Title	STUDY ON MECHANICAL PROPERTIES OF BIDIRECTIONAL ROLLING BASE ISOLATION BEARINGS
Author(s)	LT. DING; WANG, T.
Citation	Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan, F-4-1., F-4-1
Issue Date	2013-09-12
Doc URL	http://hdl.handle.net/2115/54393
Type	proceedings
Note	The Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan.
File Information	easec13-F-4-1.pdf

STUDY ON MECHANICAL PROPERTIES OF BIDIRECTIONAL ROLLING BASE ISOLATION BEARINGS

LT. DING[1] and T. WANG[1*]

[1]*Institute of Engineering Mechanics, China Earthquake Administration, China*

ABSTRACT

Proposed in this study is a metallic isolator utilizing two orthogonal roller layers to realize the bidirectional isolation. One of the advantages of the proposed metallic isolator is the low friction coefficient to realize a long period. The other is the large tension resistance in the vertical direction. These features make it easy to be used in high-rise buildings. The metallic isolator consists of top and bottom plats, two layers of rolling shafts, a middle plat, L-shaped anti-tension connecting plates, and PTFE plates. When being compressed, the rolling shafts roll on the surface of the middle plate, providing very low friction force. While being tensioned, a sliding mechanism forms between the L-shaped anti-tension connecting plats and PTFE plates, and the isolation effect depends on the friction coefficient of the contact pairs. By virtue of the two roller layers set in orthogonal directions, the top plate is able to move in any horizontal direction relative to the bottom plate. The mechanical properties of the new base isolation device are investigated experimentally. The isolator was tested under the compression from 100 kN to 1000 kN. Several horizontal loading directions were selected as 0, 30 and 45 degrees to simulate the motion in any horizontal direction. The loading frequency changed from 0.05 Hz to 0.3 Hz with the amplitude varying from 20 mm to 150 mm. It is demonstrated that the metallic isolator is able to move smoothly in any direction with a relatively constant coefficient ranging from 0.02 to 0.04. The dependency on the vertical compression and the horizontal velocity is quite low and the mechanical property is stable and reliable.

Keywords: Base isolation, rolling bearing, high-rise building, sliding surface, friction coefficient.

1. INTRODUCTION

Modern base isolation technique has been applied and promoted since the first application of rubber bearing to isolate an elementary school in Skopje, Yugoslavia. The theory of base isolation system is simple, that is to elongate the natural period of the target structure by inserting a soft layer under the structure, so that the major part of the seismic energy characterized by low period components has much smaller effect on the structure. The isolation layer consists of isolators, stoppers, and dampers to control the horizontal displacement if needed. The isolator, also named after bearing, is featured with a high stiffness in vertical to support the gravity of the superstructure, and also

---

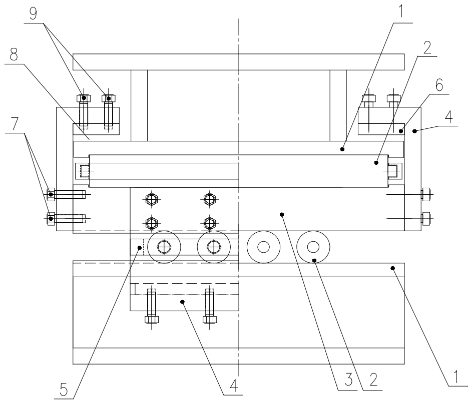
[*] Corresponding author and presenter: Email: wangtao2004@gmail.com

provides a much lower horizontal stiffness than the superstructure. The concept of the base isolation technique has been demonstrated as one of the most effective approaches to protect structures from huge earthquakes. Most widely used isolator is the elastomeric-based bearing. It is often made of natural rubber or synthetic rubber (Fuller *et al* 1997). To achieve a high vertical stiffness, the rubber is divided into many thin layers and separated by thin steel shims. The steel shims confine the horizontal expansion of rubber layers under the vertical load, so that a high stiffness is realized in the vertical direction. However, there's no confinement in the horizontal direction. The shear deformation of the rubber layers is almost free, and the horizontal stiffness is much lower than the vertical stiffness. Recently, the damping mechanism is often incorporated into the isolator by adding extra-fine carbon block and other fillers, called high-damping rubber bearing (Yamamoto 2012). The other way is to insert a lead cylinder into the rubber bearing (Robinson 1982). The plastic deformation of the lead dissipates seismic energy. This type bearing is called lead plug rubber bearing. More recently, a metallic isolator was devised to use the low friction along the spherical surface to isolate the horizontal displacement, also called friction pendulum system (Panchal *et al* 2009). These isolators, however, have no or very low tensile resistance in the vertical direction, which limits their application in high-rise buildings.

Proposed in this study is a metallic isolator featured with low friction coefficient in the horizontal direction and large tensile resistance in the vertical direction, which make it very suitable to be applied in high-rise buildings. First introduced in this paper is the configuration of the metallic isolator. Then followed is the experimental examination. A shear-and-compression testing machine which is designed especially for the bearing inspection is employed. The friction coefficient under different compression loads, and the mechanical performance is tested under sine-waves with various amplitudes and frequencies.

2. CONFIGURATION OF THE METALLIC ISOLATOR

The metallic isolator primarily consists of top and bottom plates, two layers of rolling shafts, a middle plat, L-shaped anti-tension connecting plates, and PTFE plates, as shown in Fig.1. The top and the bottom plates are used to connect the superstructure and the foundation, respectively. For each layer of rolling shafts, there's a roller frame designed to constraint the rollers move in parallel and simultaneously. The number of the shafts depends on the compression carried by the bearing. When being compressed, the rolling shafts roll on the surface of the middle plate, providing very low friction force. While being tensioned, a sliding mechanism forms between the L-shaped anti-tension connecting plats and PTFE plates, and the isolation effect depends on the friction coefficient of the contact pairs. Note that the high-strength bolts exert pre-compression on the shafts so that they always contact the rolling surfaces even though the bearing is tensioned vertically. By virtue of the two roller layers set in orthogonal directions, the top plate is able to move in any horizontal direction relative to the bottom plate.



1. Top and bottom plates
2. Rolling shafts
3. Middle plate
4. L shape anti-tension connecting plate
5. Roller frame
6. Preload force plate
7. High-strength bolts
8. PTFE plates
9. High-strength bolts

Figure 1: Configuration of the bearing

3. EXPERIMENTAL EXAMINATION

3.1. Testing scheme

The metallic isolator is tested on a shear-and-compression testing machine which can provide 2500T/200T load capability in the vertical/horizontal direction, as shown in Fig.2. The test is classified into 3 cases, noted as I, II and III, each corresponding to a group of tests to examine the friction coefficient, as listed in Tables 1 and 2. Case I investigates the static friction coefficient. Under a constant vertical load, a target displacement of 10mm is reached by a very low loading rate in the horizontal direction, and we adopted the peak load value to calculate static friction coefficient. The isolator is tested under sine-wave excitations with the frequency varying from 0.05 Hz to 0.3 Hz in both cases II and III. Each sine-wave is loaded for 3 times. In case II, the vertical load varies from 100kN to 1000kN to examine the dependency of the friction coefficient on the surface compression. Case III loaded the specimen under a constant pressure, while changing the horizontal loading amplitude. This is to investigate the influence of the loading rate on the friction coefficient. The horizontal loading directions are selected as 0°, 30° and 45° to simulate the motion in any horizontal direction, as shown in Fig.3.

(a) Shear-and-compression testing machine

(b) Metallic isolator

Figure 2: Metallic isolator and testing machine

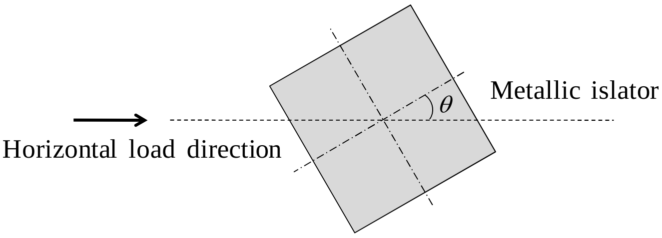


Figure 3: Horizontal loading direction

Table 1: Tests for static friction coefficient

Case		*Vertical load P (kN)*	*Target displacement (mm)*	*Loading speed v (mm/s)*
I	1-1	100	10	0.12
	1-2	300	10	0.12
	1-3	500	10	0.12
	1-4	700	10	0.12
	1-5	1000	10	0.12

Table 2: Dynamic testing scheme

Case		*Sine-wave amplitude A (mm)*	*Vertical load P (kN)*	*Sine-wave frequency f (Hz)*
II	2-1~2-4	20	100	0.05/0.1/0.2/0.3
	2-5~2-8	20	300	0.05/0.1/0.2/0.3
	2-9~2-12	20	500	0.05/0.1/0.2/0.3
	2-13~2-16	20	700	0.05/0.1/0.2/0.3
	2-17~2-20	20	1000	0.05/0.1/0.2/0.3
III	3-1~3-4	50	700	0.05/0.1/0.2/0.3
	3-5~3-8	100	700	0.05/0.1/0.2/0.3
	3-9~3-12	150	700	0.05/0.1/0.2/0.3

3.2. Static friction coefficient

Static friction coefficients and peak static horizontal loads at three loading directions 0°, 30° and 45° under different vertical loads are given in Table.3 and Fig.4, respectively. The static friction coefficient is defined as Eqation (1) where, F is the horizontal load (peak load within 10mm for case I); P denotes vertical load; and μ is the static friction coefficient.

$$\mu = \frac{F}{P} \tag{1}$$

It is observed that: (1) the static friction coefficient varies in a similar way in all three loading directions; (2) the static friction coefficient decreases as vertical load gets larger. When the vertical load is 100kN, it is greater than 0.05, while it changes slightly between 0.03 and 0.05 with the vertical load varying from 300kN to 1000kN; and (3) the peak horizontal loads approximately identical under a lower vertical load, 100kN and 300kN, which is deemed as the initiation force required to start the rolling or sliding motion of the isolator.

Table 3: Static friction coefficient under different vertical load

Vertical load P(kN)	$\theta=0^\circ$	$\theta=30^\circ$	$\theta=45^\circ$
100	0.124 (12.39)	0.106 (10.58)	0.062 (6.20)
300	0.042 (12.50)	0.052 (15.60)	0.034 (10.15)
500	0.031 (15.60)	0.040 (19.76)	0.031 (15.70)
700	0.028 (19.44)	0.040 (28.09)	0.027 (19.12)
1000	0.027 (26.81)	0.045 (45.08)	0.038 (38.35)

Note: Value in the brackets is peak horizontal load.

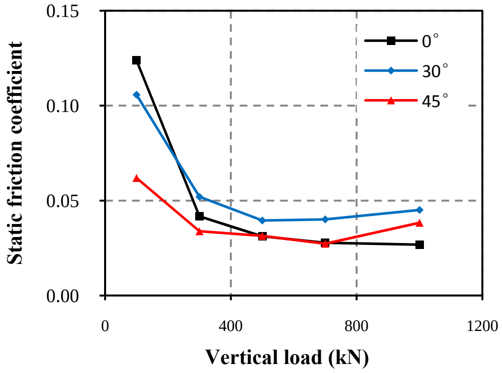


Figure 4: Static friction coefficient under different vertical load

3.3. Dynamic friction coefficient - displacement relationship

Dynamic friction coefficient is also calculated by Equation (1). Shown in Fig.5 to Fig.8 are relationships between the friction coefficient and the displacement. It is observed that: (1) the dynamic friction coefficient varies between 0.02 and 0.025, which is smaller than the static friction coefficient. When the sine-wave reaches the maximum displacement, the dynamic friction coefficient increases to the static friction coefficient; (2) the dependency on horizontal load frequency is low, as shown in Fig.5, the dynamic friction coefficient stays close to 0.02 when frequency changed from 0.05Hz to 0.3Hz; (3) as shown in Fig.6, when the displacement amplitude increases, the dynamic friction coefficient decreases; and (4) the isolator is stable in different directions, as shown in Fig.7. And the mechanical property is reliable under the vertical compression 300kN to 1000kN.

4. CONCLUSIONS

A series of tests are conducted to study mechanical properties of the metallic rolling base isolation bearing. Both static and dynamic friction coefficients are examined. Major findings are: (1) the static friction coefficient is between 0.03 to 0.05 when vertical load changes from 300kN to 1000kN, and it decreases as vertical load is larger; (2) the dynamic friction coefficient is about 0.02, and the dynamic friction coefficient vs. displacement relationship curves show a good stability in any horizontal directions; and (3) the dependency on the vertical compression and the horizontal loading rate is limited in the current available testing rate which is less than 280 mm/s. Further examination under a larger loading rate is needed before the real application.

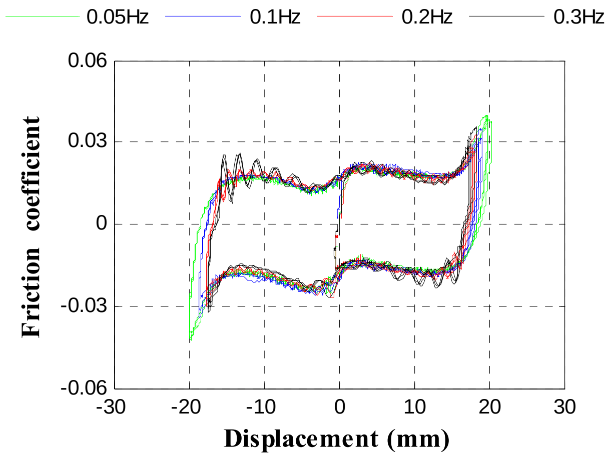


Figure 5: θ=0° and P=700kN

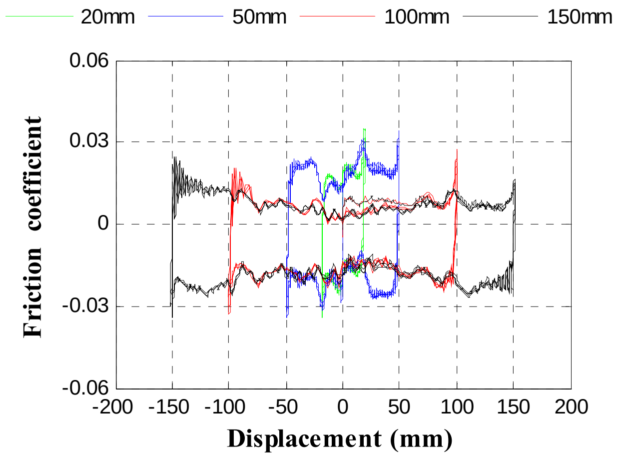


Figure 6: θ=0° and f=0.1Hz

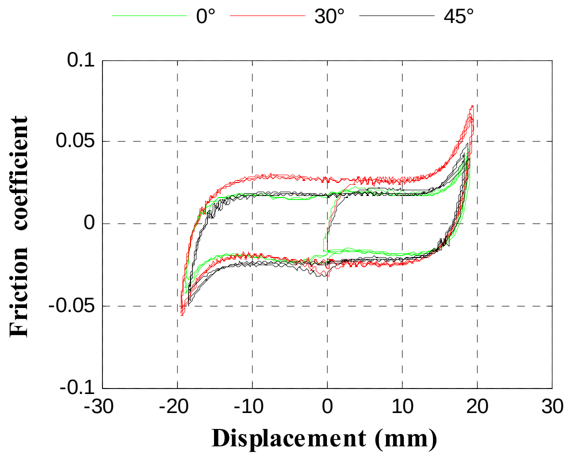


Figure 7: f=0.1Hz and P=1000kN

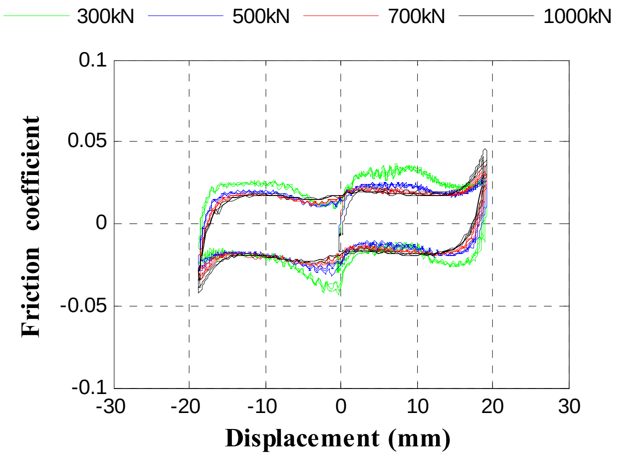


Figure 8: θ=0° and f=0.1Hz

5. ACKNOWLEDGMENTS

The authors thank the support by National Department Public Benefit Research Foundation of China (201108006). Any opinions, findings, and conclusion or recommendation expressed in this paper are those of the authors and do not necessarily reflect the views of the sponsors.

REFERENCES

Masashi Yamamoto (2012). Nonlinear behavior of high-damping rubber bearings under horizontal bidirectional loading: full-scale tests and analytical modeling. Earthquake Engineering and Structural Dynamics. 41(13), pp. 1845-1860.

W. H. Robinson (1982). Lead-rubber hysteretic bearings suitable for protecting structures during earthquakes. Earthquake Engineering and Structural Dynamics. 10(4), pp. 593–604.

K. N. G. Fuller, J. Gough, T. J. Pond, H. R. Ahmadi (1997). High damping natural rubber seismic isolators. Journal of Structural Control. 4(2), pp. 19-40.

V. R. Panchal , R. S. Jangid (2009). Seismic Response of Structures with Variable Friction Pendulum System. Journal of Earthquake Engineering. 13 (2), pp.193-216.