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DEVELOPMENT OF VARIABLE DAMPER FOR REDUCING SEISMIC RESPONSE OF HIGHWAY BRIDGES

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Presented are experimental studies on the dynamic characteristics of a variable damper developed at the Public Works Research Institute. A prototype model of the variable damper is developed and the dynamic characteristics obtained through the dynamic loading tests is presented. It is found that the damping force of the variable damper developed is controlled as commanded.

Key Words: seismic control, variable damper, prototype model

1. INTRODUCTION

Because integration of functions of a damper-stopper and a energy dissipator is effective for increasing seismic safety of highway bridges, the applicability and practicability of the variable damper, in which the damping characteristics is variable depending on the response of highway bridges, has been studied at the Public Works Research Institute 1)-2).

This paper presents experimental studies on the dynamic characteristics of the variable damper. A prototype model of the variable damper is developed and the load-displacement characteristics and the controllability obtained through the dynamic loading tests are presented.

2. FUNCTIONS OF THE VARIABLE DAMPER

The variable damper is a damper in which the damping force is variable depending on the response of highway bridges as shown in **Fig. 1**. That is:

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1) The damping coefficient of the variable damper is taken large during a small deck vibration so that the damper have the same function as a fixed bearing support against the braking load of vehicles. It is movable against actions with low−velocity such as an elongation of deck by temperature change.
2) When the amplitude of deck vibration becomes larger up to a certain level during an earthquake, the damping coefficient is decreased so that the inertia force of a superstructure to substructures be decreased appropriately.
3) Furthermore, when the vibration amplitude of the deck becomes excessive, the damping coefficient is gradually increased in order to suppress the excessive amplitude. Therefore, the damper has a function as a stopper with a shock absorber function. This is to prevent the impact response by the sudden operation of the stopper.

Therefore, the variable damper has the advantages of an usual viscous damper−stopper 3)−5), a passive energy dissipator and a stopper with a shock absorber function.

The concept of the variable damper, in which the damping characteristics can be variable depending on the situation, has been effectively adopted in a field of mechanical engineering, in particular in a suspension system for an aircraft and an automobile. An active suspension to improve driving comfortability and stability of the automobile is one of the examples 6) 7). However, it is a new idea to apply the variable damper for highway bridges based on the concept of distributing the inertia force of a superstructure to substructures.

Although various types of the variable damper can be made, the simplest one may be as shown in **Fig. 2**. The basic component is an cylinder−type viscous damper. A by−pass pipe is installed between the cylinder−cells divided by the piston. The damping characteristics can be controlled by varying the amount of flow of viscous material which passes through the by−pass. Since various technology for controlling such material flow has been developed, the variable damper is most promising and near to the practical use. Furthermore, the external energy required for the operation is significantly smaller in the variable damper than in active control devices.

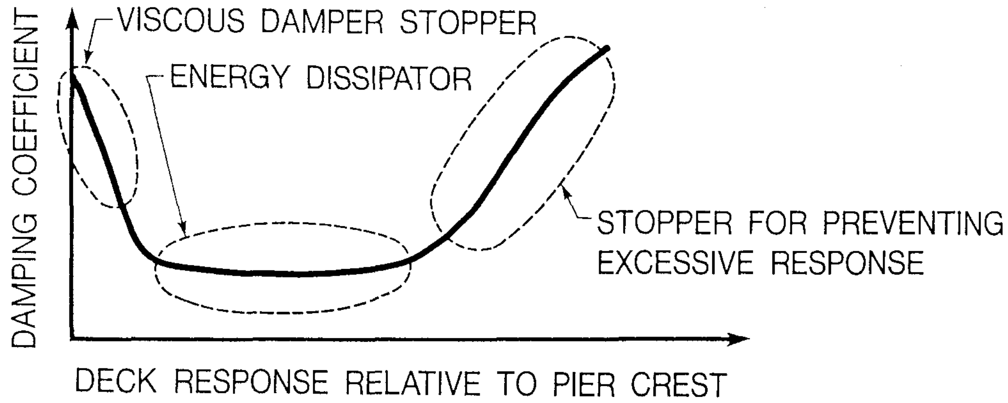


Fig. 1 Basic Concept of Variable Dampers

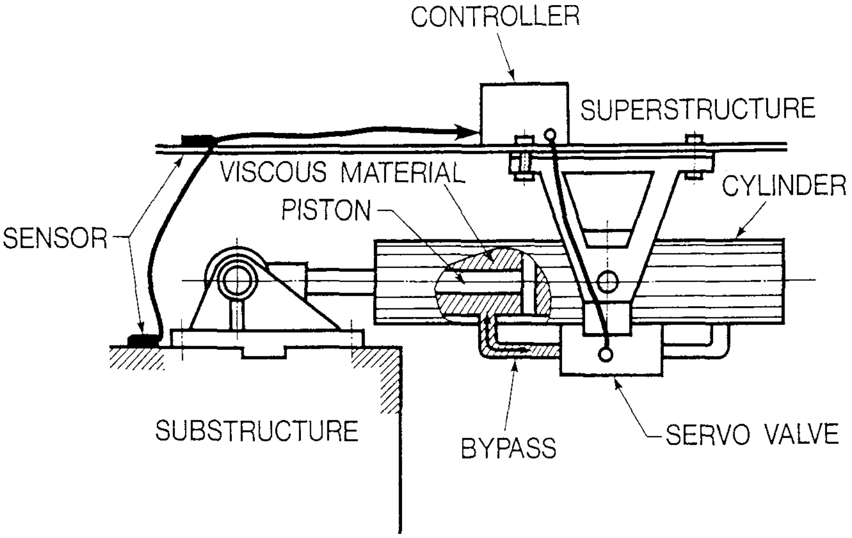


Fig. 2 Variable Damper

3. DEVELOPMENT OF A PROTOTYPE MODEL OF THE VARIABLE DAMPER

3.1 Outline of A Prototype Model of the Variable Damper

Fig. 3 and **Photo 1** show a design plan and a view of the variable damper developed. The model is designed so that the maximum damping force is 20tf, maximum relative displacement of damper piston is within ± 10cm. The control of the damping ratio is arbitrarily made by a personal computer depending on relative displacement and velocity developed between deck and substructures.

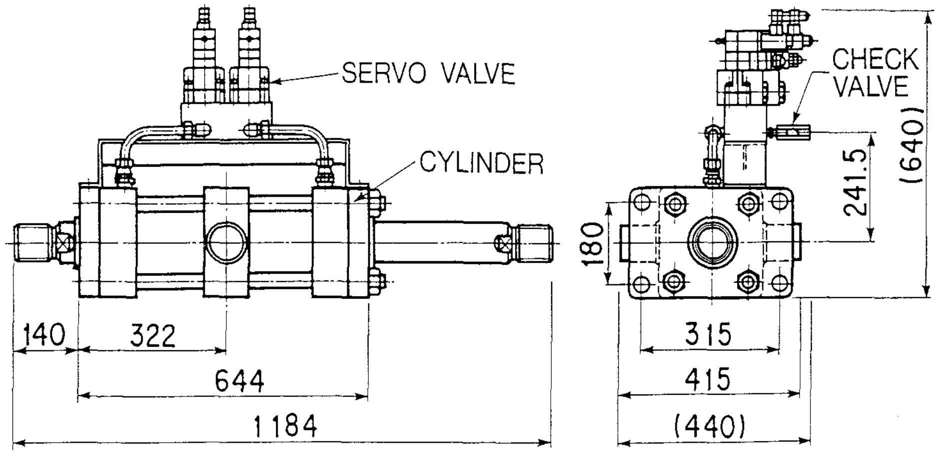


Fig. 3 Prototype Model of Variable Damper

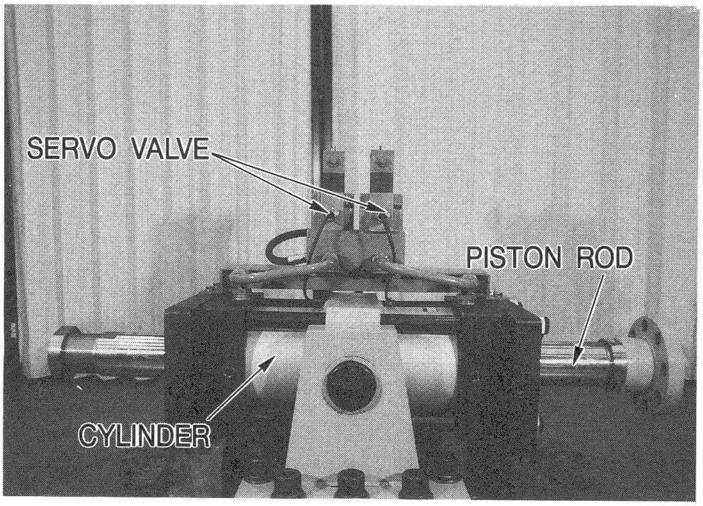


Photo 1 Prototype Model of Variable Damper

The piston−cylinder has the total length of 1,184mm, the pressure area of the piston is 137.4cm^2 and the maximum stroke of the piston is ± 13cm. A steel pipe by−pass with servo valves is installed between the cylinder−cells divided by the piston. The servo valve is a D.C. proportional relief valve. The response time lag of the servo value to the command signal is about 0.05 sec. When the oil pressure through the valve increases to specified one, the pore oil pressure is relieved. This pressure is defined hereafter as control pressure. Therefore, damping force of the piston is developed by the difference of the pressure between two cells in the cylinder. The damping force increases up to when the pressure reaches the specified one, then becomes constant after the pressure exceeds the specified one. Therefore, if the control pressure of the servo valve is assumed to be constant, the damping force is dependent on neither displacement nor velocity of the piston. Therefore, friction type damping force is developed.

The input voltage from a servo amplifier to the servo valve is designed in the range of 0 to 5V. The control pressure is 0 at the input voltage of 0V and increases with increase of the input voltage. The viscous material used for the variable damper is an usual oil for a dynamic loading actuator. The variable damper also has a fail−safe function for an emergency condition such as power failure. The control pressure can be fixed at arbitrary one for such cases.

Fig. 4 shows the flow of the viscous material in the variable damper. The damper piston can move in the left and right directions accompanying with the deck response. When the piston moves in the left side, the viscous material flows from the left cell of the cylinder to the right one through the by−pass and the servo valves. The difference of the pressure in the two cells is adjusted as specified one by servo valves. When the piston moves in the opposite direction, damping force is controlled in the same manner.

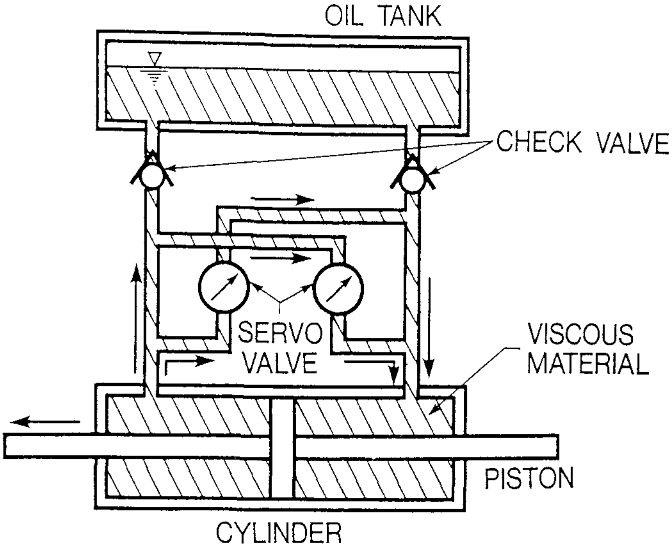


Fig. 4 Flow of Viscous Material

3.2 Dynamic Loading Tests of the Prototype Model of the Variable Damper

The variable damper can vary the damping characteristics depending on the displacement and/or velocity of the structures. Therefore, in order to provide the variable damper with the required damping characteristics it is necessary to know the basic dynamic characteristics. The damping characteristics of the variable damper is controlled by the control pressure of the servo valve and it is controlled only by the input voltage to the servo valve from the servo amplifier. Therefore, in order to arbitrarily control the damping force of the variable damper developed, the relation between the input voltage to the servo valve and damping characteristics of the variable damper is essential.

Fig. 5 shows the set−up of the dynamic loading tests. Under the condition that the control pressure of the servo valve is kept to be constant, the loading was applied to the piston by a dynamic actuator under the displacement control. The input voltage to the servo valve, reaction force and stroke of the piston are measured. The loading is assumed as harmonic and repeated by 10 cycles for each loading amplitude.

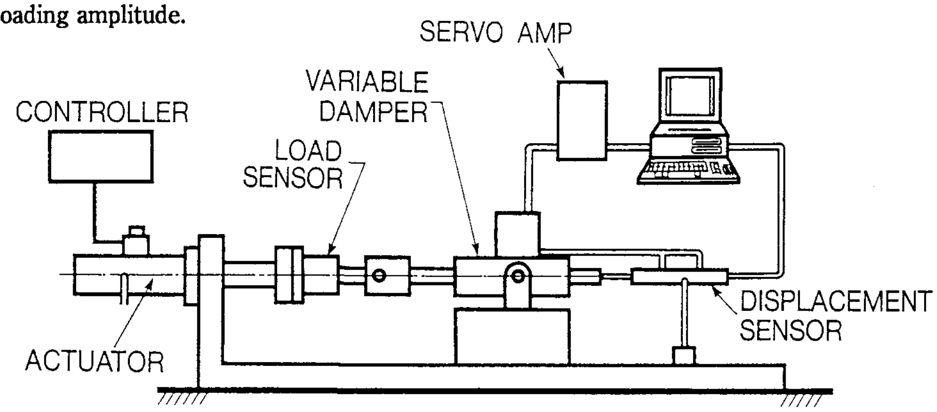


Fig. 5 Set Up of Loading Test

Table 1 shows the experimental cases. Case 1 is to measure the friction force of the damper piston. Static loading was made with loading frequency of 0.05Hz and loading displacement of ± . 100mm. The input voltage of the variable damper is set to be 0V so that the control pressure is 0.Case 2 is to obtain the relation between input voltage to the servo valve and damping force of the variable damper. Loading frequency, loading displacement and input voltage are varied. It should be noted here that the loadings, that exceed 7cm/s in maximum loading velocity were not made because of the capability of a loading apparatus.

Table 1 Experimental Cases

Case	Objective	Loading Frequency (Hz)	Loading Displacement (cm)	Input Voltage (Volt)
1	Measurement of Friction Force of Damper-stopper	0.05	±100	0
2	Relation between Damping Force and Input Voltage	0.1～1.0	±2～±100	0～5

3.3 Performance of the Prototype Model of the Variable Damper

(1) Friction force of the damper–piston

Fig. 6 shows hysteresis loops of the load–displacement relation when the damper is loaded with the loading frequency of 0.05Hz and loading displacement of ± 100mm to obtain the friction force of the damper–piston. The load–displacement relation shows almost rectangular shape. It means that the typical friction type load–displacement relation is obtained. The hysteresis is stable for a number of loading cycles. The average friction force is about 1tf.

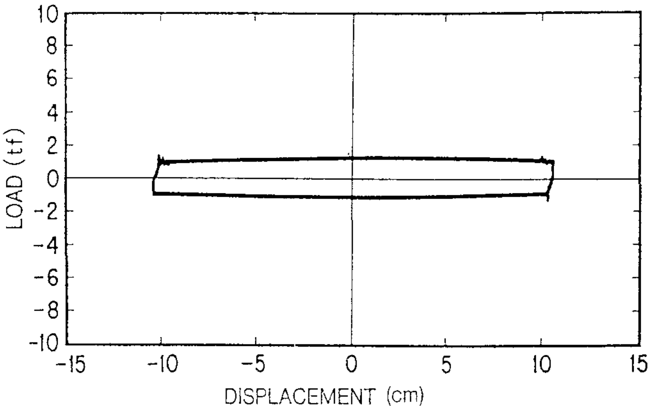
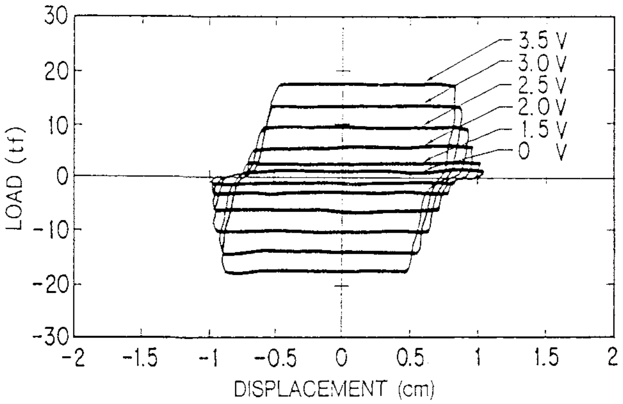


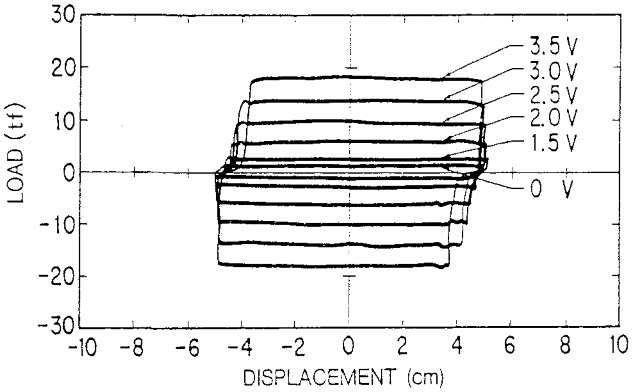
Fig. 6 Hysteresis Loops of Load–Displacement Relation (Displacement = 10cm, Frequency = 0.05Hz)

(2) Hysteresis loops of the load–displacement relation

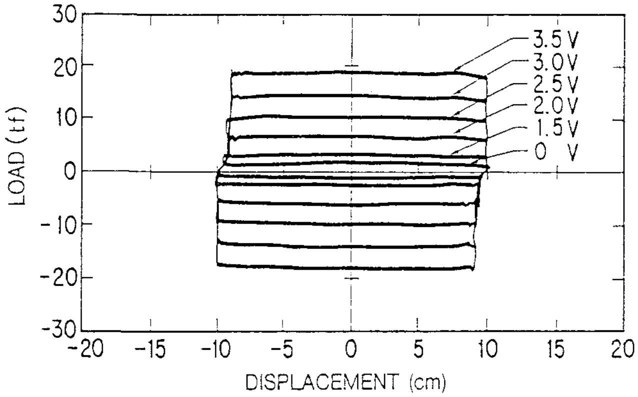
Fig. 7 shows some of hysteresis loops of the load–displacement relation obtained. The hysteresis loops are shown for the loading frequency is 0.1Hz and loading displacement of ± 1cm, ± 5cm and ± 10cm. The variation of hysteresis loops with the input voltage are also shown in **Fig. 7.** The hysteresis loops have the rectangular shape which means that the variable damper has the typical friction type hysteresis loops as designed. Although the damping force instantaneously



(a) Displacement 1cm



(b) Displacement 5cm



(c) Displacement 10cm

Fig. 7 Hysteresis Loops of Load–Displacement Relation (Frequency = 0.1Hz) decreases from specified one to 0 at the instance when the direction of movement of the piston changes at maximum displacement, the time−lag is found at the standing of the damping force. This is because increase of the oil pressure from 0 to specified one takes some time. Turbulence is also found at the instance when the damping force reaches specified one. This may be because the pressure wave motion is developed by sudden standing of the pressure. Therefore, the controllability of the damper may be affected by the loading frequency due to the response time lag of the servo valve. Since the response time lag of the servo valve used is about 0.05 sec. It is required to use the servo valve with the faster response capability for more precise control.

(3) The relation between the input voltage and damping force

Fig. 8 shows the relation between the damping force and the input voltage. The empirical equation obtained by a least square method is also shown in **Fig. 8**. The damping force varies as a power function of the input voltage when the input voltage is lower than 1.8V. When the input voltage is greater than 1.8V the relation becomes almost linear. Therefore, the empirical equation is assumed as

$$F = \begin{cases} 0.42V^{3.7}+1.0 & (0 \leqq V \leqq 1.8) \\ 8.14V-9.95 & (V>1.8) \end{cases} \qquad (1)$$

where, F and V represent damping force (tf) and input voltage (Volt), respectively. In Eq.(1), the constants are determined as averaged values of those obtained in each loading case.

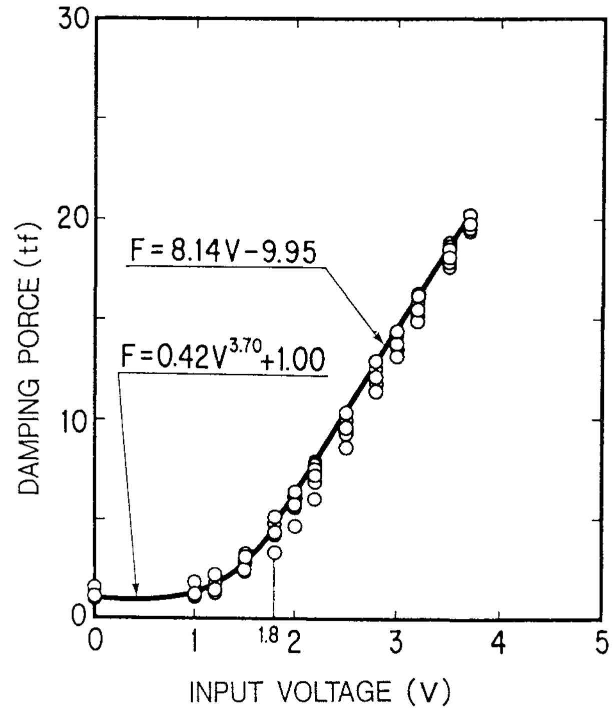
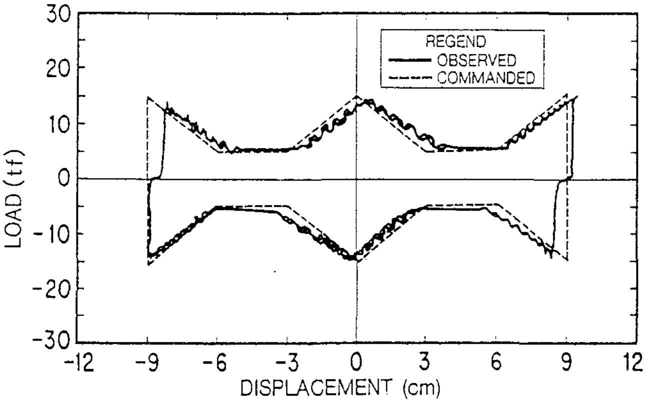


Fig. 8 Damping Force vs. Input Voltage Relation

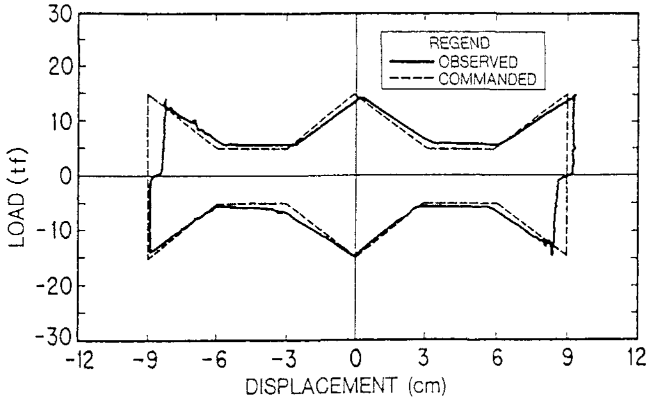
(4) Controllability of the variable damper

Based on the above experimental results, the damping force is controlled by the input voltage using Eq.(1). The controllability of the variable damper so as to control damping force as shown in **Fig. 1** is tested. The control of the variable damper can be is made by control signal from a personal computer according to the displacement and/or velocity obtained by sensors.

Fig. 9 shows hysteresis loops of load–displacement relation to show the controllability of the variable damper. The commanded damping force and the measured one are shown in **Fig. 9. Fig. 9(a)** and **(b)** show the cases when the sampling time of displacement is assumed as 0.1sec and 0.01sec, respectively. The loading frequency is 0.1 Hz. The damping force is found to be controlled almost as commanded. When the sampling time is 0.1 sec, corrugation is found when the damping force is varied with the displacement. Therefore, it is required to use the appropriate sampling time in order to precisely control in consideration with the loading velocity.



(a) Sampling Time 0.1sec



(b) Sampling Time 0.01sec

Fig. 9 Controllability of the Variable Damper Developed

4. CONCLUDING REMARKS

The applicability and controllability of the variable damper developed for reducing seismic response of highway bridges are experimentally studied. The prototype model of the variable damper was developed and the performance was studied through the dynamic loading tests. According to the above investigations the following conclusions may be deduced. Based on the dynamic loading tests of the prototype model developed, the load–displacement relation is obtained as designed. The damping force of the variable damper is controlled by the input voltage. The relation between the damping force and input voltage is given by the empirical equation. Furthermore, it is found that the damping force of the variable damper developed can be controlled almost as commanded. To implement the variable damper for actual highway bridges, further investigations on the controllability with faster loading frequency as well as the durability for long term use are required.

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