APPLICATIONS OF ROLLER TYPE ISOLATION DEVICE FOR WORKS OF ART

Satoshi UEDA[1], Takao ENOMOTO[1] and Takafumi FUJITA[2]

ABSTRACT: A roller type isolation device for works of art has been developed in several kinds of types and about 2000 systems been already installed not only Japan but overseas. This paper describes the roller type isolation device applied to the statue in the front garden of museum and the devices integrated into the wall-case in museum. The isolation device consists of two layers that form a XY-motion mechanism for two-dimensional horizontal motion, each layer consists of rails having a circular-linear-combined shape in the vertical cross-section to produce a restoring force, wheels, and fiction dampers comprising the wheels and the axles. Because the effective natural period of the device is independent of the mass, a long effective natural period can be achieved even for as showcases. Shake table tests were carried out, showing good isolation performance of system and confirming validity of the analytical method.

Key Words: Vibration Control, Seismic Isolation, Rolling Bearing, Friction Damper Shaking Table Test, Analytical Model, Work of Art, Museum

INTRODUCTION

Japan is the country where seismic isolation is most widely used for civil engineering structures and equipment. Since the Hanshin-Awaji earthquake of 17 January 1995, in which works of art in several museums in this area were damaged, seismic isolation in Japan that include seismic isolation of museum buildings, display cases, and individual works of art, together with seismic isolation of floors in conservation rooms.

A roller type isolation device for works of art has been developed in several kinds of types and about 2000 systems been already installed not only Japan but overseas. This paper describes the roller type isolation device applied to the statue in the front garden of museum and the devices integrated into the wall-case in museum. The isolation device consists of two layers that form a XY-motion mechanism for two-dimensional horizontal motion, each layer consists of rails having a circular-linear-combined shape in the vertical cross-section to produce a restoring force, wheels, and fiction dampers comprising the wheels and the axles. Because the effective natural period of the device is independent of the mass, a long effective natural period can be achieved even for as showcases. Shakeing table tests were carried out, showing good isolation performance of system and confirming validity of the analytical method.

CONSTRUCTION AND CHARACTERISTICS OF ROLLER TYPE ISOLATION DEVECE

Roller type isolation device consists of rail having circular-linear combined the 1st and 2nd stiffness, wheel and axles and plane bearing with PTFE coating. X-Y rail motion mechanism enable to absorb

[1] Advanced System Co.,Ltd Tokyo.
[2] Professor, Institute of Industrial Science, The University of Tokyo.

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. Figure 1 shows circular-linear combined shape of rail. Figure 2 shows Restoring force characteristics of roller type isolation device. Here T shows natural period of the system, r_l is radius of circular rail, k_l is spring constant (the 1st stiffness), P_v is vertical load, Q_d is breaking load, d is diameter of axle, D is diameter of wheel, μ_0 is friction coefficient of bearing and θ is inclination of linear rail. Figure 3 shows schematic drawing of roller type isolation device. 1 shows top plate, 2 shows wheel frame, 3 as base plate, 4 as wheel, 5 as bearing, 6 as axles and 7 shows rail. Natural period of system, the 1st and 2nd stiffness, break load and friction coefficient can be determined by (1) ~(5) formula.

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

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

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

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

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

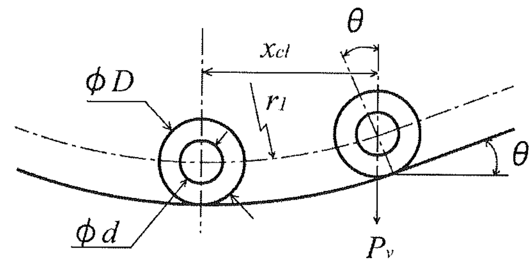

Figure 1. Section view of rail

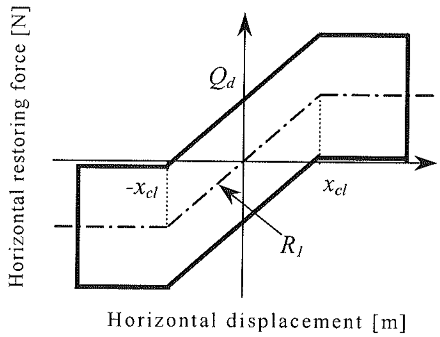

Figure 2. Restoring force characteristics of roller type isolation device

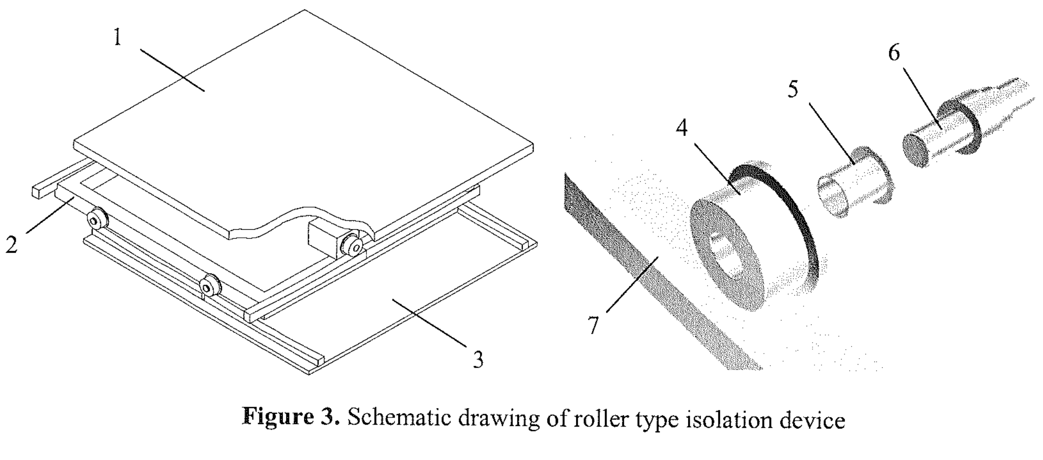

Figure 3. Schematic drawing of roller type isolation device

APPLICATION FOR THE STATUE IN THE FRONT GARDEN OF MUSEUM

Generally statues are exhibited on pedestal at museum. In case of isolation for the statue, isolation device of showcase can be applied for the statue. Until now, large statue is exhibited only by putting on a statue without fixing or anchor to the statue with bracket. In case of an earthquake, it has a possibility of falling and break a part of bracket. Isolation systems have been installed bellow The Thinker (Auguste Rodin) at National Western Art museum at Ueno/Tokyo (Shown in Figure 4). The size of The Thinker is about W1020mm×D1440mm×H1860mm. It has 3600kg weight. The Thinker is anchor to the statue with bracket. Below statue, steel frame with H-shape beam is combined. (Shown in Figure 5). The material of isolation device is all stainless steel. Table 1 shows performance of isolation device.

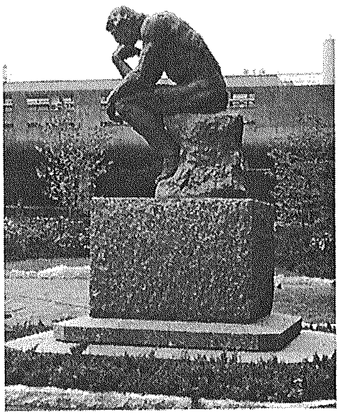

Figure 4. The Thinker (Auguste Rodin) at National Western Art museum at Ueno/Tokyo

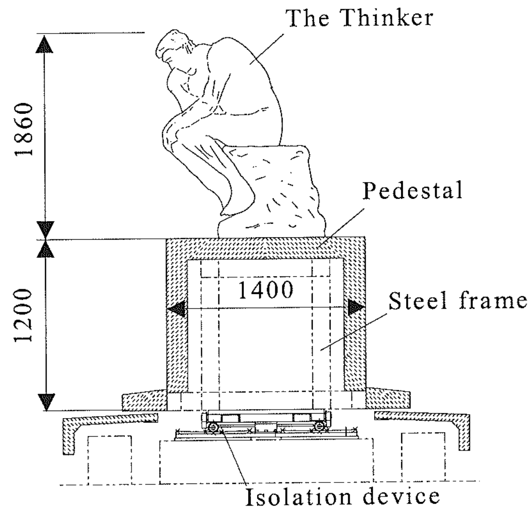

Figure 5. Section view of The Thinker

Table 1. Performance of roller type isolation device

Size		1370mm×1290mm×210mm
Load Mass		4680 kg
Circular part of	Rail	2.7 period
Liner part of		0.03 radian
X-Y Horizontal Displacement		±250 mm
Material		SUS316, SUS304

SHAKING TABLE TEST

Test model

Shaking test has been conducted using same size test model of The Thinker with isolation devices. The size of test model is W1300mm×D1400mm×H2830mm. Figure 6 shows test model. It has 4734kg weight. The acceleration of shaking table was measured and the response acceleration of test model were measured.

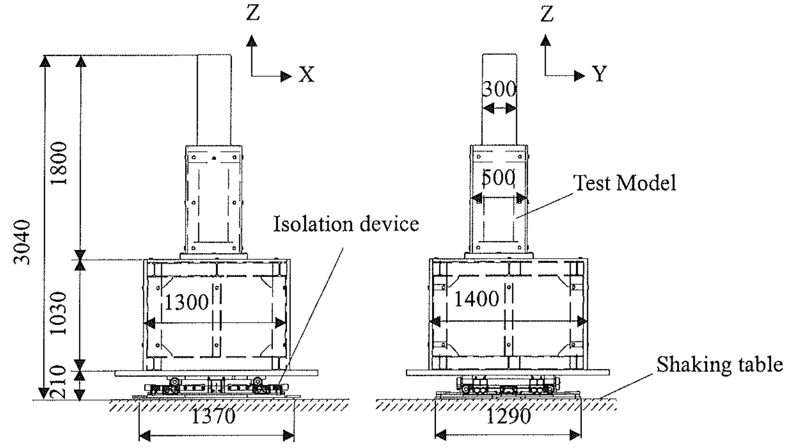

Figure 6. Same size test model of The Thinker

Analysis model

Analytical model has been settled that total mass of moving mass of the system and weight is considered as one-mass model as Figure 7 Here x_0 shows amplitude against the ground, m_0 shows total mass of moving weight of the isolation system and weight, z is acceleration of earthquake, k_0 is spring constant of the system (the 1st stiffness), k_s is the 2nd stiffness, c_0 is damping co-efficient, x_{c1} shows changing point of 1st/2nd stiffness. 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.

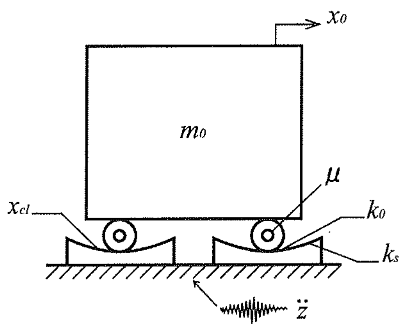

Figure 7. Analysis model

Dynamic Equation

The equation of isolation device shall be descried when no rolling (phase 1) and rolling at 1st stiffness (phase 2) also rolling at 2nd stiffness(phase 3) .

Phase1 (no rolling friction)

$$x_0 = const \tag{6}$$

$$\dot{x}_0 = 0 \tag{7}$$

$$\ddot{x}_0 = 0 \tag{8}$$

Phase2 (rolling at 1st stiffness)

$$m_0\ddot{x}_0 + k_0 x_0 + \mathrm{sgn}(\dot{x}_0)\cdot\mu\cdot m_0\cdot g = -m_0\ddot{z} \tag{9}$$

Phase3 (rolling at 2nd stiffness)

$$m_0\ddot{x}_0 + \{x_{cl}k_0 + k_s(|x_0| - x_{cl})\}\mathrm{sgn}(x_0) + \mathrm{sgn}(\dot{x}_0)\cdot\mu\cdot m_0\cdot g = -m_0\ddot{z} \tag{10}$$

The transition criteria Phase1, Phase2 and Phase3 are

From Phase1 to Phase2

$$|k_0 x_0 + m_0\ddot{z}| > \mu\cdot m_0\cdot g$$

$$|x_0| < x_{cl} \tag{11}$$

From Phase2 to Phase3

$$|x_0| > x_{cl} \tag{12}$$

From Phase3 to Phase2

$$|x_0| < x_{cl} \tag{13}$$

From Phase2 to Phase1

$$|m_0\ddot{z}| < 2\cdot\mu\cdot m_0\cdot g$$

$$\dot{x}_0 = 0 \tag{14}$$

From Phase3 to Phase1

$$|m_0\ddot{z}| < 2\cdot\mu\cdot m_0\cdot g$$

$$\dot{x}_0 = 0 \tag{15}$$

From Phase1 to Phase3

$$|k_0 x_{cl} + k_s(|x_0| - x_{cl}) + m_0\ddot{z}| > \mu\cdot m_0\cdot g$$

$$|x_0| > x_{cl} \tag{16}$$

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

Result of experiments and analysis

4 kinds of earthquake wave as EL Centro (Imperial Valley, 1940), Taft(Kern Country,1952), Hachinohe and JMA Kobe(1995) recorded at Hyougo Nanbu earthquake are used for three-dimensional shaking test. Input level has been leveled at 50 [cm/s] level at horizontal of EL-Centro, Taft wave and Hachinohe(Tokachi, 1968) wave , Original wave of JMA Kobe has been used .Figure 8 shows comparison of maximum response accelerations and input accelerations, measured and analysis results, it is confirmed input acceleration has decreased to level of 1/3 to1/8 at test model. Figure 9 to Figure 12

shows time histories of calculated and measured response. There are small differences at peak values but conformity of test and analytical methods was fully confirmed.

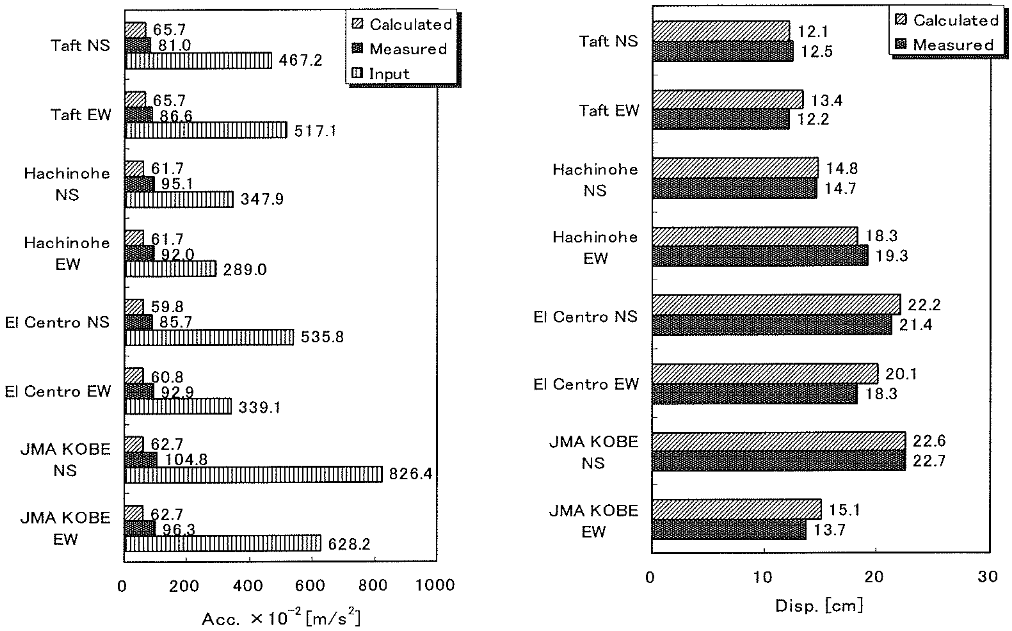

Figure 8. Response accelerations and displacement

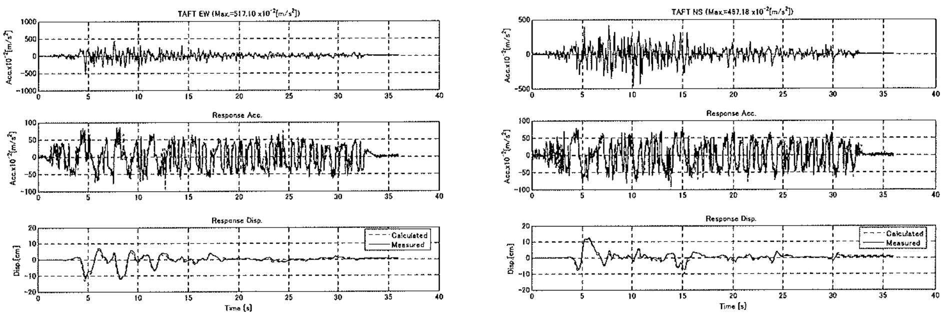

Figure 9. Time histories of calculated and measured response
Input wave: Taft 0.5m/s

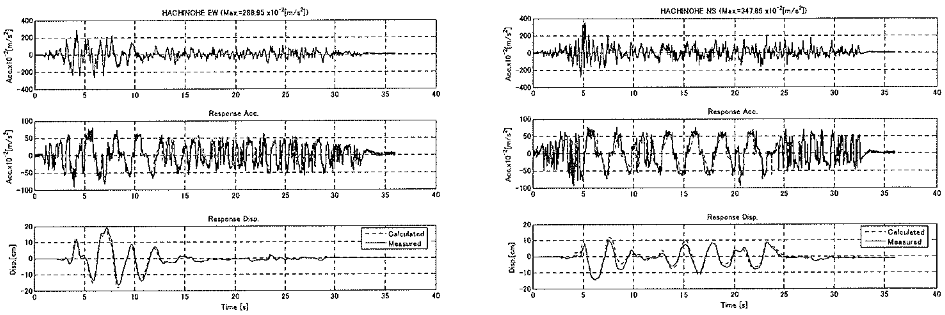

Figure 10. Time histories of calculated and measured response
Input wave: Hachinohe 0.5m/s

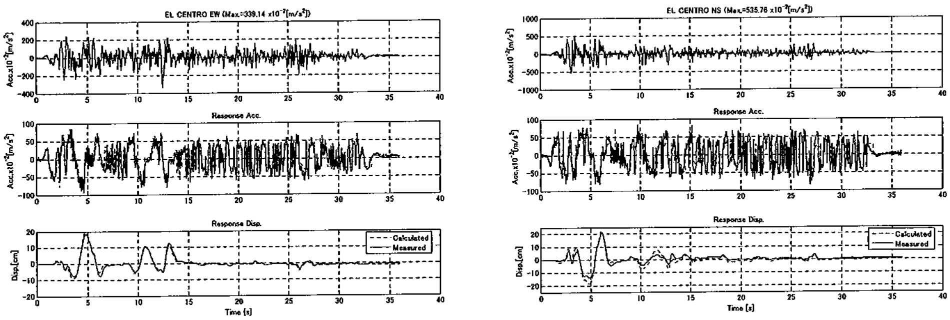

Figure 11. Time histories of calculated and measured response
Input wave: El Centro 0.5m/s

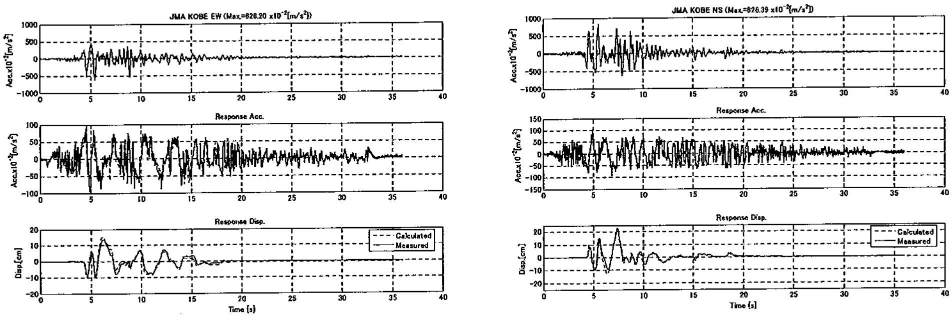

Figure 12. Time histories of calculated and measured response
Input wave: JMA Kobe

APPLICATION FOR WALL CASE

Because wall cases in museum are built into room wall ,it is difficult to base-isolate the wall case from bottom, Therefore only display platform has been base-isolated .Figure 13 shows the construction of base isolation system which been placed onto display table of wall case. As shown at Figure 14, outside dimension of this system is 1870 mm × 885mm × 150 mm height. The display table of 1420 mm × 470 mm can stroke with ±200 mm displacement into any direction (until dotted line) to absorb earthquake acceleration. This system is designed to have 20 Kg/m weights of works of art. Outside surface of this system are covered with make up cloth cover and visitors to museum can hardly find isolation device are integrated in this system. Figure 15 shows the situation in the museum.

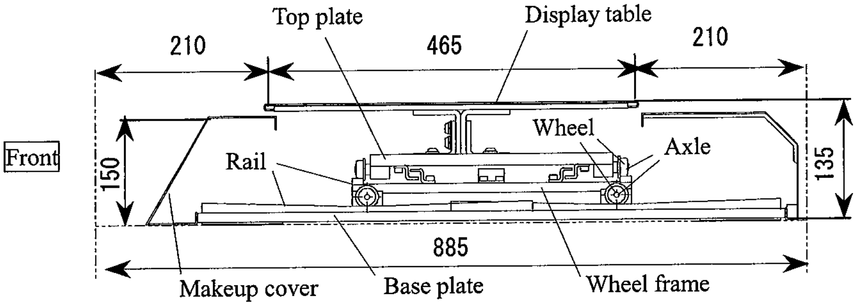

Figure 13. Section view of wall case

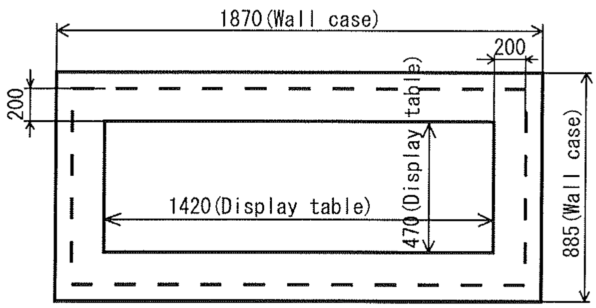

Figure 14. Plane figure of wall case

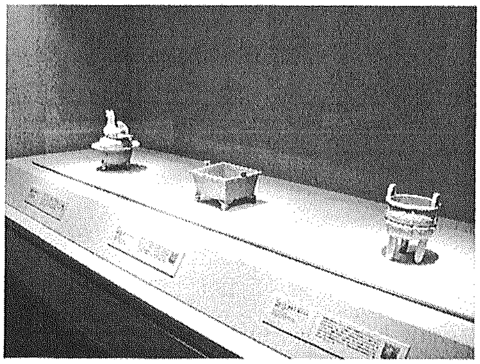

Figure 15. Exhibition state

PERFORMANCE

Table2 shows reference list from 1996 to April/2004. Already about 2000 systems have been supplied not only in Japan but also in Italy, Taiwan, China and Korea due to specific feature of this system .

Table 2. Performance of roller type isolation device (From1996to April/2004)

Case type	The number of delivery
Showcase	683 (Overseas 1 is included)
Wall case	83 (Overseas 25 is included)
Statue	1197 (Overseas 138 is included)
Total	1963 (Overseas 164 is included)

CONCLUSIONS

This paper described the roller type isolation devices been applied to the statues in the front garden of museum and to isolation system integrated in wall cases. Shaking table test been carried out showing good isolation performance and confirming validity of the analytical method.

(1) Shaking test with same size model of The Thinker and his statue confirmed good performance of system as the input acceleration has decreased to level of 1/3 to 1/8.

(2) Shaking table test of the isolation system integrated in wall case been carried out showing good performance as input acceleration of JMA Kobe decreased to 1/8 level.

(3) Although there are small difference at peak values but conformity of test and analytical methods was fully confirmed.

(4) A roller type isolation device described here has specific feature as the performance of this system is independent to variation of supported weight which enable to establish standard design to apply variable applications.

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