EXPERIMENTS AND ANALYSIS OF ROLLER TYPE ISOLATION DEVICE FOR HOUSES

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ABSTRACT: This paper describes a roller type isolation device for detached houses. The isolation device consists of rails having a circular-linear-combined shape in the vertical cross-section to produce a restoring force, wheels, and fiction dampers comprising wheels and axles. Because the effective natural period of this device is independent of the mass, a long effective natural period can be achieved even for light structures such as houses. Shake table tests were carried out showing good isolation performance of the device and confirming validity of the analytical model developed in this study.

Key Words: Vibration Control, Seismic Isolation, Rolling Bearing, Friction Damper Shaking Table Test, Analytical Model, Detached House

INTRODUCTION

Japan is the country where seismic isolation device is most widely used for civil engineering structures and equipment especially since the Hanshin-Awaji earthquake of 17 January 1995, in which many houses in this area were damaged. Mainly three kinds of seismic isolation device are available: rubber bearing type, sliding bearing type and roller type. Most of earthquake isolated buildings have used rubber bearing type which has been a well known device. However, light weight structures such as detached houses have not been isolated with rubber bearings due to difficulty in achieving long natural periods. This is because rubber bearings must be made narrow to achieve required long natural period but which will cause difficulty in supporting the house weight. To solve this problem, we developed roller type isolation device. This paper describes construction of roller type isolation device and reports on the results of shake table tests.

CONSTRUCTION AND CHARACTERISTICS OF ROLLER TYPE ISOLATION DEVECE

Roller type isolation device consists of rail having circular-linear combined 1st and 2nd stiffness, wheel and axles and plane bearing with PTFE coating. X-Y rail motion mechanism enable to absorb impact of horizontal X-Y direction when acceleration applied by earthquake by pendulum motion with friction between axles and bearing. After earthquake wheel will return to center of rail by restoring force. Fig.1 shows circular-linear combined shape of rail. Fig.2 shows Restoring force characteristics of roller type isolation device. Here T shows natural period of the system, r_1 is radius of circular rail, k_1 is spring constant (1st stiffness), P_v is vertical load, Q_d is breaking load, d is diameter of axle, D is diameter of wheel, . is friction coefficient of bearing and . is inclination of

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linear rail. Fig.3 shows schematic drawing of roller type isolation device. 1 shows top plate,2 shows wheelframe,3 as base plate,4 as wheel,5 as bearing,6 as axles and 7 shows rail. Natural period of system, 1st and 2nd stiffness, break load and friction coefficient can be determined by (1)~(5) formula.

$$T = 2\pi\sqrt{r_1 / g} \tag{1}$$

$$k_1 = P_v / r_1 \tag{2}$$

$$Q_d = P_v \cdot \mu \tag{3}$$

$$\mu = (d / D) \cdot \mu_0 \tag{4}$$

$$\ddot{x}_{cl} = x_{c.} \cdot \omega_0^2 \tag{5}$$

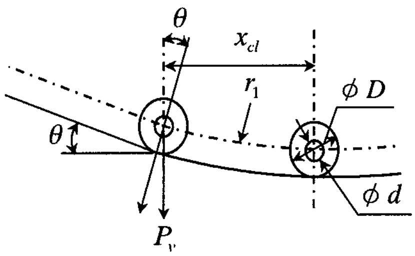

Figure.1 Circular-linear combined shape of rail

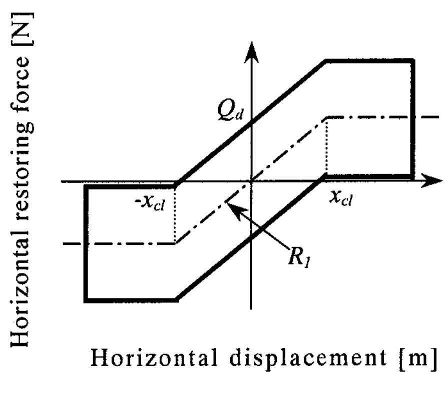

Figure.2 Restoring force characteristics of roller type isolation device

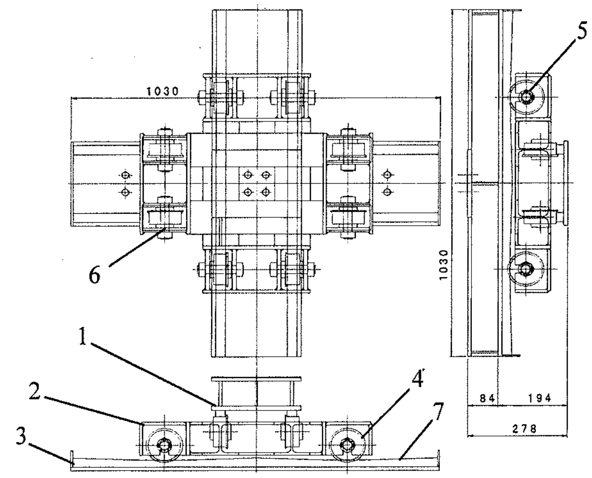

Figure.3 Schematic drawing of roller type isolation device

SHAKING TABLE TEST

Test model house

Shaking test has been conducted using model house (Figure 5) with roller type devices (Figure 6). Test model house is two stories house with 2×4 wooden constructions. Plane size is 2.73m×2.73m and each story has 2.7 m height. Following characteristic figures at table 1 has been estimated based on construction drawings. Shaking table test has been conducted on roller type isolation device supporting test model of house.

Table 1. Test model house parameters

Floor	Mass [kg]		Stiffness coefficient [kN/m]		Damping coefficient		The first mode natural frequency
First	m_0	1366	k_1	11	c_1	0.04	4.1 Hz
Second	m_1	770					
Roof	m_2	579	k_2	11	c_2	0.04	

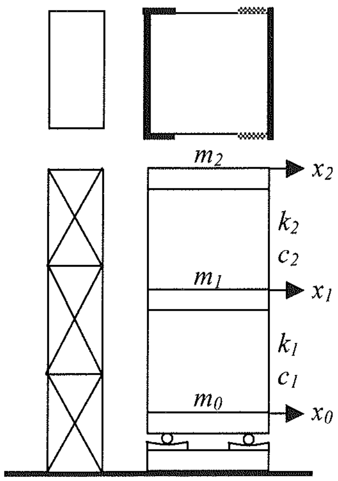

Figure.4 Analysis model

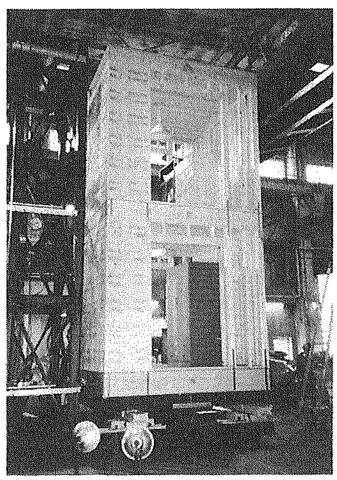

Figure.5 Test model house

Roller type isolation device

The device is designed to have approximately 4 sets natural period at circular and inclined rail part which though vary to it's amplitude. Friction coefficient μ caused by friction between roller and axle is designed as 3 % which almost independent to the load. Allowable amplitude in any direction is designed as ±250 mm.4 sets of this device are inserted to support 2715 kg model house. Below house, steel frame with H-shape beam is combined. (Shown in Figure 6)

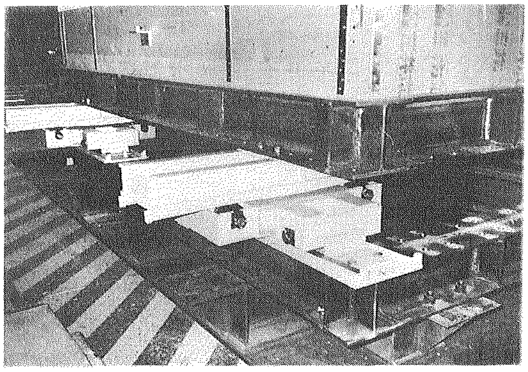

Figure.6 Roller type isolation device

Statistic load test

Statistic load test with appropriate weight has been conducted to determine friction coefficient and performance of the system. Friction coefficient has been calculated from measured horizontal load, deflection and vertical load. Here coefficient is calculated using bellow formula(6). Inclination of strait part of rail is calculated using bellow formula(7). As a result of statistic load test, coefficient of friction is about 0.027. A period of circular is about 2.7sec. Inclination of strait part of rail is 0.03 radian. Fig.7 shows performance of hysterics loop. It was confirmed that a value of an experiment accorded with a value of a design.

$$\mu = (F1_{ave} - F2_{ave})/2 \tag{6}$$

$$\theta = (F1_{ave} + F2_{ave})/2 \tag{7}$$

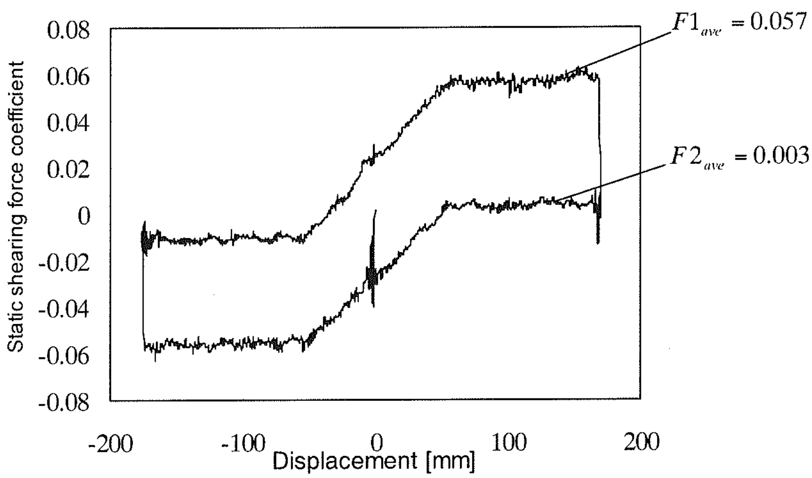

Figure.7 Shearing force coefficient vs. Displacement

Analysis model

Figure4 demonstrates that the roller type isolation system is modeled as a three-dgree-of-freedom system. Equations of motion of the model are expressed in three phases, as shown below, considering transition of static/dynamic friction due to the presence or absence of sliding at the rolling friction damper.

Phase1 (no rolling friction)

$$\begin{cases} x_0 = const & (8) \\ \dot{x}_0 = 0 & (9) \\ \ddot{x}_0 = 0 & (10) \\ m_1\ddot{x}_1 + c_1\dot{x}_1 + c_2(\dot{x}_1 - \dot{x}_2) + k_1x_1 + k_2(x_1 - x_2) = -m_1\ddot{z} & (11) \\ m_2\ddot{x}_2 + c_2(\dot{x}_2 - \dot{x}_1) + k_2(x_2 - x_1) = -m_2\ddot{z} & (12) \end{cases}$$

Phase2 (rolling at 1st stiffness)

$$\begin{cases} m_0\ddot{x}_0 + c_0\dot{x}_0 + c_1(\dot{x}_0 - \dot{x}_1) + k_0x_0 + k_1(x_0 - x_1) + \mu\cdot(m_0 + m_1 + m_2)\cdot g\cdot \mathrm{sgn}(\dot{x}_0) = -m_0\ddot{z} & (13) \\ m_1\ddot{x}_1 + c_1(\dot{x}_1 - \dot{x}_0) + c_2(\dot{x}_1 - \dot{x}_2) + k_1(x_1 - x_0) + k_2(x_1 - x_2) = -m_1\ddot{z} & (14) \\ m_2\ddot{x}_2 + c_2(\dot{x}_2 - \dot{x}_1) + k_2(x_2 - x_1) = -m_2\ddot{z} & (15) \end{cases}$$

Phase3 (rolling at 2nd stiffness)

$$\begin{cases} m_0\ddot{x}_0 + c_0\dot{x}_0 + c_1(\dot{x}_0 - \dot{x}_1) + k_1(x_0 - x_1) + \{x_{cl}k_0 + k_s(|x_0| - x_{cl})\}\mathrm{sgn}(x_0) & \\ \qquad + \mu\cdot(m_0 + m_1 + m_2)\cdot g\cdot \mathrm{sgn}(\dot{x}_0) = -m_0\ddot{z} & (16) \\ m_1\ddot{x}_1 + c_1(\dot{x}_1 - \dot{x}_0) + c_2(\dot{x}_1 - \dot{x}_2) + k_1(x_1 - x_0) + k_2(x_1 - x_2) = -m_1\ddot{z} & (17) \\ m_2\ddot{x}_2 + c_2(\dot{x}_2 - \dot{x}_1) + k_2(x_2 - x_1) = -m_2\ddot{z} & (18) \end{cases}$$

The transition criteria Phase1, Phase2 and Phase3 are:

From Phase1 to Phase2

$$\begin{cases} |k_0x_0 + m_0\ddot{z}| > \mu\cdot(m_0 + m_1 + m_2)\cdot g \\ |x_0| < x_{cl} \end{cases} \qquad (19)$$

From Phase1 to Phase3

$$\begin{cases} |x_{cl}k_0 + k_s(|x_0| - x_{cl}) + m_0\ddot{z}| > \mu\cdot(m_0 + m_1 + m_2)\cdot g \\ |x_0| > x_{cl} \end{cases} \qquad (20)$$

From Phase2 to Phase1

$$\begin{cases} |m_0\ddot{z}| < 2\cdot\mu\cdot(m_0 + m_1 + m_2)\cdot g \\ \dot{x}_0 = 0 \end{cases} \qquad (21)$$

From Phase2 to Phase3

$$|x_0| > x_{cl} \qquad (22)$$

From Phase3 to Phase1

$$\begin{cases} |m_0\ddot{z}| < 2\cdot\mu\cdot(m_0 + m_1 + m_2)\cdot g \\ \dot{x}_0 = 0 \end{cases} \qquad (23)$$

From Phase3 to Phase2

$$|x_0| < x_{cl} \tag{24}$$

4th accuracy Runge-Kutta-Gill method has been used for digital analysis of this equation.

Input wave of earthquake

2 kinds of earthquake wave as EL Centro (Imperial Valley, 1940) and JMA Kobe(1995) recorded at Hyougo Nanbu earthquake are used for test. Input level has been leveled at 25 [cm/s] level at and 50 [cm/s] level at horizontal . Each earthquake is listed at Table.2.

Table.2 Caption for table 1

Input Wave	Horizontal Input level[m/s]	Input Direction
El Centro	0.25	EW
		NS
	0.5	EW
		NS
JMA Kobe	0.25	EW
		NS
	0.5	EW
		NS

Result of experiments and analysis

Fig.8,Fig.9 shows comparison of maximum response accelerations and input accelerations, measured and analysis results, it is confirmed input acceleration has decreased to level of 1/4 at first floor, decreased to level of 1/2 at second floor and decreased to level of 1/1.5 at roof.

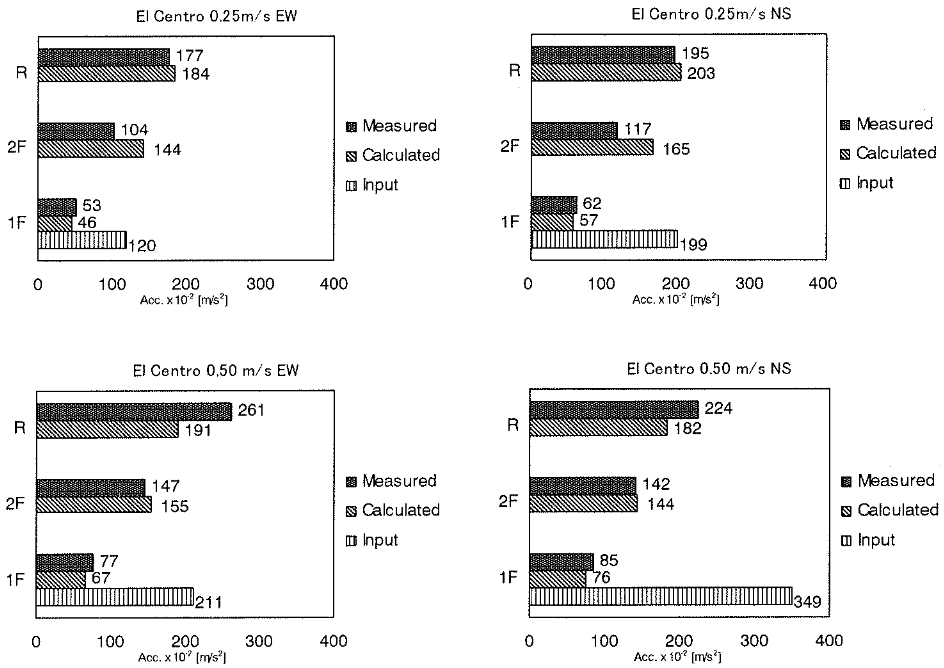

Figure.8 Response accelerations (Input wave: El Centro)

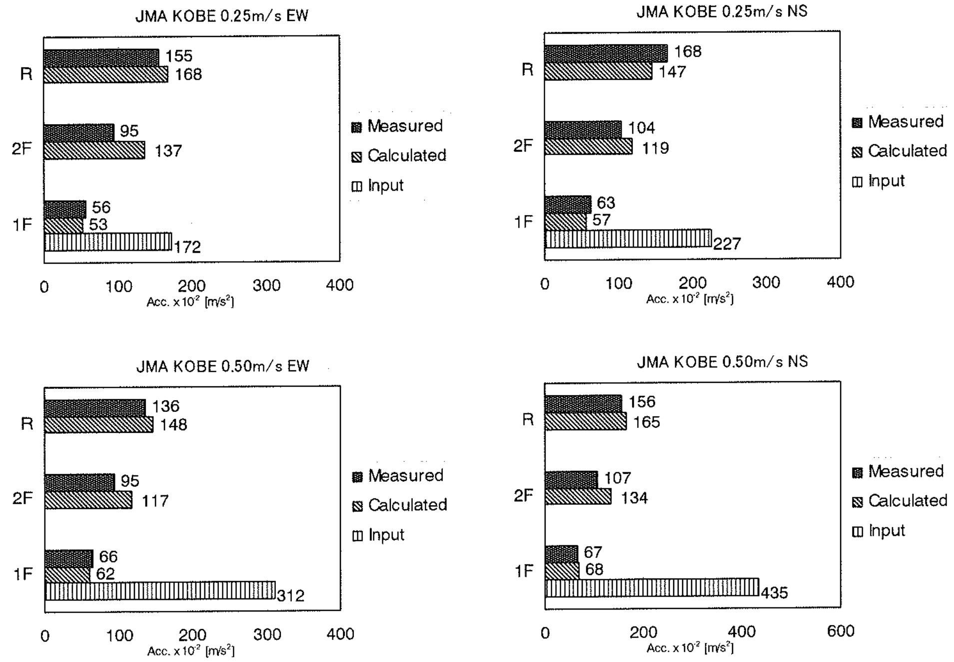

Figure.9 Response accelerations (Input wave: JMA Kobe)

Fig.10 shows comparison of maximum relative displacement measured and analysis results, it is confirmed input acceleration has decreased to level of 1/4 at first floor, decreased to level of 1/2 at second floor and decreased to level of 1/1.5 at roof.

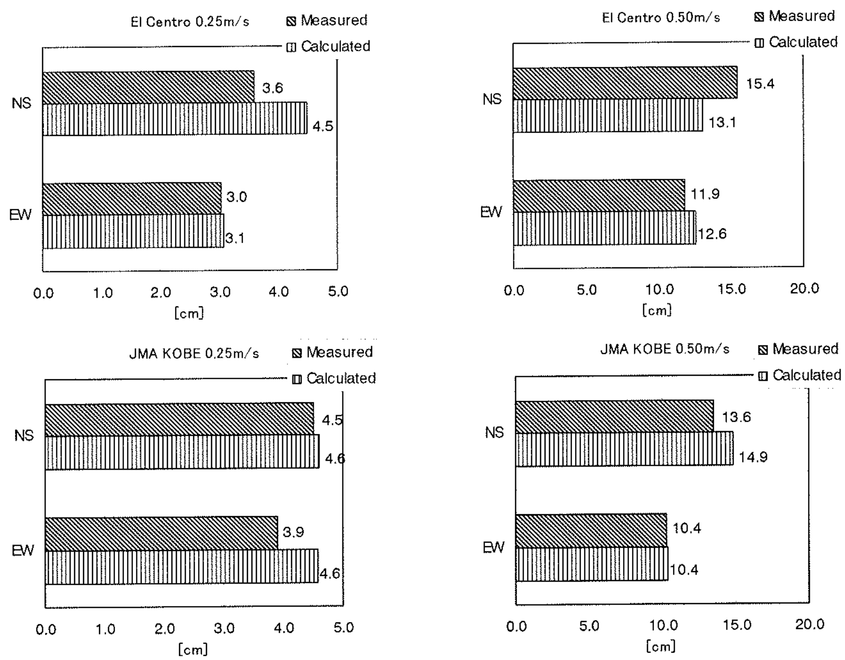

Figure.10 Response displacements

Fig.11 illustrates the time-histories. The input is El Centro NS of 0.5m/s and JMA Kobe NS of 0.5m/s. These figures also show the simulation results. The simulation results agree with measured results as well, confirming that the analysis model is valid.

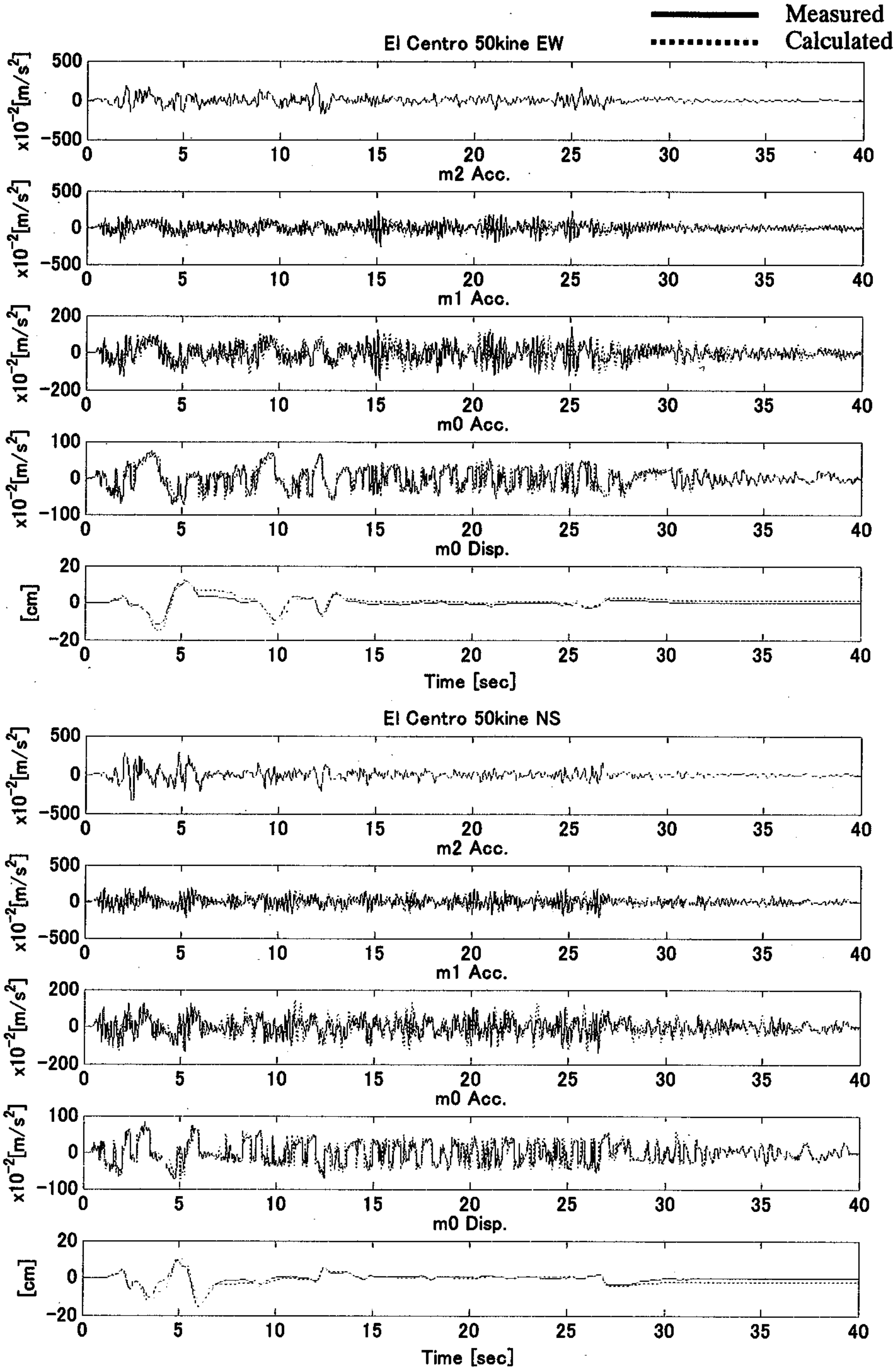

Figure.11 Time histories of calculated and measured response
Input wave: El Centro 0.5m/s

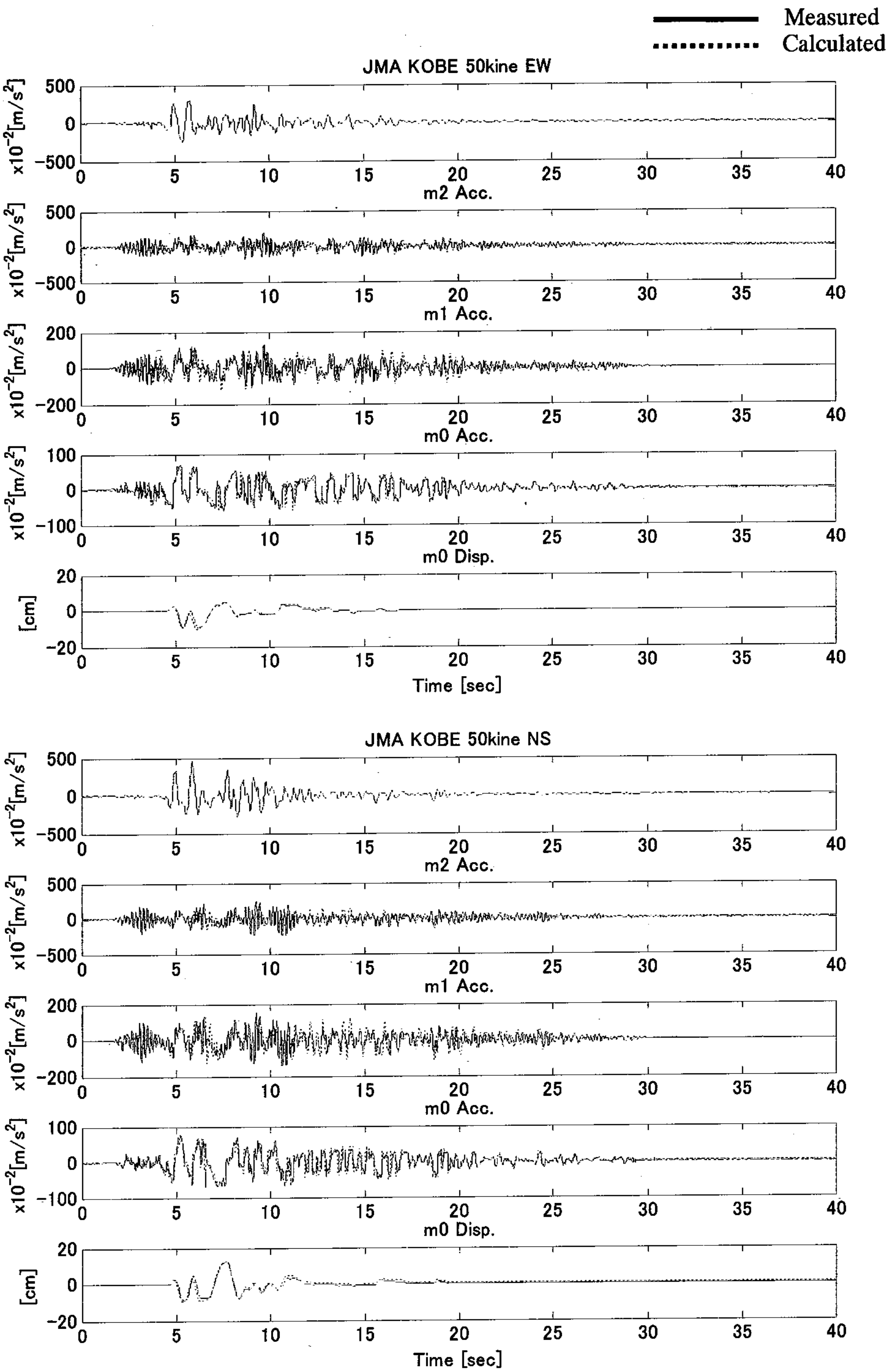

Figure.12 Time histories of calculated and measured response
Input wave: JMA Kobe 0.5m/s

CONCLUSIONS

Shaking table tests were carried out, showing good performance of the device and confirming validity of the analytical method. Earthquake acceleration such as 0.5 [m/s] level of JMA Kobe wave and El-Centro wave has decreased to about less than 1.0 [m/s^2] at first floor. Although there is some difference between experiments and analysis, each time histories of accelerations and displacements showed good conformity which confirming validity of the analytical model.

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