# Performance of Polyurethane Polymer in the Transition Zones of Ballasted and Ballastless Track

Qi Wei[1(✉)] and Li Cheng-hui[2]

[1] Key Laboratory of High-Speed Railway Engineering, Ministry of Education, Southwest Jiaotong University, Chengdu 610031, China
qw9199@126.com

[2] School of Civil Engineering, Southwest Jiaotong University, Chengdu, China

**Abstract.** Track disease significantly increased in the transition zones between ballasted and ballastless track. It is triggered by abrupt variation in the track's vertical stiffness due to different support conditions. To achieve the transition of track stiffness, the ballast bed with polyurethane polymer scheme was proposed. In this scheme, the changed of ballast bed stiffness change quantity was decided by the bonding area of ballast bed with polyurethane polymer. In the test section, three bond forms of ballast bed were adopted—full bonding section, partial bonding section and local bonding section. The field test results were as follows: the vertical stiffness of ballast bed with polyurethane polymer was increased more than 5 times, 3 times, 2 times. The vertical and horizontal resistance of ballast bed was increased more than 8 times, 4 times, 3 times. With the increase of track stiffness, the vertical force of wheel-rail and the vertical vibration of rail increase, the vertical displacement of rail reduce, the vertical displacement and vertical vibration of sleeper reduce. Merely citing the vertical displacement of rail as typical, it was reduced by 25%, 16%, 3%. After the static and dynamic test, we can conclude that performance of polyurethane polymer in the transition zones can achieve the transition of ballast bed from low stiffness to high stiffness.

## 1 Introduction

Track diseases in the transition of ballasted and ballastless track are significantly increased, such as sleeper damage, ballast crusher, slab cracking, etc. It is caused by abrupt variation in the track's vertical stiffness due to different support conditions [1–3]. Heavy haul railway in China mainly used in ballasted track, but its standard provides that ballastless track need to be used in the long tunnel and set transition section of track structure between ballasted track and ballastless track. In China, a large number of railway lines have been build and planned, and the transition zones appeared inevitably. In order to reduce the track diseases, it need to set a proper track transition section.

There are many ways to improve transition zones of ballasted and ballastless track, such as adding auxiliary rail, widen and extended sleeper, decreases sleeper spacing, increasing the thickness of ballast, etc. [4]. The change of track structure affected the


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maintenance operations, because of the widely application of standard mechanical equipment in Chinese railway line, then these treating measures have been rarely used. At present, ballast stiffness transition and fastener stiffness transition have been applied gradually, due to its simple manipulation and easy change of the track stiffness.

Asphalt, epoxy resin and polyurethane polymer can change ballast stiffness. Asphalt has low heat stability and requires high foundation drainage, so it is gradually being eliminated. Epoxy resin has poor impact resistance and easy to crack, so it is not application. Polyurethane polymer has good elasticity, toughness and plastic, and it can change ballast stiffness by control adhesive section of ballast bed, so it is gradually being applied.

The application of polyurethane polymer has been used in United Kingdom, Germany, China, etc. Since 1990s, Peter. K. Woodward has been carried out XiTRACK Technique, and conducted indoor and field testing. XiTRACK is a patented technique that has been designed to enhance the engineering properties of the railway track. It has been successfully applied to reinforce the track bed's stabilization on the West Coast Main Line near Bletchley, and fixed geometry of ballasted in tunnels, high-speed turnouts, bridge transitions, crossings and turnouts. After applied XiTRACK, line disease problems have been effectively controlled for more than 10 years [5–9]. In China, MOE key laboratory of high-speed railway engineering has done much performance of polyurethane polymer indoor testing, and have introduced a standard [10]. Part of the materials property refer to Tables 1, 2 and 3.

**Table 1.** Performance parameters

| Test item | Performance index |
|---|---|
| Viscosity (MPa·s) | 500–1500 |
| Time of surface drying (h) | $\leq 1$ |
| The polymerization shrinkage mass relate (mm) | $\leq 3$ |

**Table 2.** Mechanical property

| Test item | | Performance index |
|---|---|---|
| Apparent density (g/cm$^3$) | | $1.15 \pm 0.05$ |
| Shore hardness of A type (°) | | $\geq 90$ |
| Bond strength (MPa) | | $\geq 2$ (或底材开裂) |
| Tensile strength (MPa) | | $\geq 13$ |
| Elongation at break (%) | | $\geq 250$ |
| Low-temperature brittleness (°C) | | $\leq -50$ |
| Compressive strength (MPa) | | $\geq 40$ |
| hot air aging (168 h, 90 °C) | Retention percentage of tensile strength | $\geq 70\%$ |
| | Retention percentage of elongation at break | $\geq 70\%$ |

(*continued*)

**Table 2.** (*continued*)

| Test item | | Performance index |
|---|---|---|
| Damp heat aging (80, 95% RH, 168 h) | Retention percentage of tensile strength | ≥ 70% |
| | Retention percentage of elongation at break | ≥ 70% |
| Ultraviolet aging (168 h) | Retention percentage of tensile strength | ≥ 70% |
| | Retention percentage of elongation at break | ≥ 70% |

**Table 3.** The indoor test results of ballasted track supporting stiffness with different cured thickness

| Cured thickness (total thickness is 350 mm) | Primary ballast | Super ballast |
|---|---|---|
| 200 | 120 | 130 |
| 250 | 140 | 160 |
| 350 | 200 | 240 |

Track disease in the transition zones between ballasted and ballastless track is triggered by abrupt variation in the track's vertical stiffness due to different support conditions. XiTRACK Technique can improve the strength and stability of the ballast bed, and it effectively reduced the ballast accumulated deformation, but there is less research in this field. Therefore, it is used for bonding ballast in the transition sections of ballasted and ballastless track to reduce the volume of maintenance, and improve the transport ability, traveling comfort and safety. Up to now, the test section of the application of Polyurethane polymer in the transition of ballasted and ballastless track was established in Datong-Xian line, Haerbin-Dalian line, Chengdu-Qingchengshan line, Shanxi Mid-south-part heavy rail line, etc. (in China), and this test section is located in Shanxi Mid-south-part heavy haul rail line.

Polyurethane polymer in the Transition Zones can be achieved the stiffness transition of ballastless track to ballasted track in theory, so we established the test section to verify it by field test. Field test can further optimize the transition plan, and provide technical support for its large scale promotion. (The flow chart of this paper is shown in Fig. 1).

## 2 Engineering Overview

This test section is located at the entrance of the Hongling tunnel. The length of the ballast bed with polyurethane polymer is 20 m, and they all in the tunnel, see Fig. 2. In order to achieve a gradual transition of the ballasted bed stiffness, the bonding section of the ballasted bed with polyurethane polymer are respectively the full bonding

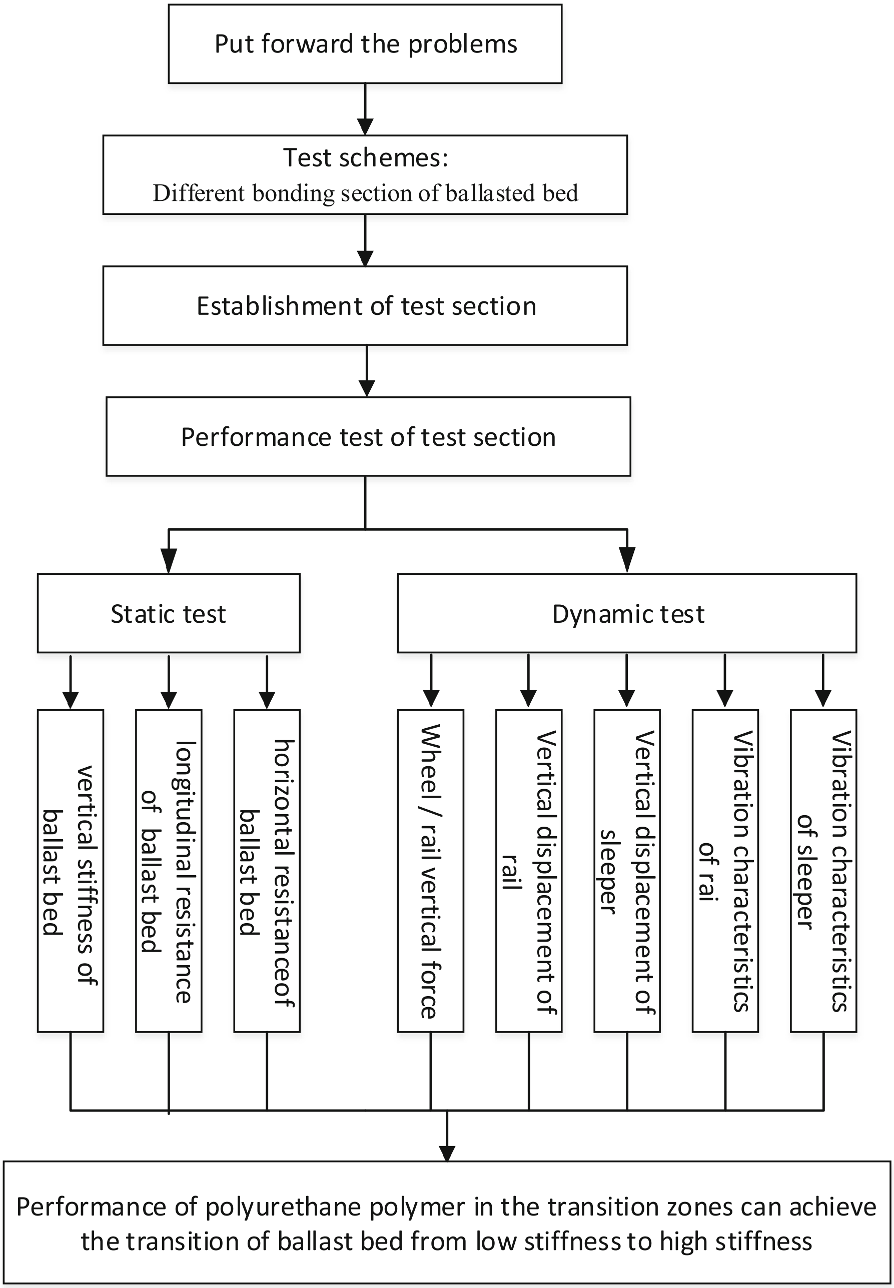



**Fig. 1.** The flowchart

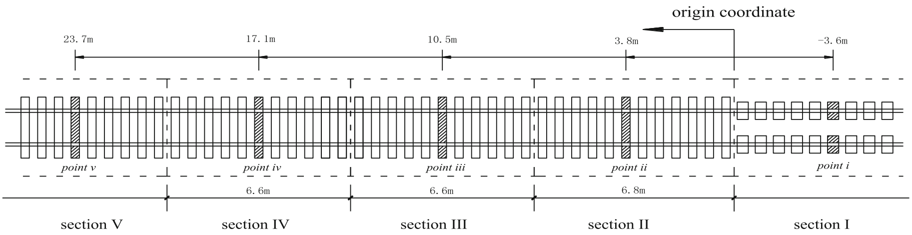
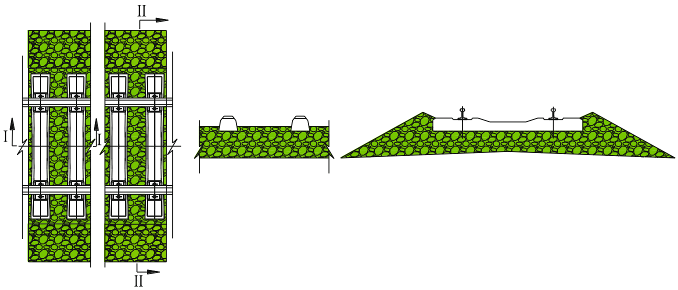
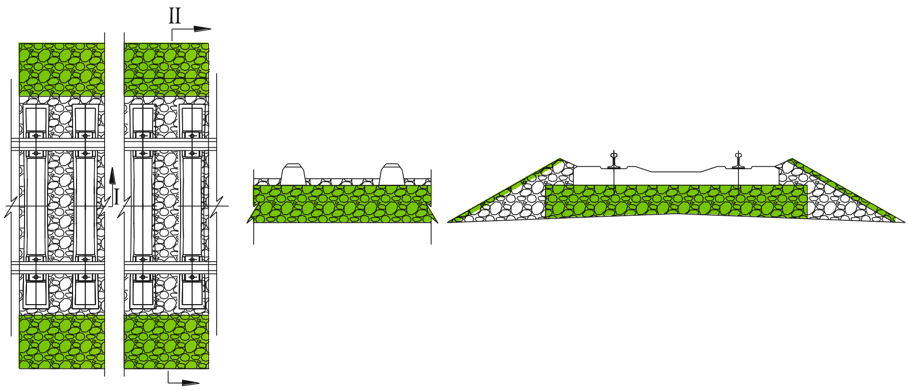



**Fig. 2.** General layout of the site




(a) plane graph (b) skiagraphy section of I-I (c) drawing cross section of II-II

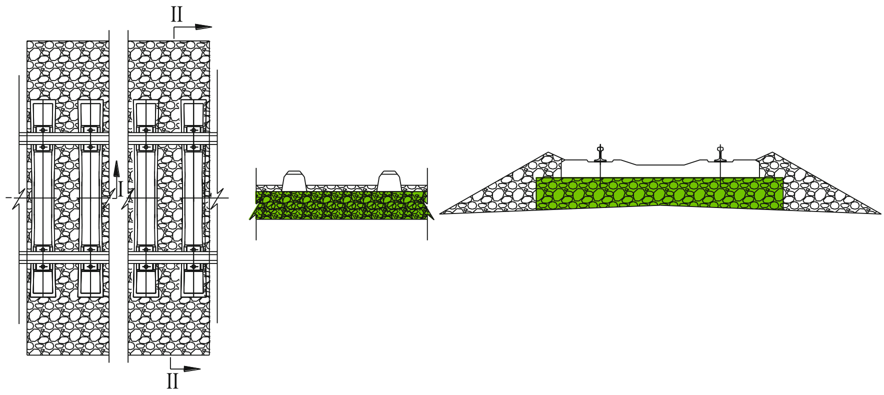
**Fig. 3.** Full bonding section




(a) plane graph (b) skiagraphy section of I-I (c) drawing cross section of II-II

**Fig. 4.** Partial bonding section

section in Fig. 3 (II section in Fig. 2), partial bonding section in Fig. 4 (III section in Fig. 2) and local bonding section in Fig. 5 (IV section in Fig. 2). Section I is low vibration track with ballastless bed, and Sect. II is the ballasted track.




(a) plane graph (b) skiagraphy section of I-I (c) drawing cross section of II-II

**Fig. 5.** Local bonding section

## 3 Test Equipment

The performance of ballast bed was significantly changed after the ballast have been bonded. This test is divided into static test and dynamic test. The static test include the vertical stiffness and longitudinal resistance and horizontal resistance of ballast bed. The dynamic test include the wheel/rail vertical force, the vertical displacement of rail and sleeper, vertical vibration of rail and sleeper.

Static testing instruments are our own design and production. The instruments of ballast bed's vertical stiffness is shown in Fig. 6. In the static test, load was applied by a hydraulic jack, Displacement was tested by the dial gauge.

The dynamic testing instruments include data acquisition equipment, strain gauge, accelerometer, displacement gage, etc. The data acquisition equipment is produced by the company of Integrated Measurement & Control Co, and a CX_5032 instrument was used for the acquisition of wheel/rail force and vertical displacement, and two CS_3008 instruments were used for the acquisition of vertical vibration. Domestic strain gauges which resistance value is 120 Ω are used in wheel/rail force and displacement test (in Fig. 7), and it was connected with full bridge circuit by the Reference of Test method for horizontal force and vertical force of wheel rail (in China).

The test train's height is 5000 t, and its axle load is 30 t. The speed of test train were 60 km/h, 70 km/h, 80 km/h, 90 km/h, and the train ran back and forth many times.

The test section takes the junction of ballasted and ballastless track as the origin of coordinate, and the direction to the ballasted is designated as the positive direction. Data acquisition points were point *i* at −3.6 m, *ii* at 3.8 m, *iii* at 10.5 m, *iv* at 17.1 m, *v* at 23.7 m, as shown in Fig. 2. Because of the existence of discrete in static test, a plurality of sleepers were tested in test section of ballasted bed which have been bonded.

**Fig. 6.** Test of ballast bed's vertical stiffness

**Fig. 7.** Dynamic test

## 4 Analysis of Static Test

The vertical stiffness of ballast bed is shown in Fig. 8, in comparison to the vertical stiffness of ballast bed which apply polyurethane polymer before and after, it increased more than 5 times, 3 times, 2 times at section. II, section III, section IV. It can be concluded that the bonded ballast which under the sleeper played a major role in enhancing the vertical stiffness of ballast bed, and secondly was the bonded ballast which between the sleeper and the shoulder of ballasted bed.

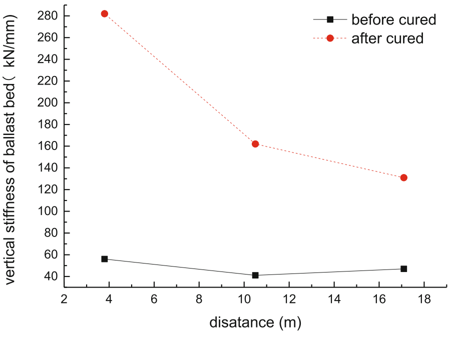



**Fig. 8.** Result of ballast bed's vertical stiffness

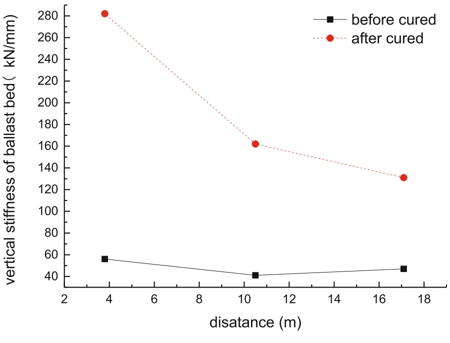



**Fig. 9.** Result of ballast bed's longitudinal resistance

The longitudinal and horizontal resistance of ballast bed is shown in Figs. 9 and 10, its value of ballast bed which apply polyurethane polymer increased more than 8 times, 4 times, 3 times. This is because the bonded ballast which under the sleeper had played the most important par for the increase of ballast bed's resistance, next was the bonded ballast which between the sleeper, and then was the bonded ballast which at the shoulder of ballasted bed.

Test results show that the performance of ballast bed which apply polyurethane polymer has caused huge changes, but the amount change are not the same at different bonding section of the ballasted bed. Performance of polyurethane polymer in the transition zones achieved the transition of ballast bed from low stiffness to high stiffness.

## 5 Analysis of Dynamic Test

### 5.1 Wheel/Rail Vertical Force

The test results as shown in Fig. 11, the wheel/rail force is gradually decreased from section II to section IV, and the value of section II is the largest, and section I is the smallest. Taking the force at speed 80 km/h as an example, the force of section II to section IV increased by 8.05%, 3.94%, 0.97% than section V. The wheel/rail force is influenced by the track stiffness, so we know that the track stiffness gradually decreased from section II to section V. The ballastless track is located in section I, its track stiffness is similar to the ballasted track due to the coordination of the stiffness of fastener and ballast bed. While, at section II, section III, section IV, their ballast bed stiffness increases, and the faster stiffness has not changed because they used the faster for ballasted track, so their wheel/rail forces are larger than section I.

From Fig. 11, we can also know that, the wheel/rail vertical force gradually increased with the increase of vehicle speed. Taking the force at section II as an example, the force increased by 4.6%, 12.9%, 22.4% from speed 60 km/h to 90 km/h.

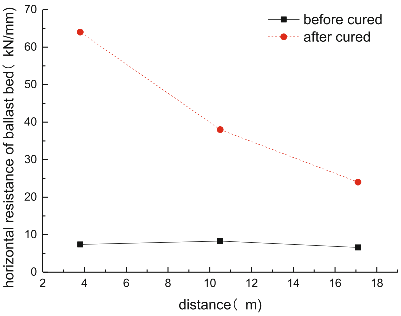



**Fig. 10.** Test result of ballast bed's horizontal resistance

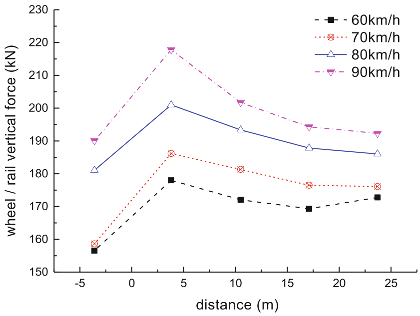



**Fig. 11.** Wheel/rail vertical force

### 5.2 The Vertical Displacement of Rail and Sleeper

The vertical displacement of rail is shown in Fig. 12, its value reduce at the ballast bed which apply polyurethane polymer. The vertical displacement of rail gradually increased from section II to section IV, taking the vertical displacement at speed 80 km/h as an example, their vertical displacement are 0.75 times, 0.84 times, 0.97

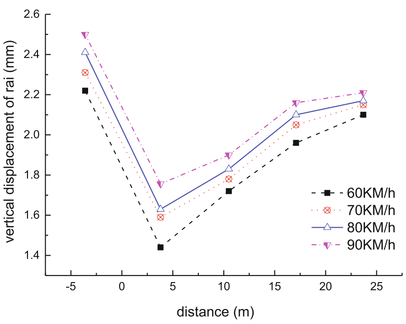



**Fig. 12.** Vertical displacement of rail

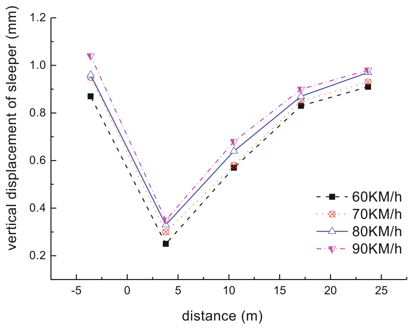



**Fig. 13.** Vertical displacement of sleeper

times of section V. The vertical displacement of rail gradually increased with the increase of vehicle speed. Taking the force at section III as an example, the vertical displacement increased 10% from speed 60 km/h to 90 km/h.

The vertical displacement of sleeper is shown in Fig. 13, its value reduce at the ballast bed which apply polyurethane polymer, especially at section II. The vertical displacement of sleeper at section II only 27.5% of the V section, this is because the full bonding section of ballasted bed had bonded the sleeper and ballast bed as a whole, and the ballast stiffness is greatly improved. Section I is Low Vibration Track, the rubber pad is located under the block-supported, so, its vertical displacement is relatively large. The vertical displacement of sleeper gradually increased with the increase of vehicle speed.

### 5.3 Vertical Vibration of Rail and Sleeper

The vertical vibration of rail is shown in Fig. 14, it is gradually decreased from section II to section IV. Because after the ballast bed applied polyurethane polymer, its integrity has been improved, and then the vertical vibration of ballast bed reduced, so the vertical vibration of rail increased. Because section V is located outside of the tunnel, its vertical vibration is different from other sections. The vertical vibration of rail gradually increased with the increase of vehicle speed. Taking the force at section III as an example, vertical vibration of rail increased 95% from speed 60 km/h to 90 km/h.

The vertical vibration of sleeper is shown in Fig. 15, it is gradually increased from section II to section V. The vertical vibration at section I is larger than section II, because after the ballast bed applied polyurethane polymer, its integrity has been improved, and then its vertical vibration reduced. While, at section I, the rubber pad is located under the block-supported, its vertical vibration relatively larger. The vertical vibration of sleeper gradually increased with the increase of vehicle speed. Taking the force at section III as an example, vertical vibration of rail increased 94% from speed 60 km/h to 90 km/h.

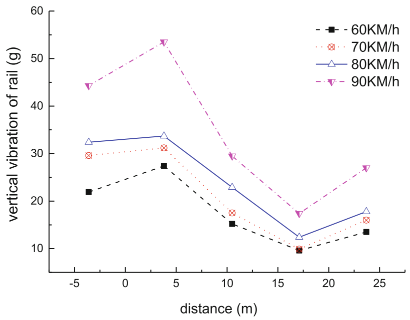



**Fig. 14.** Vibration characteristics of rail

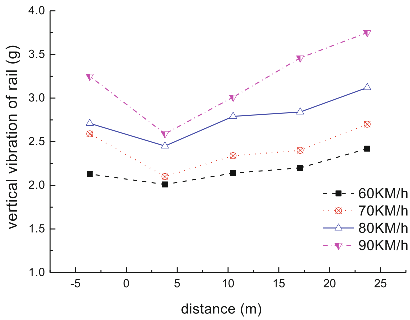



**Fig. 15.** Vibration characteristics of sleeper

## 6 Conclusion

To solve the track diseases in the transition zones of ballasted and ballastless track, a test section that the ballast bed with polyurethane polymer is established. In the test section, three bonded forms of ballast bed were adopted—full bonding section, partial bonding section and local bonding section. In order to detect the transition effect of ballast stiffness at the test section, the static test and dynamic test were carried out in the field. The results were as follows:

(1) Performance of polyurethane polymer in the transition zones can achieve the transition of ballast bed from low stiffness to high stiffness.
(2) The vertical stiffness of ballast bed with polyurethane polymer was increased more than 5 times, 3 times, 2 times. The vertical and horizontal resistance of ballast bed was increased more than 8 times, 4 times, 3 times.
(3) With the increase of track stiffness, the vertical force of wheel-rail and the vertical vibration of rail increase, the vertical displacement of rail reduce, the vertical displacement and vertical vibration of sleeper reduce.
(4) The vertical vibration of sleeper gradually increased with the increase of vehicle speed.

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