

# EXPERIMENTS AND ANALYSIS OF ROLLER TYPE **ISOLATION DEVICE**

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### SUMMARY

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.

This paper also describes a roller type isolation system for the individual showcases and individual works of art. The isolation system 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 system is independent of the mass, a long effective natural period can be achieved even for light equipment such as showcases. Shake table tests were carried out, showing good isolation performance of system and confirming validity of the analytical method.

## **INTRODUCTION**

Recently many kinds of seismic isolation systems for showcases of works of art or computer systems are under research and development. Especially showcases of works of art require higher performance against earthquake in order to protect valuable work of art from any damages. This paper describes a roller type isolation system which utilizing two layers of a XY-motion mechanism having a circular-linearcombined shape in the vertical cross section. Results of three-dimensional shaking table test by earthquake wave and validity of the analytical model.

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#### **CONSTRUCTION**

Roller type isolation system 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 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 co-efficient can be determined by bellow formula. Here T shows natural period of the system, r1 is radius of circular rail, k1 is spring constant (1st stiffness), Pv is vertical load, Qd is breaking load, d is diameter of axle, D is diameter of wheel,  $\mu$  is friction co-efficient of bearing is friction co-efficient of system and  $\theta$  is inclination of linear rail. Fig.2 shows concept model of characteristic of isolation device.



Figure.1 Schematic drawing of roller type isolation device



Figure.2 Concept model of isolation device

$T = 2\pi \sqrt{r_1/g} \qquad (1)$	)
$k_1 = P_v / r_1 \qquad (2)$	!)
$Q_d = P_v \cdot \mu \tag{3}$	)
$\mu = (d/D) \cdot \mu_0  \cdots  \cdots  \cdots  \cdots  \cdots  \cdots  \cdots  \cdots  \cdots  $	)

#### SHAKING TABLE TEST (CASE 1)

#### Analytical Model

Shaking table test has been conducted on roller type isolation system supporting museum showcase with appropriate weight. Analytical model has been settled that total mass of moving mass of the system and weight is considered as one-mass model as Fig.3 Here x0 shows amplitude against the ground, m0 shows total mass of moving weight of the isolation system and weight., z is acceleration of earthquake, k0 is spring constant of the system (1st stiffness), ks is 2nd stiffness, c0 is damping co-efficient, xc1 shows changing point of 1st/2nd stiffness.



Figure.3 Analytical model

#### Roller type isolation system

Isolation system which designed for museum high-showcase has size of 2600 mm length x 1090 mm width x 236 mm height. Isolation system is designed for experiment as the natural period is 2.68 sec, inclination of strait part of rail is 0.03rad, friction co-efficient is 0.036, allowable amplitude of system as  $\pm$ 275 mm. Weight of 833 kg is loaded on 1200 kg weigh isolation system. Fig.4 shows drawings of the system and Fig.5 photo of the system installed three-dimensional shaking table.



Figure.4 Drawings of the system



Figure.5 Test using three-dimensional shaking table

#### 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).

Phase 1 (in case no rolling occur)

 $x_0 = const, \dot{x}_0 = 0, \ddot{x}_0 = 0$  (5)

Phase 2 (in case rolling occur at 1st stiffness)

Phase 3 (in case rolling occur at 2nd stiffness)

$$m_{0}\ddot{x}_{0} + c_{0}\dot{x}_{0} + \{x_{c}k_{0} + k_{s}(|x_{0}| - x_{c})\}\operatorname{sgn}(x_{0}) + \mu \cdot m_{0} \cdot g \cdot \operatorname{sgn}(\dot{x}_{0}) = -m_{0}\ddot{z} \quad \cdots \quad \cdots \quad (7)$$

Switching condition is described as follows.

In case Phase 1 –Phase 2 $ k_0 x_0 + m_0 \ddot{z}  > \mu \cdot m_0 \cdot g \text{ and }  x_0  < x_{cl}$ (8)
In case Phase2 –Phase 3 $ x_0  > x_{cl}$ (9)
In case Phase3 –Phase 2 $ x_0  < x_{cl}$ (10)
In case Phase2 –Phase 1 $ m_0\ddot{z}  < 2\mu \cdot m_0 \cdot g$ and $\dot{x}_0 = 0$ ·····(11)
In case Phase3 –Phase 1 $ m_0 \ddot{z}  < 2\mu \cdot m_0 \cdot g$ and $\dot{x}_0 = 0$ (12)
In case Phase 1 –Phase 3 $ k_s x_0 + m_0 \vec{z}  > \mu \cdot m_0 \cdot g$ and $ x_0  > x_{cl}$ ······(13)

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

#### Input wave of earthquake

3 kinds of earthquake wave as EL Centro (Imperial Valley, 1940), Taft(Kern Country, 1952) 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 and 25 [cm/s] at vertical of EL-Centro and Taft wave, Original wave of JMA Kobe has been used. Maximum value of acceleration of each earthquake is listed at Table.1.

Input	Horizontal	Input	Horizontal Acc.	Vertical Acc.
Wave	Input level	Direction	MAX[m/s <sup>2</sup> ]	MAX[m/s <sup>2</sup> ]
El Centro	0.50[m/s ]	EW	3.14	2.06
		NS	5.10	2.00
Taft		EW	4.90	1.03
		NS	4.25	
JMA	Original	EW	6.17	2 22
Kobe	NS	8.18	5.52	

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#### Result of experiments and analysis

Fig .6 shows comparison of maximum acceleration and amplitude between input, measured and analysis results, it is confirmed input acceleration has decreased to level of 1/4 to 1/5. Fig.7 shows time histories of calculated and measured.



Figure.6 Response accelerations and displacements





SHAKING TABLE TEST (CASE 2)

Results of 3D shaking test with real museum showcase and isolation system is described here. Monetization of showcase and isolation system has been studied for simulation of response.

#### Isolated equipment (Museum showcase)

Isolated showcase has 900 mm square x 2700 mm height size and 350 kg weight. Fig.8 shows photos of showcase and position of acceleration sensors. In order to confirm basic performance of showcase, showcase has been oscillated by random mode at fixed condition.

From this random oscillation test, natural frequency of showcase (first mode) has been determined as 6.9 Hz. Fig.9 shows transfer function of acceleration from shaking table to display point and one from shaking table to top of showcase.



**Figure.8** Show case (□900x900x2700h)



**Figure.9** Show case (□900x900x2700h)

#### Roller type isolation system

Isolation system used for this test has 900 mm square x 1900 mm height, 2.68 seconds natural time period of rail, 0.03 inclined strait rail and allowable maximum amplitude of  $\pm$ 220mm.It has 400 kg weight and is shown at photo of Fig .10.



**Figure.10** Isolation device (□900x900x190h) for show case

#### Statistic load test

Statistic load test with appropriate weight has been conducted to determine friction co-efficient and performance of the system. Testing equipment shown at Fig.11 has been used to survey horizontal performance of each X,Y direction. Friction co-efficient has been calculated from measured horizontal load, deflection and vertical load. Here co-efficient at zero horizontal deflection is calculated using bellow equation.(4.1)(4.2) Co-efficient of  $\mu$  =0.032 is calculated for X direction at total moving weight of 1.9 kN and  $\mu$  =0.031 for Y direction at total weight of 1.6 kN. Fig.12 shows performance of X and Y direction.



Figure.11 Test apparatus for isolation device



Figure.12 Restoring force vs. horizontal displacement

#### Analytical Model

Analytical model is considered as 2 degree of freedom as Fig.13 when the showcase is supported by isolation system.



Figure.13 Analytical model

#### Result of experiments and analysis

Fig.14shows comparison of maximum acceleration and amplitude between input, measured and analysis results, it is confirmed input acceleration has decreased to level of 1/4 to 1/5. Fig.15 shows time histories of calculated and measured.



Figure.14 Response accelerations and displacement



Figure.15 Histories of calculated and measured

#### CONCLUSION

Shaking table tests were carried out, showing good performance of the system and confirming validity of the analytical method. Earthquake acceleration such as JMA Kobe original wave and 0.5 [m/s] level of El-Centro and Taft has decreased to about less than 1.0  $[m/s^2]$  at showcase. 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.

## **EXAMPLE OF APPLICATION TO MUSEUMS**

Fig 16(a),(b) Isolation systems have been installed bellow The Thinker and Burghers of Calais (Auguste Rodin) at National Western Art museum at Ueno/Tokyo. Fig 17(a),(b) Isolation system has been integrated bellow beautiful showcase at Gifu Modern Museum at Gifu prefecture.



Figure.16(a) The Thinker (Auguste Rodin)



Figure.16(b) Burghers of Calais (Auguste Rodin)



Figure.17(a) Show case





Figure.17(b) Show case

## REFERENCES

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