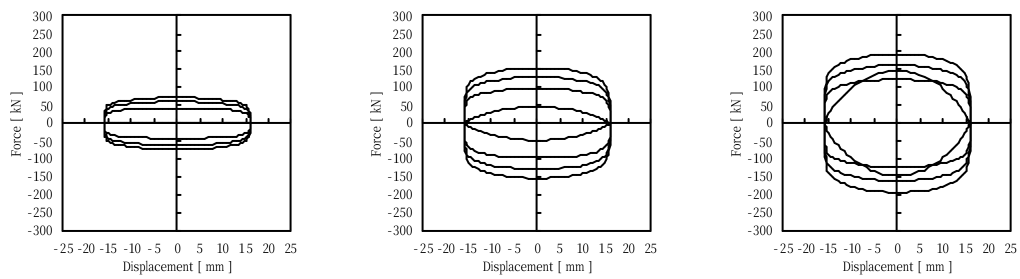
a) 0.1 Hz, 1 cm/s　　b) 1 Hz, 10 cm/s　　c) 2 Hz, 20 cm/s

1) Experimental results



a) 0.1 Hz, 1 cm/s　　b) 1 Hz, 10 cm/s　　c) 2 Hz, 20 cm/s

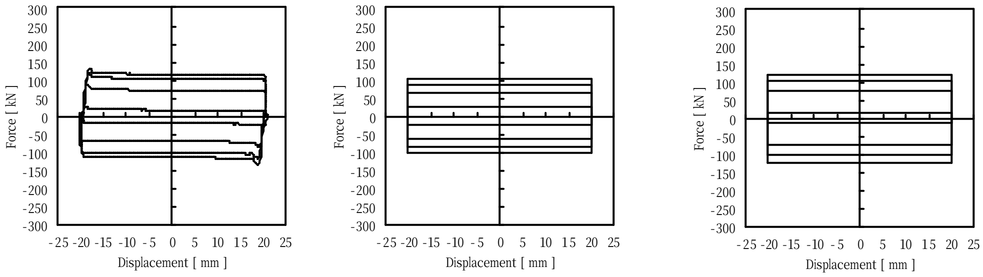
2) Simulated results (Bingham model)



a) 0.1 Hz, 1 cm/s　　b) 1 Hz, 10 cm/s　　c) 2 Hz, 20 cm/s

3) Simulated results (Involution Model)

Figure 7: Comparison between experimental and simulated results (Sinusoidal loading)



(a)Experimental results (b) Simulated results (Bingham model) (c) Simulated results (Involution Model)

Figure 8: Comparison between experimental and simulated results (Triangular loading: 50mm/s 20mm)

5. CONCLUSIONS

Various tests have been carried out using a vibration-testing machine to verify the damping characteristics of developed MR dampers. The following test results were obtained: (1) The MR damper with the bypass flow portion functioned by using the orifice to magnetize the fluid under an appropriate electrical current control. (2) The magnitude of the damping force depends on the input magnetic field. (3) In the absence of an applied magnetic field, an MR damper exhibits viscous-like behavior, while it shows friction-like behavior in a magnetic field. Through analytical simulation, it is identified that both Bingham model and Involution model can predict the behavior of the MR damper well. It is clarified that the MR dampers provide a technology that enables effective semi-active control in real building structures.

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