Study on the Influence of Fatigue on the Shear Performance of Metal Rubber Bearing

Xin Qiao[1,a], Xiushen Xia[2,b*]

[1,2] Faculty of Civil Engineering, Lanzhou Jiaotong University, Lanzhou, Gansu, 730000, China

[a] Email: 1557108840@qq.com
[b*] Corresponding author's e-mail:xiaxiushen@mail.lzjtu.cn

Abstract. The metal rubber bearing has excellent characteristics such as anti-fatigue, anti-aging and anti-corrosion, while the vehicle live load will cause fatigue damage to the metal rubber bearing and thus affect its shear mechanical properties. This paper is based on 2 million times of vertical fatigue test and fatigue before and after the shear test to investigate the fatigue damage on the metal rubber bearing shear mechanical properties. The test results show that: after the fatigue test, the hysteresis curve of the bearing is fuller than before fatigue, and the basic symmetric shuttle shape before fatigue is changed to asymmetric shape after fatigue; fatigue damage reduces the equivalent stiffness of the bearing and the stiffness after yielding, while the horizontal energy dissipation capacity of the bearing and the damping performance are improved.

Keywords: metal rubber bearing; shear test; fatigue test; hysteresis curve; post-yield stiffness

1 Introduction

Commonly used rubber bearings will have durability problems caused by aging and cracking of bearings. A new type of bridge bearing-metal rubber bearing is proposed, which has excellent characteristics such as good corrosion resistance and strong bearing capacity[1].

At present, many scholars at home and abroad have carried out some research on metal rubber components. qian Du et al[2] carried out mechanical tests such as compression-shear test and compression test on metal rubber bearings. The experimental results are basically consistent with the trilinear restoring force model of the proposed simulation test curve. xiushen Xia et al[3] conducted a compression experiment on the designed and processed metal rubber bearing.The experiment showed that the vertical energy dissipation capacity of the bearing decreased with the increase of density,and the theoretical calculation of the loading and unloading curve was in good agreement with the experimental data.The rotation performance test of metal rubber bearing was carried out by[4].The test shows that the metal rubber bearing has good rotation performance. jian Jiang et al[5] conducted a mechanical performance test on a cylindrical metal rubber isolation bearing, and obtained the influence of loading frequency, load-

A. S. B. A Rashid et al. (eds.), *Proceedings of the 2024 3rd International Conference on Applied Mechanics and Engineering Structures (AMES 2024)*, Advances in Engineering Research 34,
https://doi.org/10.2991/978-94-6463-473-0_5

ing amplitude and aspect ratio on the mechanical properties of the bearing.senlin Sun et al[6] carried out compression-shear quasi-static tests on two full-scale metal rubber bridge bearings with different densities,and studied the effects of shear strain, compressive stress, loading frequency and repeated loading times on bearing shear. Kuteneva S.V. et al[7] conducted impact cycling and fatigue tests on metal/rubber composites, and found that the fatigue resistance of metal rubber composites was improved, and their strength was comparable to that of low-carbon steel. Kuteneva Svetlana et al[8] conducted three-point bending tests to investigate the static, dynamic, and cyclic mechanical states of metal rubber composites. Yu A Burian et al[9] validated the seismic isolation effect of conical metal rubber bearings. A. M. Zhizhkin et al[10] designed a sealing element made of porous metal rubber material, studied its friction process, and determined the wear form of porous metal rubber material in the seal.

In this paper, a highway simply supported girder bridge as the engineering background, to carry out 2 million times of metal rubber bearing fatigue test and fatigue before and after the shear test to explore fatigue before and after the change rule of bearing shear performance, for the design and application of metal rubber bearing to provide reference.

2 Shear Test of Bearing

2.1 Specimens for Metallic Rubber Bearings

In order to facilitate the comparative study of the impact of fatigue damage on the shear performance of metal rubber bridge bearings, two metal rubber bearing specimens (Figure 1) were designed and manufactured for shear test and fatigue test. The material of metal rubber bearing test piece is stainless steel metal austenite (06Cr17Ni10), the wire diameter is 0.5mm, and the spiral diameter is 5mm. Its key parameters are shown in Table 1.

Table 1. Parameters related to metal rubber bearings

Specimen number	Size/mm		density $/g/cm^3$	quality /g	relative density	shape factor
	diameter	height				
b1	165	35	3.08	2302	0.4	4.71
b2	165	44	2.83	2664	0.4	3.75

(a) MRB 1 (b) MRB 2

Fig. 1. Specimen of metal rubber bearing

2.2 Shear Test

The shear test was conducted in the National and Local Joint Engineering Laboratory of Road Engineering Disaster Prevention Technology of Lanzhou Jiaotong University. According to the available instruments in the laboratory, the shear test was completed by combining compression and shear. The vertical force is provided by a 50t jack connected with a small manual oil pump through an oil pipe. The vertical force acquisition is read by an intelligent display instrument equipped with a spoke pressure sensor, with an accuracy of 0.1kN. The electro-hydraulic servo actuator is used for horizontal loading. The maximum horizontal force is 300kN, and the displacement range is 100mm. The loading diagram and physical drawing are shown in Figure 2 and Figure 3. Due to the limitations of laboratory conditions, the shear test is conducted before and after the fatigue test. With reference to the specifications of Rubber Bearings Part 1-Test Methods for Seismic Isolation Rubber Bearings (GB/T 20688.1-2007)[11], the test loading conditions are shown in Table 2, and the loading steps are as follows:

(1) Vertical force loading. The vertical force is applied by means of a jack to a predetermined value and remains constant throughout the shear test.

(2) Horizontal force hysteresis loading. At a loading rate of 2mm/s, the metal rubber bearings were subjected to horizontal loading with shear strain percentages of 25%, 35%, and 45%, and subjected to cyclic loading three times, while the entire loading process remained continuous;

(3) Repeat the above steps for other conditions of horizontal hysteresis loading.

Table 2. Shear test loading conditions for metal rubber bearings

The content of the study	experimental specimens	compressive stress/MPa	shear strain percentage	loading rate /mm/s
Shear strain	MRB1、MRB2	8	25%、35%、45%	2
compressive stress	MRB1、MRB2	4、6、8、10	25%	2

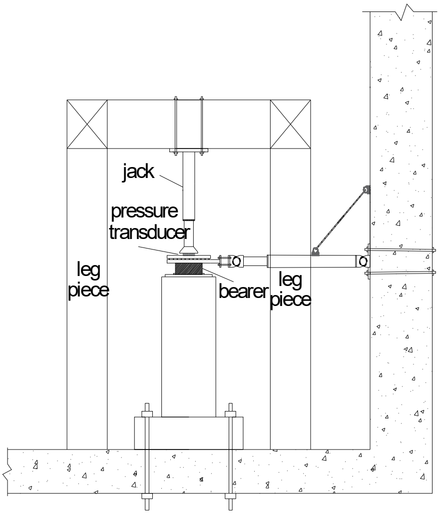


Fig. 2. Loading diagram of shear test

Fig. 3. Physical diagram of shear test loading

2.3 Fatigue Test

Taking the highway standard span 10m hollow slab simply supported beam bridge as the engineering background, the PME-50A fatigue testing machine (Figure 4) was used to carry out the vertical fatigue test (Figure 5) for the two groups of metal rubber bearings, with reference to the specification of Rubber Bearings Part 1-Test Methods for Seismic Isolation Rubber Bearings (GB/T 20688.1-2007)[11].The test loading program was as follows.

(1) Sine wave is used as the test loading waveform, the loading frequency is 5Hz, and the total number of repeated loading times is 2 million;

(2) The minimum stress is the permanent load (structural weight) of the background simply-supported beam, and the maximum stress is taken as the sum of the permanent load and variable load (lane load) of the simply-supported beam, and the specific loading stress is shown in Table 3.

Table 3. Fatigue test loading stresses

bearing test piece	loading frequency /Hz	permanent load /kN	The sum of permanent load and variable load/kN	minimum stress /MPa	maximum stress /MPa
MRB 1	5	109	217	6.5	10
MRB 2	5	141	217	5.1	10

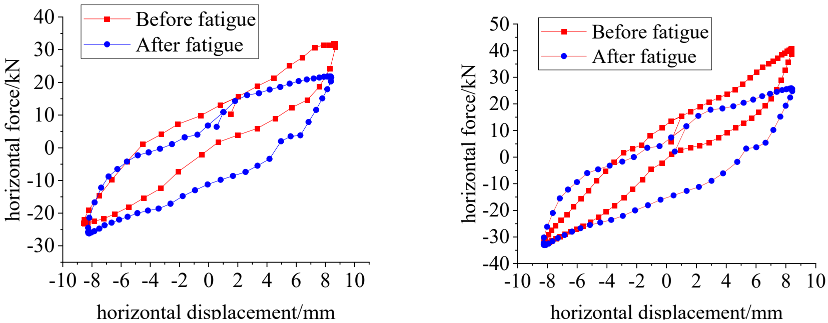
Fig. 4. PME-50A fatigue testing machine

Fig. 5. Fatigue test

3 Test Results and Analysis

3.1 Bearing Hysteresis Curves Before and After Fatigue

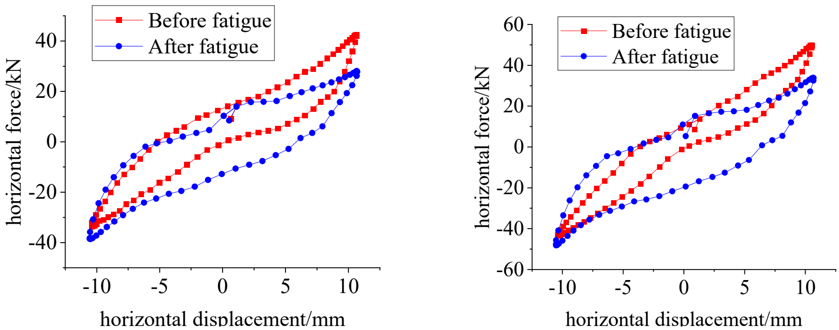
The third cyclic loading shear test data of No. 1 and No. 2 metal rubber bearings were analyzed, and the horizontal force horizontal displacement hysteresis curves were plotted for compressive stresses of 4MPa and 6MPa, respectively, with a shear strain percentage of 25%, as shown in Figure 7.



(a) The compressive stress is 4MPa and the shear strain is 25%.

(b) The compressive stress is 6MPa and the shear strain is 25%.

Fig. 6. Hysteresis Curve before and after Fatigue of MRB 1



(a) The compressive stress is 4MPa and the shear strain is 25%.

(b) The compressive stress is 6MPa and the shear strain is 25%.

Fig. 7. Hysteresis Curve before and after Fatigue of MRB 2

From Figures 6 and 7, it can be seen that compared to before fatigue, the shear hysteresis curves of the two groups of supports after fatigue become more full. This is because after fatigue testing, the internal metal wires of the metal rubber bearings have changed from smooth connections before fatigue testing to wear connections after fatigue, increasing the hooking and friction between the metal wires, resulting in an increase in support hysteresis energy consumption and an increase in hysteresis curve area. After fatigue testing, the stiffness of the support significantly decreased after yielding, while there was no significant change in the stiffness before yielding. In addition, the maximum horizontal bearing capacity of the support on the pushed side was reduced, and the shear hysteresis curve showed an asymmetric shape compared to the basically symmetrical shuttle deformation before fatigue.

3.2 Effect of Fatigue on the Shear Performance of Bearings

In order to study the influence of fatigue on the shear performance of metal rubber bridge bearings, the following mechanical parameters are selected for analysis:(1) Energy dissipation W, the area surrounded by the horizontal force-horizontal displacement shear hysteresis curve of the bearing, reflecting the horizontal energy dissipation capacity of the bearing;(2) The equivalent stiffness is an important index to reflect the bearing capacity of the bearing.(3) Post-yield stiffness,(4) Equivalent damping ratio, reflecting the damping performance of the bearing,please refer to reference 2 for specific calculation methods. The mechanical parameters of shear performance before and after fatigue of bearing under compressive stress of 4MPa, 6MPa,and shear strain percentage 25% are calculated, as shown in Table 4.

Table 4. Equivalent stiffness of the bearing before and after fatigue

loading conditions		The equivalent stiffness of No.1 metal rubber bearing/kN·mm^{-1}			The equivalent stiffness of No.2 metal rubber bearing//kN·mm^{-1}		
shear strain	Compressive stress/MPa	Before fatigue	After fatigue	Difference	Before fatigue	After fatigue	Difference
25%	4	3.19	2.88	9.72%	3.62	3.14	13.26%
25%	6	4.42	3.54	19.91%	4.47	3.87	13.42%

Table 5. Hysteresis energy dissipation of the bearing before and after fatigue

loading conditions		The Hysteresis energy consumption of No.1 metal rubber bearing /J			The Hysteresis energy consumption of No.2 metal rubber bearing /J		
shear strain	Compressive stress/MPa	Before fatigue	After fatigue	Difference	Before fatigue	After fatigue	Difference
25%	4	224	275	-22.77%	299	406	-35.79%
25%	6	212	326	-53.77%	282	499	-76.95%

Table 6. Equivalent damping ratio of the bearing before and after fatigue

loading conditions		The equivalent damping ratio of No.1 metal rubber bearing			The equivalent damping ratio of No.1 metal rubber bearing		
shear strain	Compressive stress/MPa	Before fatigue	After fatigue	Difference	Before fatigue	After fatigue	Difference
25%	4	0.15	0.22	-46.70%	0.12	0.18	-50.00%
25%	6	0.11	0.21	-90.90%	0.09	0.18	-100.00%

Table 7. Stiffness of the bearing after yielding before and after fatigue

loading conditions		The post yield stiffness of No.1 metal rubber bearing /kN·mm^{-1}			The post yield stiffness of No.1 metal rubber bearing /kN·mm^{-1}		
shear strain	Compres-sive stress/MPa	Before fatigue	After fatigue	Differ-ence	Before fatigue	After fatigue	Differ-ence
25%	4	2.75	1.80	34.6%	2.88	2.05	28.8%
25%	6	3.63	2.23	38.6%	3.96	2.44	38.4%

Note: The difference is equal to the difference between before and after fatigue, and then divided by the difference before fatigue

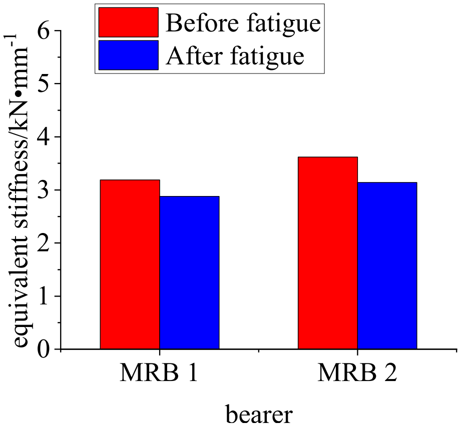


Fig. 8. Comparison of the equivalent stiffness of the bearing before and after fatigue

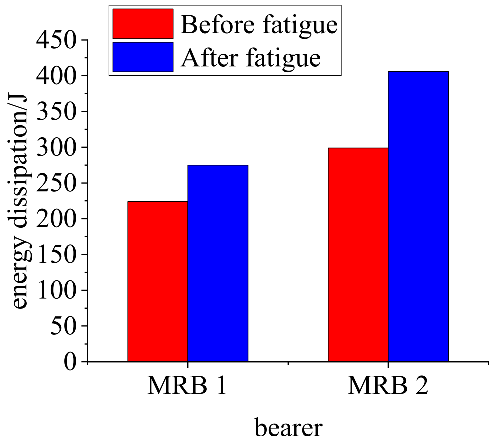


Fig. 9. Comparison of hysteretic energy dissipation the bearing before and after fatigue

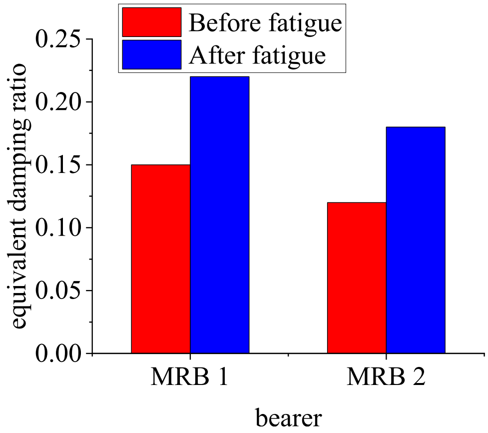


Fig. 10. Comparison of the equivalent damping ratio of the bearing before and after fatigue

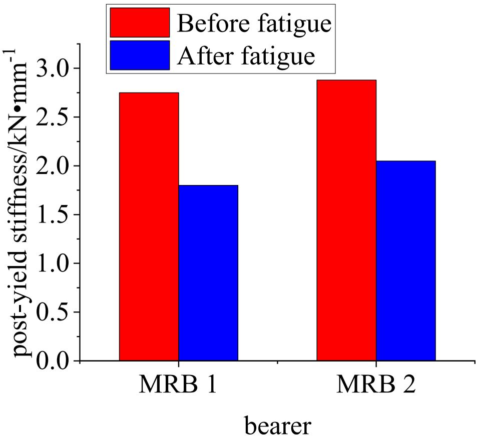


Fig. 11. Comparison of stiffness of the bearing after yielding before and after fatigue

From Figures 7, 8, 9, 10, and 11, as well as Tables 4, 5, 6, and 7, it can be observed that under the loading conditions of compressive stress of 4MPa and 6MPa, and shear strain percentage of 25%,the equivalent stiffness of No.1 and No.2 metal rubber bearings before fatigue decreased by 9.72%,19.91%, 13.26%, and 13.42% compared to before fatigue, with a decrease range of 9% to 20%.The hysteresis energy consumption and equivalent damping of the No.1 and No.2 metal rubber bearings have increased compared to before fatigue.Under the loading conditions of compressive stress of 4MPa and 6MPa, and shear strain percentage of 25%, the energy consumption of the two groups of metal rubber bearings has increased by 22.77%, 53.77%, 35.79%, and 76.95% respectively compared to before fatigue. After fatigue, their equivalent damping ratio has increased by 45% to 100%, and the stiffness after yield has also decreased. The stiffness after yield has decreased by 28% to 38%.

4 Conclusion

This article conducts shear tests and fatigue tests on metal rubber bearings, and analyzes and compares their shear mechanical performance parameters before and after fatigue tests under the same loading condition. The following conclusions are drawn:

(1) After fatigue testing, the frictional force between the internal metal wires of the metal rubber bearing increases, leading to an increase in the area of the hysteresis curve and a fuller hysteresis curve. The hysteresis curve changes from a basically symmetrical shuttle shape before fatigue to an asymmetric shape after fatigue.

(2) After fatigue testing, the equivalent stiffness and post yield stiffness of the metal rubber bearing have decreased, while the equivalent damping ratio and energy dissipation have increased compared to before fatigue, thereby improving the horizontal energy dissipation capacity and damping performance of the metal rubber bearing.

References

1. Zhang Yingzhou. Experimental study on mechanical properties of new bridge bearings [D].Lanzhou Jiaotong University,2019
2. Du Qian, Xia Xiushen. Experimental study on shear performance of metal rubber bearing [J].Journal of Earthquake Engineering,2021,43(05):1176-1182 +1196.
3. Xia Xiushen, Zhang Yingzhou.Experimental study on compression perfor-mance of metal rubber bearing [J].Journal of Applied Basic and Engineering Sciences,2021,29(04):952-960.
4. Xia Xiushen, Zhang Yingzhou, Du Qian. Experimental study on rotation performance of metal rubber bridge bearing [J].Journal of Lanzhou Jiaotong University,2021,40(01):1-5.
5. Jiang Jian. Study on isolation performance of cylindrical metal rubber isolation bearing [D].Seismological Research Institute of China Earthquake Administration,2014.
6. Sun Lin, Xia Xiushen, Ji Lei and so on. Experimental Study on Hysteretic Behavior of Metal Rubber Bridge Bearings [J].Highway Traffic Technology, 2023,40(08):96-101.
7. S.V.K ,S.V.G ,D.I.V ,et al.Microstructure and properties of layered metal/rubber composit es subjected to cyclic and impact loading[J].Composite Structures,2022,285.
8. Svetlana K ,Sergei G ,Pavel N ,et al.Investigation of Mechanical Behavior of Layered Metal Rubber Composites Based on Steel and Aluminum Alloy[J].Key Engineering Materials,2021,6 26487-94.
9. Burian A Y ,Silkov V M .Conical metal-rubber support with quasi-zero stiffness effect[J].Journal of Physics: Conference Series,2019,1210(1):012027 (5pp).
10. Zhizhkin M A ,Zrelov A V ,Zrelov V V ,et al.Rotor Sealings based on a Metal–Rubber El astic Porous Material for Turbomachinery[J].Journal of Friction and Wear,2018,39(3):259-263.
11. GB/T20688.1-2007.Rubber bearings-Part 1:Test methods for seismic isolation rubber bearings[S].Beijing:China Standards Press,2007.