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SEISMIC RESPONSES OF THE ISOLATION DEVICE SYSTEM WITH AN ELASTOPLASTIC–FRICTION DAMPER USING V–SHAPED PLATES

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ABSTRACT

In this paper, a new type of damper using an elastoplastic damper and a friction damper in combination is studied. It is composed of an elastoplastic damper using V-shaped plates and a friction damper consisting of V-shaped springs, brake shoes and a brake plate. The trial damper was made, and the resisting force characteristics and the fatigue strength of the damper were measured. A machine-isolation device system with the elastoplastic-friction damper was also made, and its seismic responses were measured making use of an electrohydraulic-type shaking table. Moreover, the reduction in the seismic responses were studied through numerical analyses by changing the input seismic wave and its intensity.

KEYWORDS

Seismic response; elastoplastic damper; friction damper; isolation device; machine-isolation device system; resisting force characteristics; fatigue strength; shaking table test.

INTRODUCTION

Many studies and practical uses of isolation device systems consisting of dampers and springs have been carried out recently (Shibata *et al.*, 1991; Namita *et al.*, 1991; Ohmata *et al.*, 1994; Ohmata *et al.*, 1995). The seismic response control technology using an isolation device enable one to reduce the accelaration and displacement responses of a machine supported with the isolation device installed on the floor of a building. The elastoplastic damper is useful for controlling a response displacement to severe seismic input. And the friction damper is suitable for controlling a small response displacement. In this paper, a new type of damper using an elastoplastic damper and a friction damper in combination is studied. The purpose of this study is to obtain the damper for an isolation device system which is useful for a small displacement as well as a large displacement. The trial damper was made, and the resisting force characteristics and the fatigue strength of the damper were measured. An experimental model of a machine-isolation device system using the elastoplastic-friction damper was also made, and the seismic responses of the system were measured making use of an electrohydraulic-type shaking table. Moreover, the reduction in the seismic responses were studied through numerical analyses by changing the input seismic wave and its intensity.

CONSTRUCTION OF THE ELASTOPLASTIC-FRICTION DAMPER

The conceptional sketches of two kinds of elastoplastic dampers using V-shaped plates are shown in Fig. 1. Fig. 1 (a) is the elastoplastic damper that the authors proposed in the previous paper (Ohmata *et al.*, 1991), and Fig. 1 (b) is the elastoplastic-friction damper that it is proposed in this paper. The idealized load-displacement curves of the dampers are also shown in Fig. 1. The collapse load F_p and the stiffness k in the elastic region of the elastoplastic damper are given by

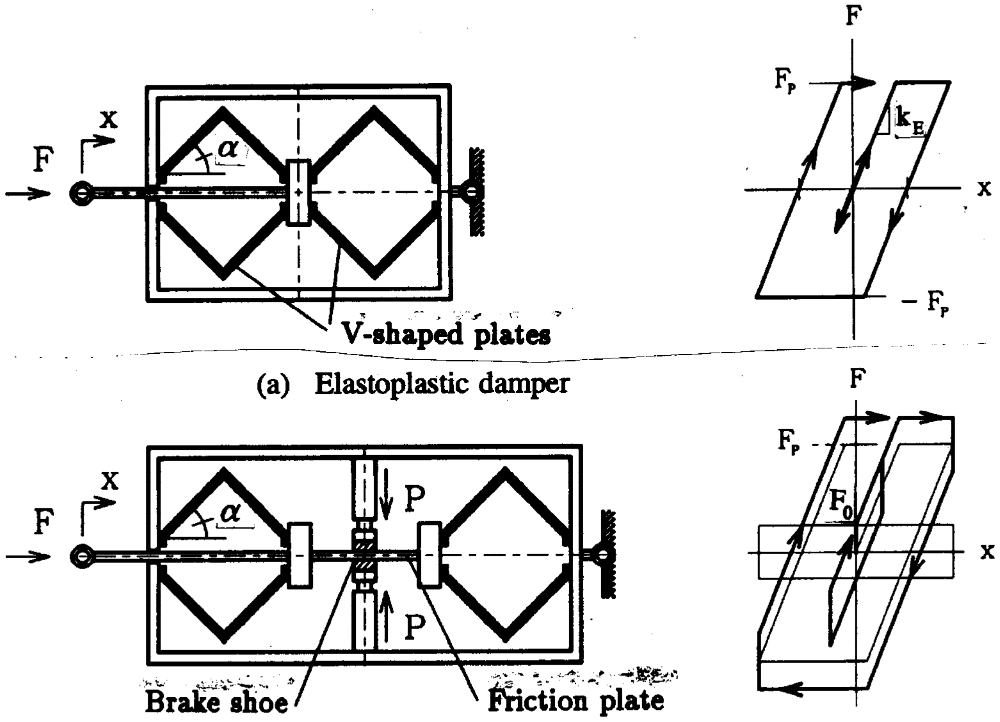
$$F_p = \frac{4\,n\,M_p}{L \sin \alpha} \tag{1}$$

$$k = \frac{12\,n\,EI}{L^3 \sin^2 \alpha} \tag{2}$$

where n is the number of the V-shaped plates, and L, α and EI are the length of a side, the inclination angle and the flexural rigidity of a V-shaped plate, respectively. M_p denotes the fully plastic moment of a V-shaped plate and is given by

$$M_p = \frac{B\,H^2 \sigma_y}{4} \tag{3}$$

where B, H and σ_y are the width, the thickness and the yield stress of a V-shaped plate, respectively. It will be seen from the load-displacement curves in Fig. 1 that the elastoplastic-friction damper gives damp-



(a) Elastoplastic damper

(b) Elastoplastic-friction damper

Fig. 1. Conceptional sketch of elastoplastic dampers using V-shaped plates

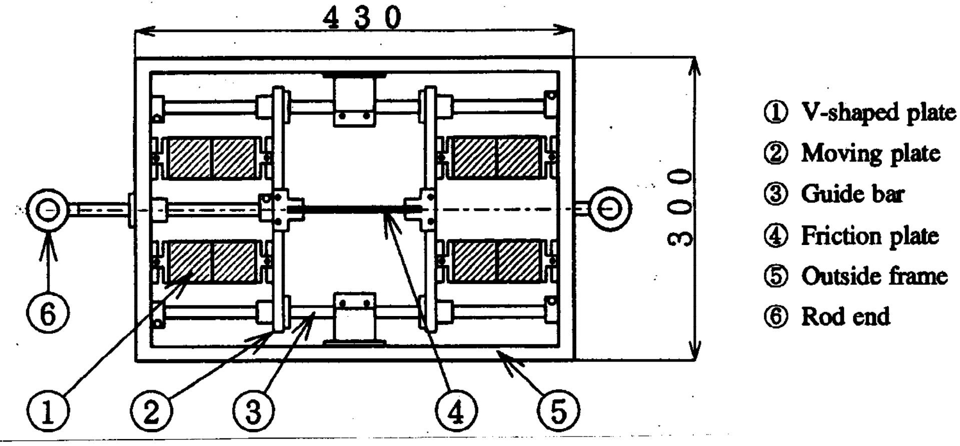


Fig. 2. Elastoplastic-friction damper

Table 1. Physical condition of a V-shaped plate

Material		C1100
Young's modulus		103.0 GPa
Yield stress		235.4 MPa
Length	H	0.5 mm
	B	40 mm
	L	60 mm
	α	45 °

ing in a small displacement and the the friction force performs as a fail-safe mechanism. The trial damper was made using four pairs of V-shaped copper plates. Fig. 2 shows the construction of the trial damper and table 1 shows the numerical conditions of V-shaped plates. The friction plate and the brake shoes were made using hard steel plates (S45C).

RESISTING FORCE CHARACTERISTICS AND FATIGUE STRENGTH OF THE DAMPER

Resisting Force Charasteristics

The elastoplastic-friction damper is attached between a shaking table and a rigid wall through a load cell, and the hysteretic resisting force characteristics are measured. The experimental apparatus is shown in Fig. 3. The Lissajous' figures of the damper when it was subject to sinusoidal displacement of frequency 1 Hz are shown in Fig. 4 (a) and (b), for the case of amplitude 10 mm and 20 mm respectively. Fig. 4 (a) is the Lissajous' figure in the case of elastic range and (b) is that in the case of plastic range. It can be seen from Fig. 4 that Coulomb damping on the friction plate is nearly constant regardless of the displacement, and the damper is practically useful for controlling a small displacement as well as a large displacement. Therefore, in the seismic response simulations for the machine-isolation device system, it was assumed that the damper has the resisting force characteristics as shown in Fig. 1 (b).

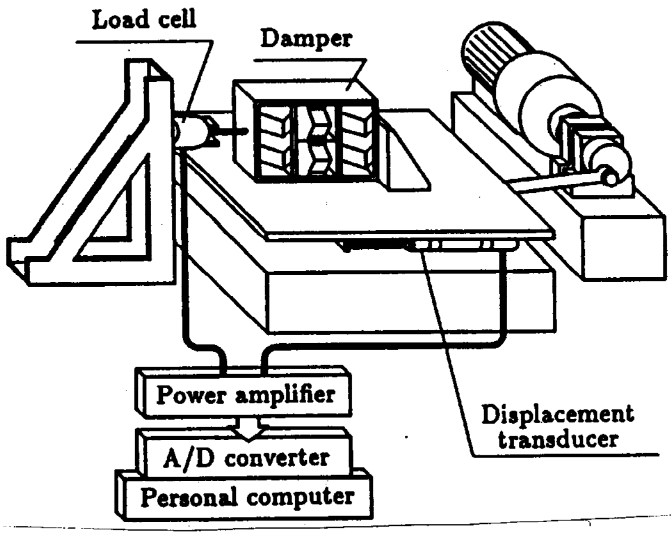
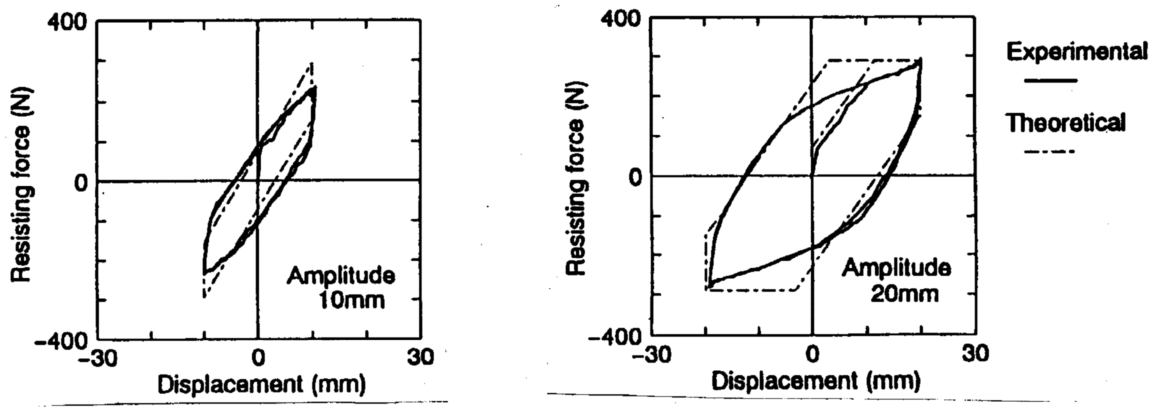


Fig. 3. Experimental apparatus



(a) In the case of elastic range (b) In the case of plastic range

Fig. 4. Lissajous' figure of the elastoplastic-friction damper

Fatigue Strength of the Damper

The fatigue strength of the elastoplastic-friction damper obviously depends on the lift of V-shaped plates. The relation between the number of cycles and the maximum resisting force of the damper until a V-shaped plate broke off were measured using the experimental apparatus shown in Fig. 3. It is subject to sinusoidal displacement of frequency 1 Hz, 5 mm, 10 mm, 15 mm and 20 mm in the amplitude. The experimental results are shown Fig. 5. It can be seen from Fig. 5 that a V-shaped plate brakes at the number of cycles more than 1000.

SEISMIC RESPONSES OF A MACHINE-ISOLATION DEVICE SYSTEM

Equations of Motion

Let us consider a case in which the damper is attached to a machine-isolation device system as shown in Fig. 6. The damper device is subjected to a seismic excitation $\ddot{z}$. The equations of motion are given by

one of the following two cases according to the behavior of friction damper.
1) phase I (While stagnating)

$$u = \text{constant}, \quad \dot{u} = 0, \quad \ddot{u} = 0 \tag{4}$$

2) phase II (while sliding)

$$m\ddot{u} + ku + F_E + F_0 \cdot \text{sign}(\dot{u}) = -m\ddot{z} \tag{5}$$

where u is the relative displacement of the main mass, m the quantity of the main mass, k the stiffness of the coil spring, F_E the resisting force of the elastoplastic damper and F_0 the friction force due to the friction plate. Designating the absolute displacement of the main mass by x = u + z, the changing condition from phase I to phase II is given by

$$|\, m\ddot{z} + ku + F_E \,| > F_0 \tag{6}$$

And the changing condition from phase II to phase I is given by

$$u = 0, \quad |\, m\ddot{x} + ku + F_E \,| \leqq F_0 \tag{7}$$

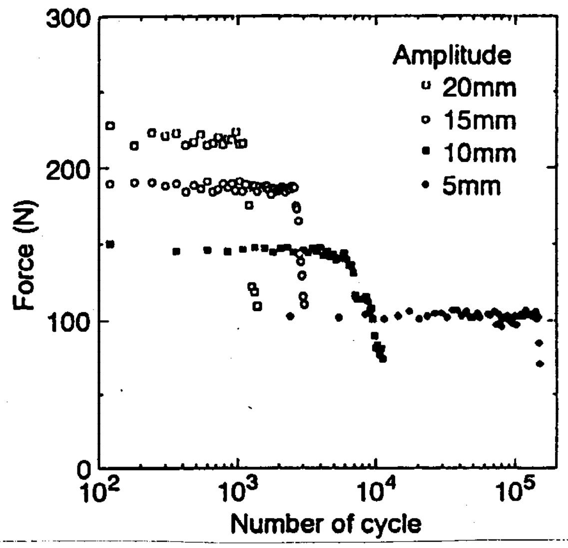


Fig. 5. Relation between number of cycle and maximum resisting force of V-shaped plate

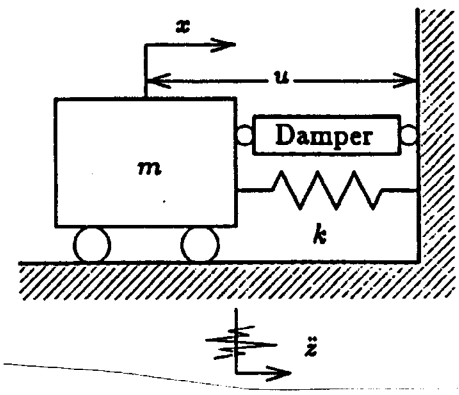


Fig. 6. Analytical model

Table 2. Numerical condition of the analytical model

Mass	m	300 kg
Spring	k	2,020 N/m
Damper	Fp	220 N
	k_E	19,200 N/m
	P	20 N
	μ	0.2

Table 3. Maxima of response

(a) $|\ddot{z}| = 0.3$ m/sec ^{2}

Input acceleration	El Centro(1940)NS $\lvert\ddot{z}\rvert_m$ 0.30 m/s^2	Akita(1983)NS $\lvert\ddot{z}\rvert_m$ 0.30 m/s^2
Without damper	$\lvert\ddot{x}\rvert_m$ 0.20 m/s^2 $\lvert u\rvert_m$ 29.93 mm	$\lvert\ddot{x}\rvert_m$ 1.10 m/s^2 $\lvert u\rvert_m$ 163.6 mm
With elasto-plastic damper	$\lvert\ddot{x}\rvert_m$ 0.18 m/s^2 $\lvert u\rvert_m$ 1.51 mm	$\lvert\ddot{x}\rvert_m$ 0.21 m/s^2 $\lvert u\rvert_m$ 2.17 mm
With friction damper	$\lvert\ddot{x}\rvert_m$ 0.20 m/s^2 $\lvert u\rvert_m$ 0.91 mm	$\lvert\ddot{x}\rvert_m$ 0.26 m/s^2 $\lvert u\rvert_m$ 1.19 mm
With composite damper	$\lvert\ddot{x}\rvert_m$ 0.20 m/s^2 $\lvert u\rvert_m$ 0.75 mm	$\lvert\ddot{x}\rvert_m$ 0.21 m/s^2 $\lvert u\rvert_m$ 0.79 mm

(b) $|\ddot{z}| = 1.0$ m/sec ^{2}

Input acceleration	El Centro(1940)NS $\lvert\ddot{z}\rvert_m$ 1.00 m/s^2	Akita(1983)NS $\lvert\ddot{z}\rvert_m$ 1.00 m/s^2
Without damper	$\lvert\ddot{x}\rvert_m$ 0.66 m/s^2 $\lvert u\rvert_m$ 99.77 mm	$\lvert\ddot{x}\rvert_m$ 3.68 m/s^2 $\lvert u\rvert_m$ 545.30 mm
With elasto-plastic damper	$\lvert\ddot{x}\rvert_m$ 0.77 m/s^2 $\lvert u\rvert_m$ 19.98 mm	$\lvert\ddot{x}\rvert_m$ 0.81 m/s^2 $\lvert u\rvert_m$ 25.20 mm
With friction damper	$\lvert\ddot{x}\rvert_m$ 1.00 m/s^2 $\lvert u\rvert_m$ 8.33 mm	$\lvert\ddot{x}\rvert_m$ 0.80 m/s^2 $\lvert u\rvert_m$ 39.79 mm
With composite damper	$\lvert\ddot{x}\rvert_m$ 0.81 m/s^2 $\lvert u\rvert_m$ 15.65 mm	$\lvert\ddot{x}\rvert_m$ 0.81 m/s^2 $\lvert u\rvert_m$ 16.46 mm

Numerical Examples

Equations (4), (5), (6), and (7) are programmed using a continuous system simulation language (FUJITSU SLCS 5), and El Centro (1940) N-S and AKITA (1983) N-S normalized to be 0.3 and 1.0 m/sec ^{2} at the maximum acceleration are used as an input seismic wave. The numerical conditions of the analytical model are given in Table 2. The maximum responses of the acceleration and the relative displacement of the main mass are listed in Table 3. It is apparent from Table 3 (a) and (b) that the elastoplastic-friction damper is effective for suppressing both the absolute acceleration and the relative displacement of the machine, and the maximum acceleration decreases 20 - 40 % to that of the calculation without damper. And it is confirmed that the damper is useful for both usual medium seismics and rare severe seismics.

Shaking Table Tests of a Machine–Isolation Device System

An experimental model of a machine-isolation device system using the elastoplastic-friction damper is made, and seismic responses of the system are measured making use of an electrohydraulic-type shaking

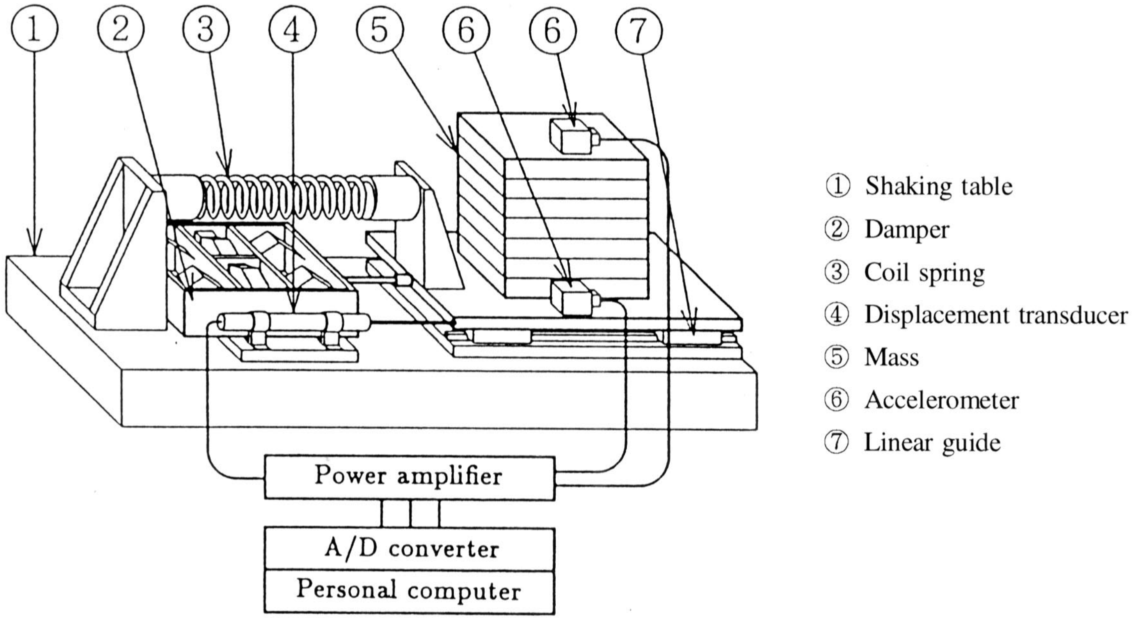


Fig. 7. Experimental apparatus

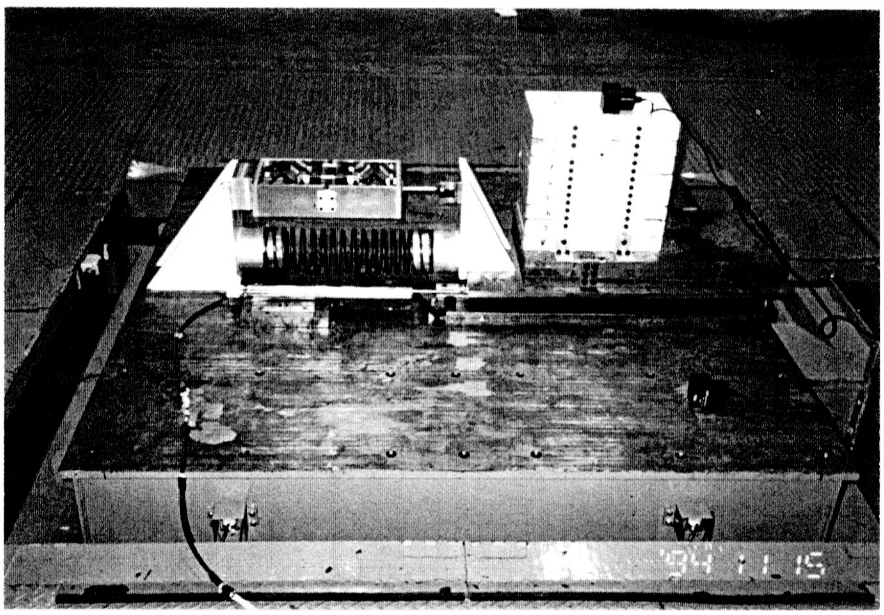


Photo. 1. Experimental apparatus

table. The experimental apparatus is shown in Fig. 7 and Photo. 1. The experimental conditions are equal to the numerical conditions of the analytical model given in Table 2. Fig. 8 shows the response acceleration and displacement waves of the machine when it was subject to El Centro (1940) N-S wave normarized to be 1.0 m/sec ^{2} at the maximum acceleration. The results of the shaking table tests show that the maximum response accelaration of the machine decreases by 35% compared with that of the tests without isolation device. The calculated results agree fairly well with the experimental results, and the validity of the calculations was substantiated.

CONCLUSIONS

A new type of an elastoplastic-friction damper using V-shaped plates was made successfully. The experi

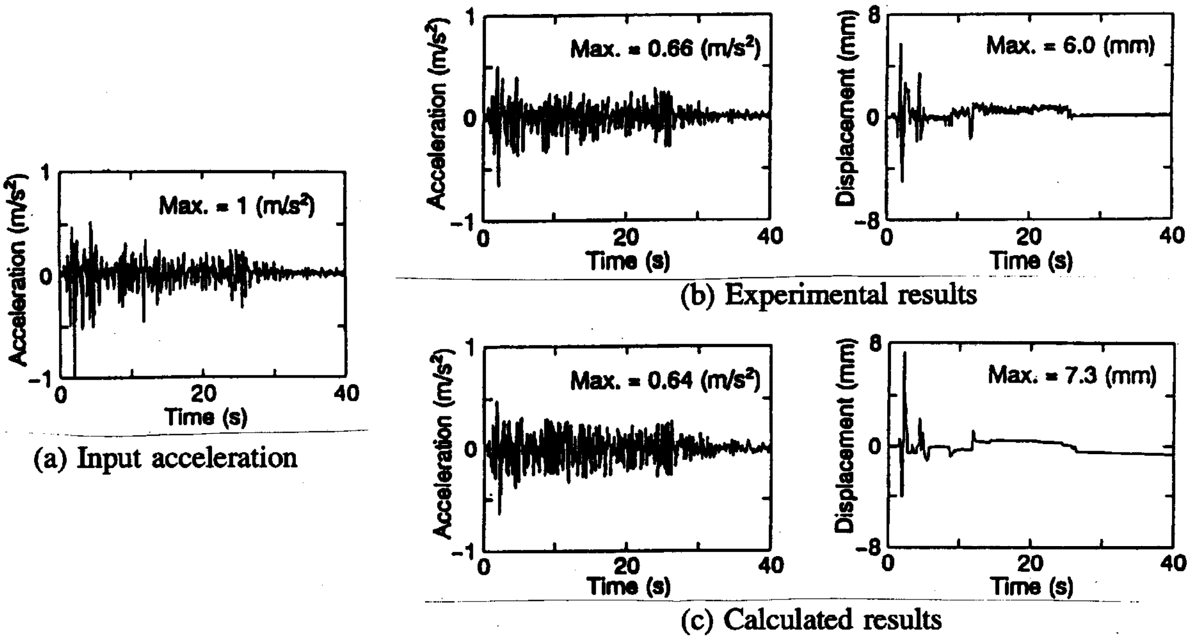


Fig. 8. Response waves (El Centro 1940 N-S)

mental results show that the damper gives damping in a small displacement as well as a large displacement and V-shaped plates withstand repeating loads more than 1000 cycles at the amplitude 20 mm. The seismic responses of a machine-isolation device system using the elastoplastic-friction damper are calculated and measured making use of an electrohydraulic-type shaking table. From the experimental and caluculated results, it was confirmed that the isolation device system using the elastoplastic-friction damper is effective in reducing the seismic responses of a machine-isolation device system.

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