

Service Performance Evaluation of Rubber Floating Slab Track for Metro in Operation



Qiuyi Li and Wei Luo

Abstract Guangzhou metro line 1 is one of the first to adopt floating slab track in the Chinese mainland, it has been in operation for more than 20 years up to now. In order to obtain the vibration reduction performance of the floating slab track after long service, systematic field test and laboratory test are carried out. The results show that: (1) The rubber bearing of floating slab track keeps good appearance. (2) The measurement results of shore hardness and elongation at break show that, the rubber bearing has a certain degree of hardening after long service. Other mechanical properties of the rubber bearing still meet the design requirements. (3) The first natural frequency of the floating slab track is 33.9 Hz, its vibration reduction effect keeps good, the test result is 12.9 dB. The effective damping frequency band of the floating slab track is above 35 Hz. (4) The vertical dynamic displacement amplitude of rail and track bed is lower than the limit value given in relevant specifications. (5) The test results show that after 20 years of service, the floating slab track is in good condition, it's still qualified to maintain normal service.

Keywords Metro · Floating slab track · Vibration reduction · Service performance · Experimental study

1 Introduction

In 1997, the floating slab track was introduced into China (mainland) and first used in Guangzhou metro line 1 [1–4]. Up to now, its service time has been more than 20 years, the operation of 6 type A trains. The floating slab track of Guangzhou metro line 1 uses rubber bearings as vibration isolation elements. Considering the extreme environment (wet, ozone, etc.) in underground line tunnels, the aging, deformation and damage that may occur in the long-term service of rubber materials are directly

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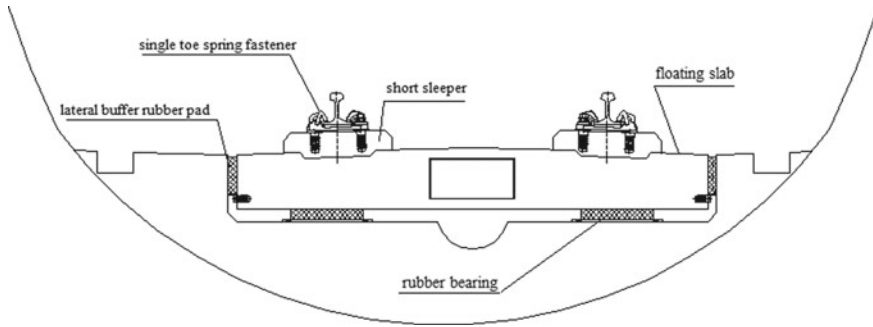


Fig. 1 Typical cross section of floating slab track of Guangzhou metro line 1

related to the safe service and vibration reduction performance of the floating slab track [5–7]. It is necessary to evaluate the performance of the floating slab track comprehensively and systematically after long service.

The research team to which the author belongs has carried out an experimental study on the floating slab track of Guangzhou metro line 1.

2 Design Overview of Floating Slab Track

A floating slab track of 1110 m is laid on the main line of Guangzhou metro line 1, which is a single rubber bearing floating slab track. Each floating slab is 2.95 m in length, 2.8 m in width, 0.335 m in thickness at the center and 0.3 m at the edge, and weighs about 6.5 t. The bottom of the standard floating slab is prefabricated with 4 circular grooves, and 4 rubber bearings are installed. The rubber bearings are natural rubber products, with a diameter of 400 mm and a thickness of 75 mm. The design static stiffness of the rubber bearing is 12–16 kN/mm, and the lateral static stiffness of the lateral buffer rubber pad is 3.2–4.2 kN/mm [2]. The single toe spring fastener is adopted for the section of floating slab track. The typical cross section of the track is shown in Fig. 1.

3 Field Test and Analysis

3.1 Appearance Detection of Rubber Bearings

Electronic video endoscope was used to detect the appearance of rubber bearings. As shown in Fig. 2, the electronic video industrial endoscope consists of a display, a joystick, a cable and a probe, among which the probe is generally composed of two parts: a light source and a miniature camera. The endoscope works as follows:

Fig. 2 Electronic video endoscope for industrial use



A tiny camera takes pictures of the scene under the light source, and then converts the images into digital signals that are transmitted by cable to the display screen [8].

By using the sampling method of “separate one and pump one” (separate one floating slab and pump one floating slab for detection), 50% of the floating slab track of line 1 was extracted and its rubber bearings were tested. The appearance images of the rubber bearing obtained on site are shown in Figs. 3 and 4. The main conclusions of appearance detection are as follows:

- (1) No obvious cracks were observed;
- (2) No obvious damaged blocks were found;
- (3) There was no obvious void or joint between the rubber bearing and the bed slab, and between the tunnel base;
- (4) There is no obvious inclination and deviation of the rubber bearing;
- (5) During the test, the rubber bearing is not wet and soaked in water;
- (6) Surface cracking and peeling of some rubber bearings, accounting for about 11% of the total amount detected.

Fig. 3 Appearance detection image 1 of rubber bearing

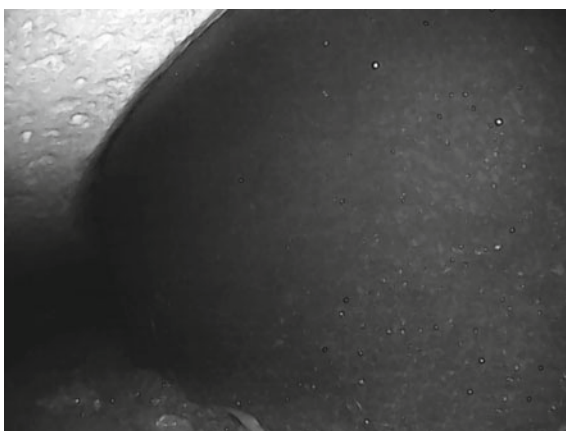


Fig. 4 Appearance detection image 2 of rubber bearing



3.2 Laboratory Test of Rubber Bearings

Three rubber bearing samples were obtained from line 1 in the way of “take one for one”, and then the mechanical property parameters of rubber bearings were tested in the laboratory. The test items included: appearance size, Shore hardness, tensile strength, elongation at break, permanent deformation under constant compression, static stiffness and dynamic stiffness. Figure 5 shows the rubber bearing sample, and the rubber bearing stiffness testing device is shown in Fig. 6.

The laboratory test results of the mechanical properties of the rubber bearing are shown in Table 1. The difference between the size of the bearing and the design size after permanent deformation is less than 1 mm, and the tensile strength and static stiffness still meet the design requirements. The Shaw hardness value of the rubber bearing material is about 15% higher than the designed upper limit value, and the elongation at break is about 9.5% lower than the designed lower limit value, indicating that the rubber bearing material has a certain degree of hardening after a long time of service.

Fig. 5 Rubber bearing sample

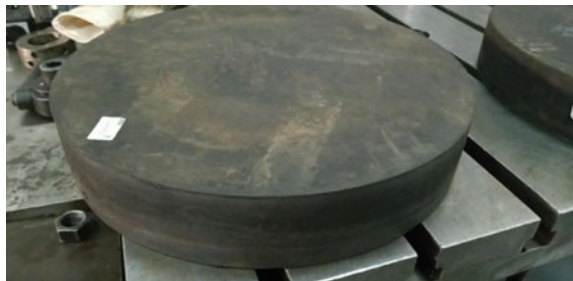


Fig. 6 Rubber bearing stiffness detection device



Table 1 Laboratory test results of mechanical properties of rubber bearings

Test items		Test results	Design requirements
Appearance size	Diameter/mm	400.00~400.56	400
	Thickness /mm	74.20~74.82	75, After 1×10^7 cycles of load, the change value is no more than 1 mm
Shore hardness/shore A		52	40 ± 5
Tensile strength/MPa		22.8	≥ 20
Elongation at break/%		543	≥ 600
Constant compression permanent deformation		24%	–
Stiffness	Static stiffness/kN/mm	15.22	10~16
	Static and static stiffness ratio	1.343~1.442	–

3.3 Natural Vibration Characteristics of Floating Slab Track

In this study, the field test of the vibration characteristics of the floating slab track was completed. The block length of line 1 floating slab track is 2.95 m. Three rows of measuring points are arranged, as shown in Fig. 7, with 6 measuring points in each row and 1 vertical acceleration sensor installed in each measuring point. The rigid force hammer is used as the excitation equipment, as shown in Fig. 8, and the measuring points 3, 4, 15 and 16 are used as the four hammering points.

The random subspace method is used to identify the modes and modal parameters of the floating slab track [9]. The natural vibration frequency and damping test results corresponding to modes 1–7 of line 1 floating slab track are shown in Table 2. The first order natural frequency is 33.9 Hz, and the corresponding structural damping is 6.866%. Figure 10 shows the mode shape correlation matrix of modes 1–7. The main diagonal elements of the matrix are all 1, and the values of the other

Fig. 7 Layout diagram of measuring points for testing natural vibration characteristics of floating slab track

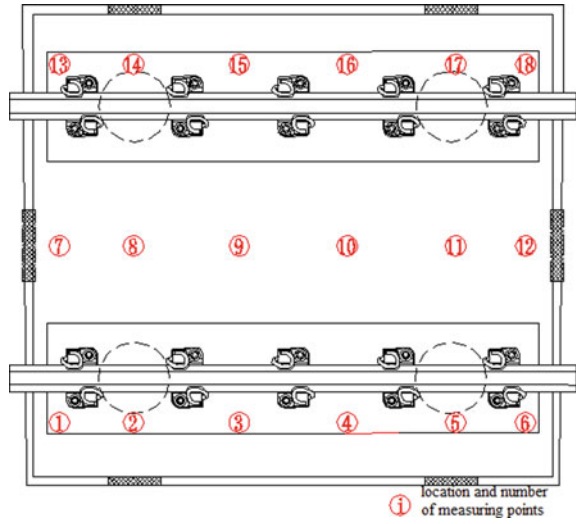


Fig. 8 Field test of free vibration characteristics of floating slab gauge bed



Table 2 Natural frequencies and damping of floating slab track of order 1–7

Order number	Frequency/Hz	Damping/%
1	33.903	6.866
2	46.235	6.924
3	114.103	3.151
4	143.840	3.734
5	185.530	0.977
6	253.801	1.695
7	263.984	1.397

elements are very small, which indicates that the mode shapes of modes 1–7 obtained through identification have good orthogonality, and the identification results have high reliability.

3.4 Damping Effect of Floating Slab Track

Layout of Test Section and Measuring Point. Combined with the data of lines and running vehicles, this study selected two sections as shown in Table 3 to carry out field tests. The acceleration measurement point used to evaluate the vibration reduction effect of the floating slab track is arranged at the side wall of the tunnel 1.5 m away from the top surface of the rail, as shown in Fig. 9. The acceleration sensor used has been verified as qualified product by the third party testing institution, with a range of 10 g and a resolution of 0.0004 m/s².

The Measurement Value. In the Standards of *Technical Guidelines for Environmental Impact Assessment for Urban Rail Transit (HJ453-2018)*, *Standard for Environmental Vibration in Urban Areas (GB10070-88)*, and *Measurement Method for Environmental Vibration in Urban Areas (GB10071-88)*, the measurement value is the maximum value of V_{L_z} vibration level in the process of train passing, which is shown as $V_{L_{zmax}}$ in Fig. 11.

The frequency range of the analysis was 1–80 Hz, and the weighting factor was the whole-body Z-weighting factor stipulated by *ISO2631/1-1985*, as shown in Table 4.

Table 3 Profiles of each test section

Section number	The speed of the car	Straight/curve	Type of orbit	Note
Section 1	46 km/h	A straight line	Ordinary orbit	They are a group of contrast cross sections
Section 2	48 km/h	A straight line	Floating slab track	

Fig. 9 Vertical acceleration sensor on tunnel side wall installed on site

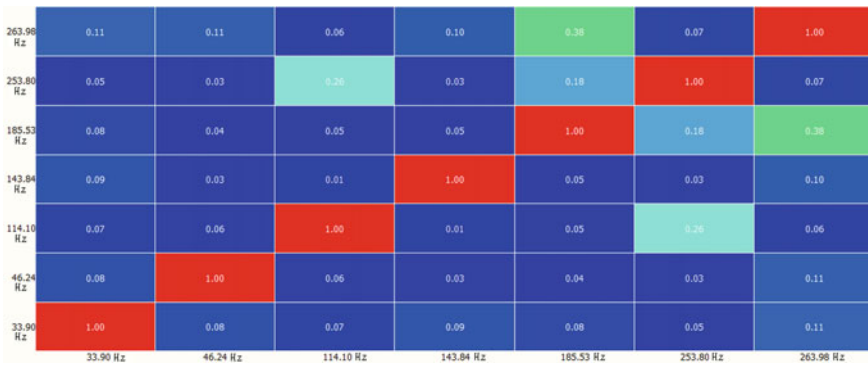


Fig. 10 Mode correlation matrix

Fig. 11 Typical time history curve of VL_z vibration level during train passing

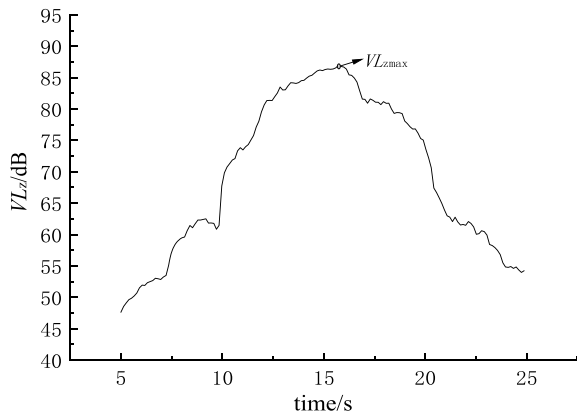


Table 4 Z-weighting factors stipulated in ISO2631/1-1985

Central/Hz	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
Weighting factor	0.5	0.56	0.63	0.71	0.80	0.90	1.0	1.0	1.0	1.0
Central/Hz	10	12.5	16	20	25	31.5	40	50	63	80
Weighting factor	0.8	0.63	0.5	0.4	0.315	0.25	0.2	0.16	0.125	0.1

Aiming at the vibration acceleration data of a passing event, it is divided into several 1 s length data paragraphs (which can consider certain overlap coefficient). The method of calculating the VL_z vibration level of each paragraph data is detailed as follows.

Fourier transform is performed on the data of time history of vibration acceleration to find out the vibration components in the frequency band corresponding to each central frequency, and inverse Fourier transform is performed on the vibration components identified. Then, the effective value of acceleration a_w corresponding to each central frequency can be obtained according to Eq. (1).

$$a_w = \left[\frac{1}{T} \int_0^T a_w^2(t) dt \right]^{\frac{1}{2}} \tag{1}$$

where, $a_w(t)$ is the acceleration data whose frequency is in the frequency band corresponding to a certain central frequency, and is the time function; T is the length of measurement time.

Further, the calculation formula of VL_z vibration level is as follows:

$$VL_z = 20 \log_{10} \left\{ \frac{\left[\sum_{j=1}^n (W_j \times a_{wj})^2 \right]^{\frac{1}{2}}}{a_0} \right\} \tag{2}$$

where: W_j is the weighting factor corresponding to the J th central frequency; a_{wj} is the effective value of acceleration in the frequency band corresponding to the J th central frequency. a_0 is the base acceleration, $a_0 = 10^{-6} \text{m/s}^2$

The damping effect Δ of floating slab track is calculated by the following formula:

$$\Delta = VL_{z \max 1} - VL_{z \max 2} \tag{3}$$

In the formula, $VL_{z \max 1}$ is the maximum value of VL_z vibration level in the passing process of trains in the ordinary track section, and $VL_{z \max 2}$ is the maximum value of VL_z vibration level in the passing process of trains in the floating slab track section.

Test Results. When the train passes through, the frequency domain distribution comparison of vertical acceleration level on the tunnel side walls of Sections 1 and 2 is shown in Fig. 12. Compared with the ordinary track, the vertical acceleration

Fig. 12 Frequency domain distribution curve of vertical acceleration level of tunnel sidewall of Sections 1 and 2

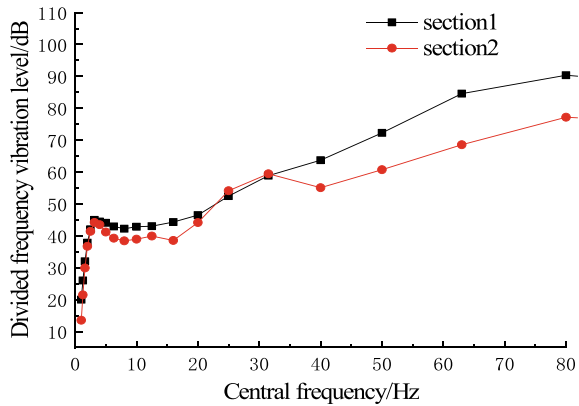


Table 5 VL_{zmax} calculation values of tunnel sidewall of Sections 1 and 2

Project	Section 1 VL_{zmax1}	Section 2 VL_{zmax2}	Damping effect Δ
VL_{zmax}/dB	76.2	63.3	12.9

level of the tunnel side walls is significantly reduced by the floating slab track. The corresponding frequency is 63 Hz.

VL_{zmax} calculation values of tunnel sidewall of Sections 1 and 2 are shown in Table 5. The test result of damping effect of floating ballast bed is 12.9 dB.

3.5 Dynamic Displacement of Floating Slab Track

At the location of Section 2 in Table 3, the floating slab track is selected to carry out dynamic displacement test. The measuring points are arranged as shown in Fig. 14, where the rail displacement is the relative displacement between the rail and the track bed, and the track bed displacement is the relative displacement between the track bed and the tunnel backfill layer. The displacement sensor is verified as qualified product by the third party testing institution, the measuring range is ± 10 mm, and the accuracy can reach 0.01 mm. The typical time-history curve of the dynamic displacement of the floating plate track bed at the time when the train passes through is shown in Fig. 13. The peaks of the dynamic displacement curve reflect the impact of the wheel when it passes through the test section. The statistical values of dynamic displacement amplitude of rail and track bed are shown in Table 6. The average vertical dynamic displacement amplitude of floating plate is 1.32 mm at the end of the slab and 1.21 mm in the middle of the slab, which is less than the limit value of 3 mm given in Technical Specification for Floating slab track (CJJ/T 191-2012). The average vertical dynamic displacement amplitude of the rail is 3.5 mm at the end of

Fig. 13 Typical time-history curve of dynamic displacement of floating slab track (vertical)

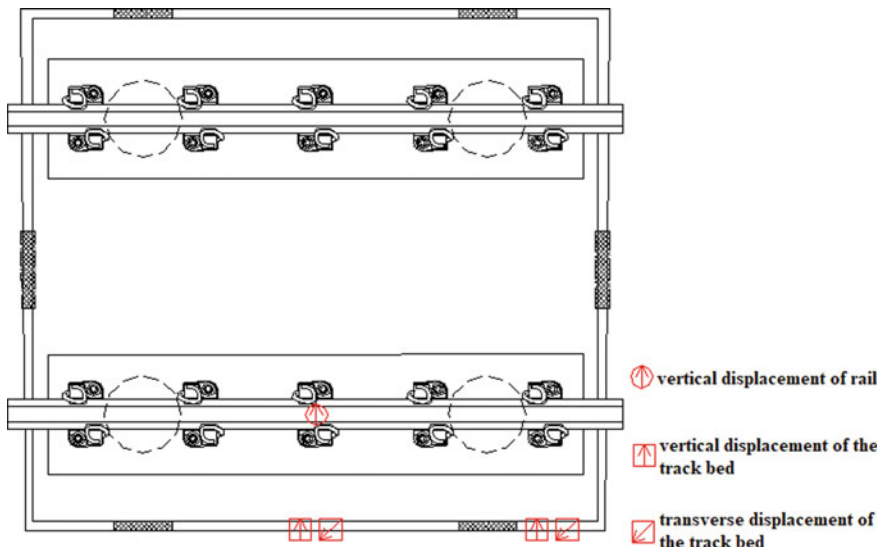
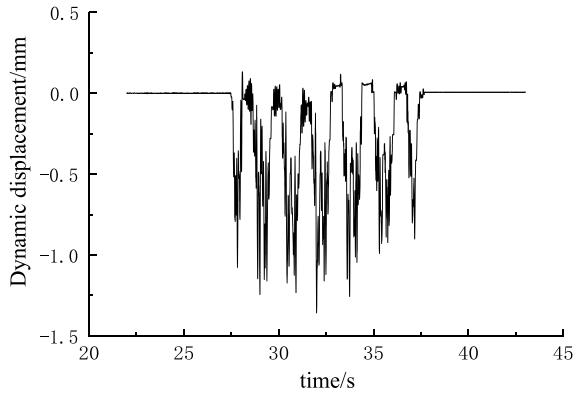


Fig. 14 Plane layout of dynamic displacement measuring points of floating slab track

the slab and 2.5 mm in the middle of the slab, which is less than the limit value of 4 mm given in Technical Specification for Floating slab track (CJJ/T 191–2012).

4 Conclusion

Combined with the laboratory and field tests, the current performance of the floating slab track of Guangzhou metro line 1 was systematically studied. The main conclusions were drawn as follows:

Table 6 Statistical table of dynamic displacement amplitude of rail and track bed (unit: mm)

Sample number	Vertical relative displacement of rail		Vertical displacement of floating slab		Transverse displacement of floating slab		Vertical absolute displacement of rail	
	The end of sab	The middle of sab	The end of sab	The middle of sab	The end of sab	The middle of sab	The end of sab	The middle of sab
1	-2.1	-1.1	-1.1	-1.0	-0.9	-1.1	-3.2	-2.1
2	-2.2	-1.1	-1.3	-1.1	-0.9	-0.9	-3.5	-2.2
3	-2.1	-1.1	-1.2	-1.2	-1.0	-1.1	-3.3	-2.2
4	-2.0	-1.2	-1.2	-1.2	-1.1	-1.0	-3.2	-2.4
5	-2.2	-1.3	-1.4	-1.3	-1.1	-1.1	-3.6	-2.6
6	-2.4	-1.2	-1.5	-1.3	-0.9	-0.8	-3.9	-2.5
7	-2.1	-1.1	-1.4	-1.2	-1.0	-0.8	-3.4	-2.3
8	-2.2	-1.2	-1.3	-1.1	-0.9	-0.9	-3.4	-2.2
9	-2.2	-1.2	-1.3	-1.2	-1.0	-1.0	-3.5	-2.3
10	-2.3	-1.3	-1.3	-1.2	-0.9	-0.9	-3.5	-2.6
11	-2.3	-1.3	-1.3	-1.1	-1.0	-0.9	-3.5	-2.4
12	-2.2	-1.3	-1.3	-1.2	-1.1	-1.1	-3.6	-2.5
13	-2.4	-1.4	-1.5	-1.3	-1.2	-1.2	-3.8	-2.7
14	-2.3	-1.4	-1.4	-1.3	-1.2	-1.2	-3.7	-2.7
15	-2.2	-1.3	-1.4	-1.2	-1.0	-1.0	-3.6	-2.5
16	-2.2	-1.3	-1.2	-1.2	-1.0	-1.1	-3.4	-2.5
17	-2.3	-1.2	-1.4	-1.3	-1.0	-0.9	-3.7	-2.5
18	2.6	-1.6	-1.7	-1.5	-0.8	-0.8	-4.3	-3.2
19	-2.3	-1.4	-1.3	-1.1	-0.9	-0.8	-3.5	-2.5
20	-2.0	-1.1	-1.1	-1.0	-0.9	-0.8	-3.1	-2.1
Mean value	-2.2	-1.2	-1.3	-1.2	-1.0	-1.0	-3.5	-2.5

- (1) The rubber bearing of the floating slab track is generally in good appearance except for a few surface cracks and peeling.
- (2) The mechanical properties of the rubber bearing of the floating slab track still meet the design requirements, except that the test results of Shore Hardness and tensile elongation reflect a certain degree of hardening.
- (3) The first natural frequency test result of the floating slab track is 33.9 Hz, and the vibration reduction effect is maintained well, which is 12.9 dB. Above 35 Hz is the effective vibration reduction frequency band of the floating slab track.
- (4) When the train passes, the vertical displacement amplitude of the rail and track in the section of floating slab track is lower than the relevant limit given in the *Technical Specification for Floating Slab Track*.

- (5) The test results of various indexes show that, after 20 years of service, the state of the floating slab track is generally good, and it has the conditions to maintain normal service.

References

1. Yao JC, Yang YQ, Sun N (2003) Development of floating slab track structure. *China Railway* 7:20–22
2. Yan H, Yao L (2002) Design of floating slab track. *J Railway Eng Soc* 4:12–15
3. Wang D (2005) Analysis on vibration characteristics of floating slab track of Guangzhou Metro Line 2. Southwest Jiaotong University
4. Xu ZQ, Yao JC, Yang YT (2003) Rubber support floating slab track structure dynamic calculation and analysis. *Railway Stand Des* 8:11–13
5. Zhu YZ (2020) Study on aging characteristics of rubber under prestress. Harbin Institute of Technology University
6. Dong ZH, Zhang JQ, Wei H (2020) Shear property of aging ordinary slab rubber bearing research on energy. *Eng Mech* 37(S1):208–216
7. Jin QQ, Zheng XT, Wu DM (2020) Natural rubber aging time on rubber springs Influence of mechanical properties. *Plastics* 4:131–134
8. Han FD (2020) Application of endoscope detection in internal inspection of power plant boiler. *China Spec Equip Saf* 3:44–48
9. Tao J (2009) Structural modal analysis and damage recognition based on random subspace method. Chongqing University

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