A full-section asphalt concrete waterproof sealing structure for the high-speed railway subgrade

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Abstract

Purpose – This study aims to investigate the service performances of a new full-section asphalt concrete waterproof sealing structure (FSACWSS) for the high-speed railway subgrade through on-site tracking, monitoring and post-construction investigation.

Design/methodology/approach – Based on the working state of the waterproof sealing structure, the main functional characteristics were analyzed, and a kind of roller-compacted high elastic modulus asphalt concrete (HEMAC) was designed and evaluated by several groups of laboratory tests. It is applied to an engineering test section, and the long-term performance monitoring and subgrade dynamic performance testing system were installed to track and monitor working performances of the test section and the adjacent contrast section with fiber-reinforced concrete.

Findings – Results show that both the dynamic performance of the track structure and the subgrade in the test section meet the requirements of the specification limits. The water content in the subgrade of the test section is maintained at 8–18%, which is less affected by the weather. However, the water content in the subgrade bed of the contrast section is 10–35%, which fluctuates significantly with the weather. The heat absorption effect of asphalt concrete in the test section makes the temperature of the subgrade at the shoulder larger than that in the contrastive section. The monitoring value of the subgrade vertical deformation in the test section is slightly larger than that in the contrastive section, but all of them meet the limit requirements. The asphalt concrete in the test section is in good contact with the base, and there are no diseases such as looseness or spalling. Only a number of cracks are found at the joints of the base plates. However, there are more longitudinal and lateral cracks in the contrastive section, which seriously affects the waterproof and sealing effects. Besides, the asphalt concrete is easier to repair, featuring good maintainability.

Originality/value – This research can provide a basis for popularization and application of the asphalt concrete waterproof sealing structure in high-speed railways.

Keywords High-speed railway, Subgrade, Asphalt concrete, Waterproof sealing structure, Service performance

Paper type Research paper

1. Introduction

The high regularity of high-speed railway puts forward strict requirements on the durable stability and deformation control of railway subgrade (Zhai & Zhao, 2016). Although the subgrade design standards are strictly stipulated in relevant codes (National Railway Administration of the People's Republic of China, 2015; National Railway Administration of the People's Republic of China, 2017), the climatic environment, such as rainfall and temperature, during the operation period will still cause various diseases to the subgrade, reduce the overall strength and long-term stability of the subgrade and cause the irregularity

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of track structure, which seriously threatens the safe operation of trains (Zhu & Yang, 2000). Fiber concrete waterproof sealing layer is usually set on shoulders of the existing ballastless track structure and subgrade surface between two tracks, but this kind of rigid waterproof sealing layer is prone to crack in different degrees after being used for a period of time, resulting in poor waterproof effect (Tang, 2018). As a flexible waterproof sealing material with many advantages, such as long service life and low maintenance cost, asphalt is an effective measure for subgrade protection of high-speed railway.

Germany, Japan, France, Italy and the USA, etc. have applied hot-mix asphalt concrete to railway engineering, and various types of substructures with asphalt concrete layers, such as asphalt concrete cushion, the reinforced surface layer of subgrade bed and asphalt concrete ballast bed, etc., have been formed, which effectively brings the beneficial effects in terms of uniform dispersion of asphalt concrete and transfer of upper load, maintenance of railway geometric alignment, reduction of ballast pollution, buffer and vibration damping of structure, and provision of durable waterproof protection for subgrade, etc. (Chupin, Martin, Piau, & Hicher, 2014; Ferreira, Teixeira, & Cardoso, 2011; Lee, Choi, Lee, & Park, 2016; Momoya & Sekine, 2007; Rose & Souleyaette, 2014; Sol-Sanchez, Pirozzolo, Moreno-Navarro, & Rubio-Gamez, 2015, 2016). For example, in GETRAC track structure of Germany, asphalt concrete with a thickness of 15–35 cm is laid between the track slab and the cement-stabilized base supporting layer. Asphalt concrete is generally used for the sub-ballast layer in the high-speed railway of France, Italy and Spain, with a thickness of 12–14 cm (Chupin *et al.*, 2014; Ferreira *et al.*, 2011). In the Japanese slab track, asphalt concrete is laid between the Cement-Asphalt mortar layer at the bottom of track slab and graded crushed stone (Momoya & Sekine, 2007). Since the last century, the application research of asphalt cemented ballast bed has been carried out for the traditional ballasted track structure in China (Fang, Ai, Qiu, Wei, & Zhang, 2010; Fang, 2012), and the current research focuses on the asphalt concrete technology of high-speed railway. For example, with the local scheme, the asphalt concrete waterproof sealing layer test section was paved for the passenger-dedicated lines with the ballastless track, such as Beijing–Tianjin, Suining–Chongqing and Wuhan–Guangzhou (Fang, Cerdas, & Qiu, 2013; Yang, Wang, Qiu, & Luo, 2015). The local waterproof sealing layer test section of self-compacting asphalt concrete (SCAM) was paved for Harbin–Qiqihar passenger-dedicated line, which effectively prevented such subgrade diseases as frost heave and thawing settlement in high and cold areas (Chen, Tao, Yang, Yan, & Yang, 2019; Liu, Yang, Chen, Yang, & Cai, 2018; Wang, 2015). Relevant scholars from Southwest Jiaotong University proposed to strengthen the surface layer of subgrade bed for the ballastless track in the seasonally frozen region (Leng, 2018; Liu, 2018).

Although relevant scholars at home and abroad had carried out few research studies on railway asphalt concrete based on relevant engineering test sections, foreign railway asphalt concrete was mostly applied to the sub-ballast layer structure of ballasted track, and the implementation effect of many domestic subgrade surface waterproof layer mixture (SAMI) engineering test sections failed to reach the expected goal. Although the implementation effect of SCAM was good, the application cost was high. At present, local scheme is mainly adopted for the waterproof sealing layer of asphalt concrete in high-speed railway, which leads to weak links such as joint between the waterproof sealing layer and the facade of base plate, which affects the waterproof performance. In this paper, a full-section asphalt concrete waterproof sealing structure (FSACWSS) for high-speed railways is proposed. As the full-section is paved between the surface layer of subgrade bed and the base plate, problems such as the joint between base plate or structural facade can be avoided, and the overall waterproof performance becomes better. This structure has both waterproof and drainage and load-bearing functions, so asphalt concrete material should have good functionality, structure and durability. Based on this, a kind of roller-compacted high elastic modulus asphalt concrete (HEMAC) is designed, and its performance is evaluated by several groups of laboratory tests.

Finally, the structure and materials are applied to the test section of a high-speed railway passenger-dedicated line. The waterproof sealing characteristics and dynamic response of track structure are further analyzed through onsite tracking, monitoring and postconstruction investigation, which will provide a basis for popularization and application.

2. FSACWSS

2.1 Structure and materials

The FSACWSS for subgrade of high-speed railways is a layered waterproof sealing structure formed by hot mixing and spreading a certain thickness of roller-compacted dense graded asphalt concrete between the surface layer of subgrade bed and the concrete base. The general structural form is as shown in Figure 1. Compared with the asphalt waterproof sealing method in traditional local scheme, its remarkable feature lies in the full-section laying, and the overall waterproof property is further strengthened.

Since asphalt concrete is laid in full section, it is not only an important part of subgrade waterproof and drainage system but also bears the action of upper track structure and train load. Therefore, asphalt concrete material should have the following basic functions:

(1) It should be compact and impervious, with a flat and compact surface, which is conducive to the rapid drainage of water;

(2) It should have excellent anti-fatigue performance and should withstand repeated action of train loads;

(3) It should maintain high deformation resistance under the long-term action of external environment and train loads;

(4) It must have high elastic modulus to meet the load-bearing requirements of the structure;

(5) It has to be closely combined with the track slab base to avoid delamination or slippage;

(6) It should have good durability and avoid diseases such as oxidation and fragmentation due to factors such as light, heat, water and load and other factors;

(7) It should have good temperature stability, provide high deformation resistance in high temperature weather and have strong low-temperature flexibility and relaxation ability in low temperature season so as to resist reflection cracks and adapt to uneven frost heaving.

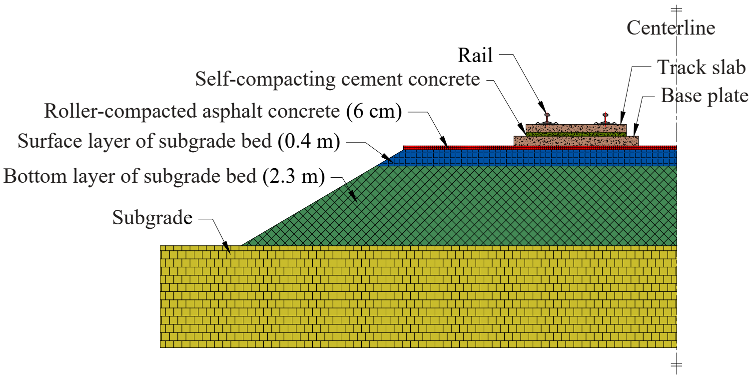


Figure 1. Diagram of full-section asphalt concrete waterproof sealing structure

The above basic functional requirements are also the keys to material design.

Through the adjustment and optimization of asphalt properties, mineral aggregate gradation and spatial structure, asphalt-aggregate interface cohesion and asphalt-aggregate ratio, etc., and in combination with the laboratory tests and repeated fitting, the roller-compacted HEMAC for full-section paving was designed and determined. The selected raw materials included styrene-butadiene-styrene (SBS) modified asphalt, limestone aggregate and limestone mineral powder. Among them, the basic performance results of SBS modified asphalt measured according to *Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering* (JTG E20-2011) (Ministry of Transport of the People's Republic of China, 2011) are shown in Table 1, all of which can meet the requirements of technical indicators (School of Transportation Southeast University, 2016).

The mix proportion design was determined by Marshall test design method specified in *Technical Specifications for Construction of Highway Asphalt Pavements* (JTG F40 – 2004) (Ministry of Transport of the People's Republic of China, 2005). Based on the medium-sized dense graded asphalt concrete AC-20, the median gradation, upper median gradation and lower median gradation were initially taken as the target composite gradation. AC-20 Marshall specimens were respectively formed, and their volume parameters and stability were compared. Figure 2 shows the composite gradation for the finally determined mineral aggregate gradation curve. Marshall specimens with different asphalt-aggregate ratios (3.5, 4.0, 4.5, 5.0 and 5.5%) were formed to test their volume parameters, Marshall stability and flow value, respectively. See Table 2 for the test results. According to the method in *Technical Specifications for Construction of Highway Asphalt Pavements* (JTG F40-2004) (Ministry of Transport of the People's Republic of China, 2005), the optimum asphalt-aggregate ratio of roller-compacted asphalt concrete was determined as 4.5%.

2.2 Performance evaluation

Based on the functional requirements of FSACWSS for high-speed railway subgrade, laboratory tests were carried out on the designed performance of HEMAC according to *Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering* (JTGE20-2011) (Ministry of Transport of the People's Republic of China, 2011) in five aspects: waterproof sealing property, bearing capacity, crack resistance at low temperature, structural safety and durability. Some test specimens and devices are shown in Plate 1. The structural safety was achieved by preparing the composite specimens of cement concrete and asphalt concrete and testing the interface tensile strength and shear strength of composite specimens by indoor tension and compression device, as shown in Plate 1e and f. The test results are shown in Table 3. It can be seen from Table 3 that all technical indicators of HEMAC can meet the proposed technical requirements and can be used for the implementation of FSACWSS engineering.

Technical indicators		Test results	Technical requirements
Penetration (25 °C, 100 g, 5 s)		69.8 (0.1 mm)	55–70 (0.1 mm)
Penetration index (PI)		1.3	≥0.5
5 °C ductility		43.8 (cm)	≥30 (cm)
Softening point $T_{R\&B}$		74 (°C)	≥70 (°C)
135 °C Brookfield viscosity		1.56 (Pa • s)	≤3 (Pa • s)
Residue after RTFOT	Quality change	0.25 (%)	≤±1.0 (%)
	Residual penetration ratio	94.6 (%)	≥80 (%)
	5 °C ductility	37.9 (cm)	≥20 (cm)

Table 1.
Basic performance of SBS-modified asphalt

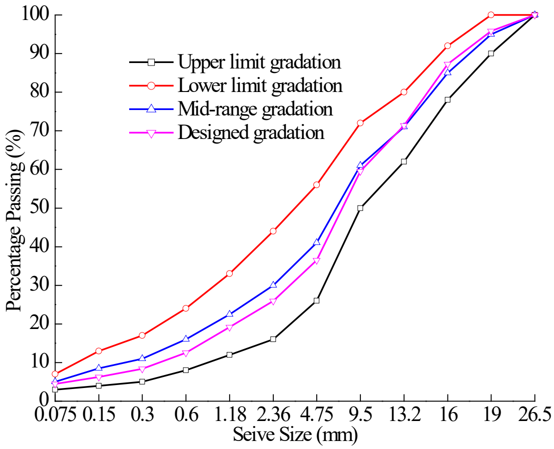


Figure 2. HEMAC mineral aggregate gradation curve

Asphalt-aggregate ratio/%	Bulk density γ_f/ (g • cm^{-3})	Porosity VV/%	Voids in mineral aggregate VMA/%	Effective voids filled with asphalt VFA/%	Stability/ kN	Flow value/ dmm
3.5	2.411	6.048	14.640	57.20	13.53	2.55
4.0	2.443	4.129	14.243	68.88	13.93	2.75
4.5	2.463	3.583	13.350	81.18	14.15	2.71
5.0	2.446	2.635	13.763	81.53	12.71	2.94
5.5	2.438	2.302	14.005	84.34	12.00	3.29

Table 2. Test results of Marshall specimens with different asphalt-aggregate ratios

3. Engineering application of FSACWSS

3.1 Project overview

The FSACWSS engineering test section is located in Kaifeng, Henan province. The starting pile and ending pile are K51 + 860 and K51 + 930, respectively, with a total length of 70 m. The cross-section diagram of the test section is shown in Figure 3. The HEMAC with a thickness of 6 cm was laid on the full section of the surface layer of subgrade bed in the test section, and the thickness of the base plate was appropriately reduced to 24 cm. The test section was completed in late September 2015.

3.2 Key construction procedure

The FSACWSS was constructed according to the overall process shown in Plate 2, and paving was carried out by section and stage so that the construction interval could be shortened as much as possible for continuous construction.

(1) Before prime coat asphalt was applied, the design elevation of subgrade surface should be checked, and the surface scum should be cleaned;

(2) Asphalt distributor was used to spray prime coat asphalt at one time according to the designed dosage and maintain it;

(3) The intermittent mixer of asphalt mixing station was adopted to mix asphalt concrete, and the mixing temperature was strictly controlled;

(4) Dump trucks were used for transportation and effective heat preservation measures were taken to ensure the temperature requirements on site;

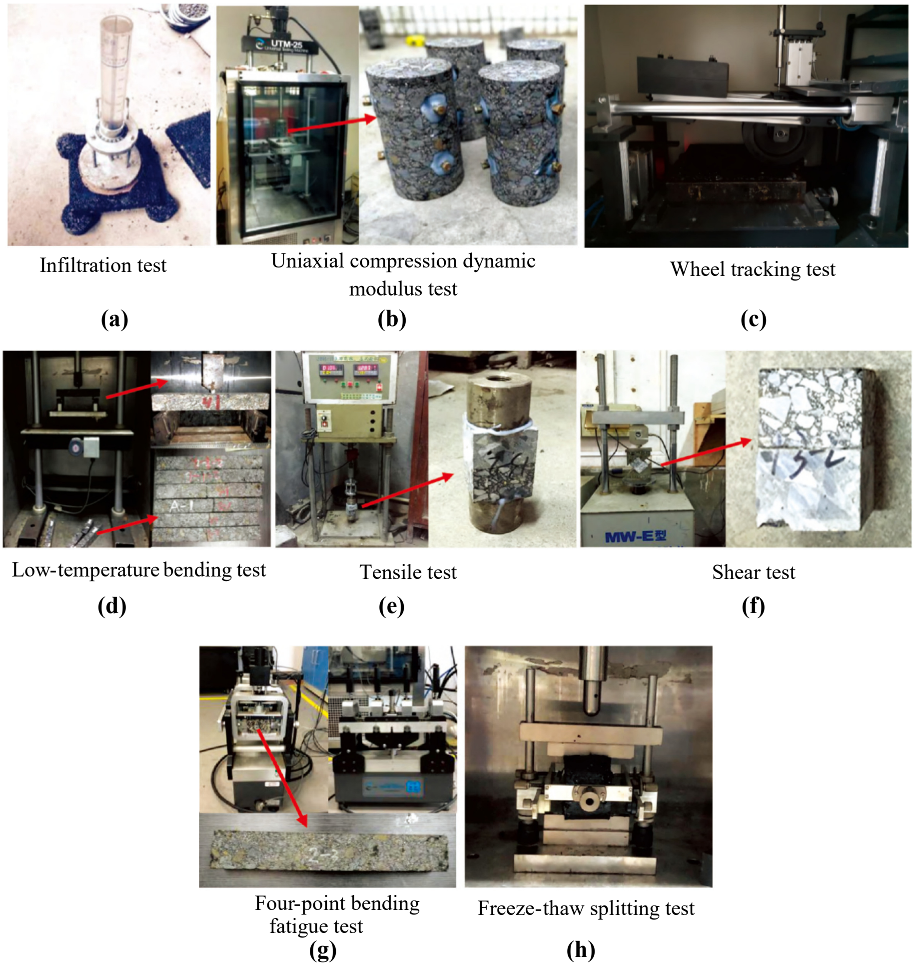


Plate 1.
Specimens and devices for laboratory evaluation

(5) Crawler-type paver was used to pave asphalt concrete, supplemented by manual paving;

(6) The combined steel-glue-steel-steel mode was adopted for initial rolling, rerolling, final rolling and forming, and the rolling temperature was strictly controlled;

(7) The traffic was blocked to make asphalt concrete naturally cured and formed.

3.3 Layout of monitoring sensor

In order to verify the waterproof sealing effect of FSACWSS and to test whether the stress and deformation characteristics of asphalt concrete track structure meet relevant technical requirements of ballastless track, long-term performance monitoring and subgrade dynamic performance testing system were installed simultaneously during the construction as shown in Plate 3. Long-term performance test includes water content of surface layer of subgrade bed, temperature and deformation of sealing structure, displacement of base plate, etc. The

Functional requirements	Technical indicators	Test results	Technical requirements
Waterproof sealing property	Water permeability coefficient	0 (mL • min^{-1})	≤60 (mL • min^{-1})
	Porosity	3.5 (%)	≤5 (%)
Bearing capacity	Uniaxial compression dynamic modulus (10 Hz, 15 °C)	12,762 (MPa)	≥10,000 (MPa)
	Compressive modulus of resilience (15 °C)	1,311 (MPa)	≥1,000 (MPa)
	Dynamic stability (60 °C)	4,247 (time·min^{-1})	≥2,400 (time·min^{-1})
Crack resistance at low temperature	Bending failure strain (−10 °C, 50 mm·min^{-1})	3,484 (με)	≥2,600 (με)
Structural safety	Shear strength with cement concrete interface (20 °C)	2 758 (MPa)	≥0.6 (MPa)
	Bond strength with cement concrete interface (20 °C)	0.463 (MPa)	≥0.2 (MPa)
Durability	Immersion residual stability	99.52 (%)	≥85 (%)
	Freeze-thaw splitting tensile strength ratio	83.40 (%)	≥80 (%)
	Four-point bending fatigue (500 με, 10 Hz, 15 °C)	78,000 (times)	≥50,000 (times)

Table 3. Performance evaluation results of HEMAC

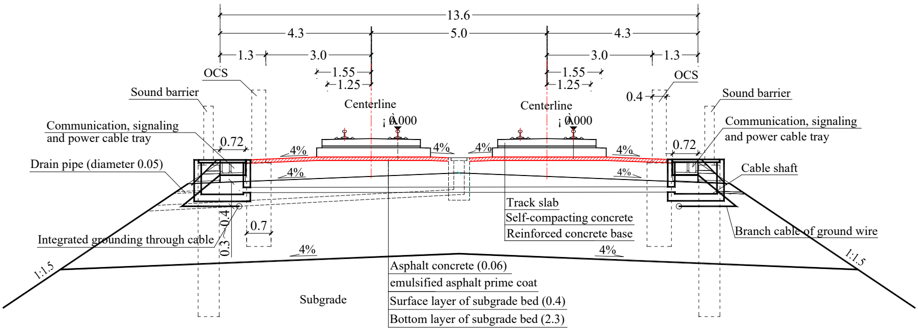


Figure 3. Cross-section diagram of FSACWSS test section (Unit: m)

dynamic performance test of subgrade includes acceleration and dynamic deformation of subgrade and base, etc.

4. Service characteristics of the FSACWSS test section

4.1 The dynamic performance of track structure

In April 2016, during the testing and commissioning stage, the dynamic performance of track structure in the standard subgrade section (section A) and the asphalt concrete engineering test section (section B) of asphalt-free concrete waterproof sealing structure was carried out, including the stability and vibration characteristics of the track structure.

4.1.1 Stability of track structure. See Table 4 for the measured results of parameters such as the maximum running speed, derailment coefficient, reduction rate of wheel load and other parameters of each section passed by track inspection car. It can be seen from Table 4 that the parameters of asphalt concrete test section and standard subgrade section are equivalent, and both of them can meet the train operation stability indicators proposed in *Technical*

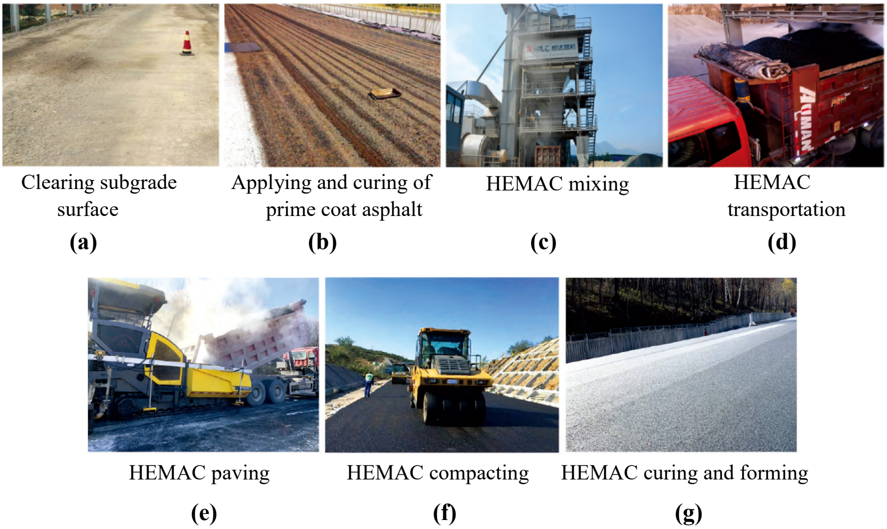


Plate 2.
Construction procedures of the FSACWSS

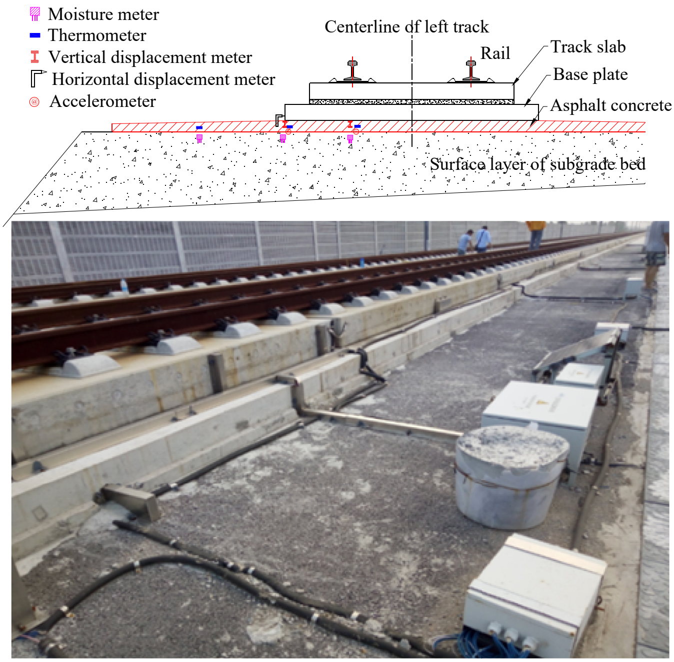


Plate 3.
Layout of sensor at the monitoring profile of FSACWSS test section

regulations for dynamic acceptance for high-speed railway construction (TB 10761-2013) (Ministry of Railway of the People's Republic of China, 2013).

4.1.2 Vibration of track structure. See Table 5 for the measured vibration acceleration results of each section of track structure. It can be seen from Table 5 that the acceleration increases with the increase of speed; the acceleration of track slab in Section B does not increase significantly with the increase of speed, but the acceleration of base increases significantly. The vibration acceleration amplitude of the base and track slab in Section B is slightly larger than that in Section A because the asphalt concrete sealing structure replaces the base plate with the same thickness in the structural design of Section B, which weakens the stiffness of the base and is not conducive to the stress of the track. In the follow-up engineering application, it is suggested not to weaken the base plate, but to replace the surface layer of subgrade bed with the same thickness of asphalt concrete.

4.2 Dynamic test results of subgrade in the test section

Two test points (located at K51 + 910 and K51 + 913 sections) were set on the south shoulder in the subgrade dynamic test system of asphalt concrete test section to respectively monitor the dynamic deformation and vibration acceleration of subgrade surface when train passes so as to evaluate whether the dynamic performance of subgrade could meet the requirements of *Technical regulations for dynamic acceptance for high-speed railway construction* (TB 10761-2013) (Ministry of Railway of the People's Republic of China, 2013), that is, the dynamic deformation of subgrade should be not more than 0.22 mm, and the vibration acceleration should be not more than 10 $m \cdot s^{-2}$.

The measured dynamic deformation of subgrade surface in asphalt concrete sealing structure test section is shown in Figure 4, and the vibration acceleration of subgrade surface is shown in Figure 5. The statistics on its dynamic characteristics are shown in Table 6. It can be seen that the dynamic deformation does not change obviously with the increase of train speed, the amplitude of dynamic deformation on the surface of embankment subgrade bed is 0.20 mm and there is little difference between the two test points, which all meet the requirements in the regulations; there is little difference between the two test points of subgrade surface vibration acceleration, and the peak acceleration is about 0.54 $m \cdot s^{-2}$, far less than the limit in the regulations.

4.3 Investigation on service characteristics of test section

During the testing and commissioning in April 2016, relevant personnel tracked and investigated the test section and found that the overall condition of the test section of asphalt

Test section	Thickness of asphalt concrete layer/cm	Thickness of base plate/cm	Lateral displacement of track/mm	Derailment coefficient	Reduction rate of wheel load	Lateral force of wheel and axle (kN)
Section A		30	0.06	0.24	0.32	6.77
Section B	6	24	0.03	0.16	0.22	12.00
Requirements in regulations			≤1.0	≤0.80	≤0.65	≤52.00

Table 4. Measured amplitude of track safety parameters in Section A and B

Train speed/($km \cdot h^{-1}$)	Vibration acceleration amplitude/($m \cdot s^{-2}$) Rail Section A	Rail Section B	Track slab Section A	Track slab Section B	Base plate Section A	Base plate Section B
180	752.5	1084.1	17.1	29.7	1.06	1.99
380	680.6	1173.0	26.3	27.9	1.86	2.25
Requirements in regulations	≤5,000		≤300			

Table 5. Measured vibration acceleration amplitude of each section of track structure

concrete waterproof sealing structure was good, the surface was compact and intact, without any cracking, looseness and spalling, etc. The joints among asphalt concrete, base plate and structures along the line were good with any cracks. During the period from July 6 to July 9, 2017, the research on the using status of asphalt concrete waterproof sealing structure was carried out again, and the service status of adjacent fiber concrete waterproof sealing structure (pile: K51 + 639 – K51 + 860, hereinafter referred to as the contrast section) was also investigated. This section mainly analyzed the results of this investigation.

4.3.1 Overall condition of test section. The conditions of shoulders and between tracks in the test section of asphalt concrete waterproof sealing structure are shown in Plate 4. The overall condition is good, without diseases such as spalling, looseness and pits; the surface is compact and intact, and the waterproof effect is good, without diseases such as subgrade bed softening and mud-pumping.

4.3.2 Crack in the test section. The joints between shoulders on both sides of the test section, the asphalt concrete sealing structure between tracks and the base plate and structures were in good condition, and cracks with irregular distribution only occurred at the joints of the base plate in the whole length range. Upon completion of the investigation, asphalt potting repair was carried out (as shown in Plate 5), showing good maintainability.

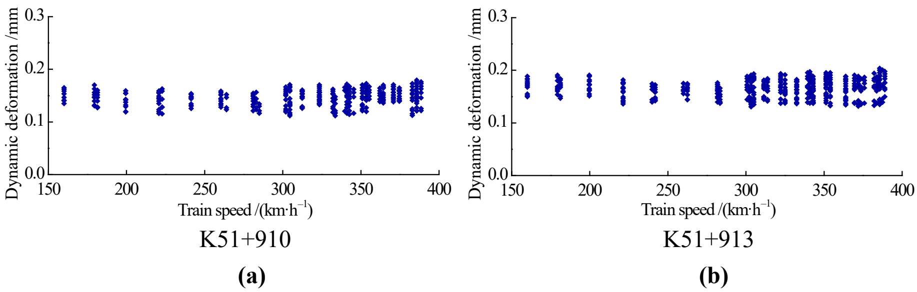


Figure 4.
Measured dynamic deformation of subgrade surface in test section (Unit: mm)

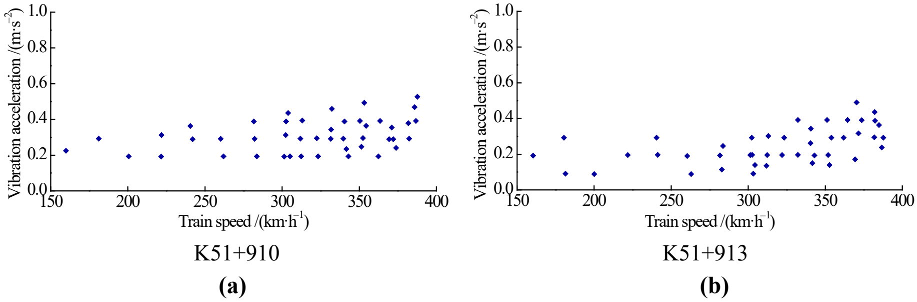


Figure 5.
Measured vibration acceleration of subgrade surface in test section (Unit: $m \cdot s^{-2}$)

Table 6.
Statistical table for dynamic characteristics of subgrade surface

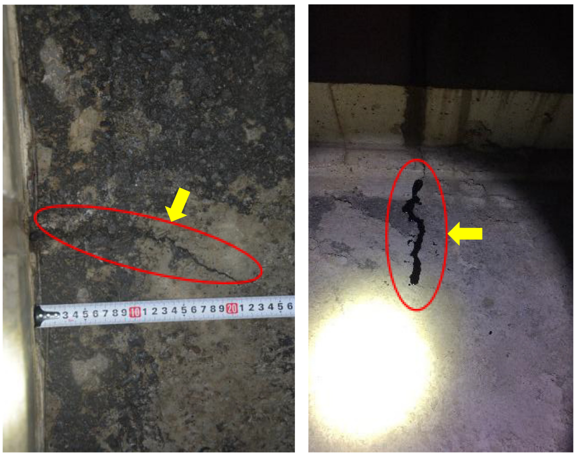
Position of test points	Dynamic deformation/mm Average	Maximum value	Standard deviation	Vibration acceleration/($m \cdot s^{-2}$) Average	Maximum value	Standard deviation
K51 + 910	0.15	0.17	0.012	0.31	0.54	0.10
K51 + 913	0.17	0.20	0.013	0.31	0.53	0.10

According to statistical analysis, the crack length is generally 30–50 cm, the width is about 3–5 mm and the crack depth is about 3–6 mm, which may be caused by passive stretching of asphalt concrete due to the temperature shrinkage of base plate, and further study is needed.

South shoulder **(a)** North shoulder **(b)** Between tracks **(c)**

Plate 4. The overall condition of FSACWSS test section

Joint with base plate **(a)** Joint with structure **(b)**



HEMAC crack **(c)** Crack repair **(d)**

Plate 5. FSACWSS status and crack repair

4.3.3 The service status of contrast section. According to the investigation of the adjacent fiber concrete contrast section, the joint between the fiber concrete and the base plate is good, but more temperature shrinkage cracks have been found on shoulders and between tracks; the north shoulder is mainly composed of oblique cracks and lateral cracks at the edge of the structure; lateral cracks, longitudinal cracks and map cracking all exist between tracks. A few lateral cracks and oblique cracks in the corner of structural bearing have been found in the whole length range, as shown in Plate 6, which will seriously affect the waterproof effect.

4.4 Long-term monitoring results

4.4.1 Water content. The monitoring data of water content in the test section and contrast section from December 29, 2015 to July 7, 2017 are shown in Figure 6. It can be seen from Figure 6 that the waterproof sealing effect of asphalt concrete test section is better than that of fiber concrete control section; the water content in the shoulder center of the test section is not significantly affected by weather and basically remains between 8 and 18%, while the water content in the surface layer of subgrade bed of the contrast section is significantly affected by weather. The monitoring data at several test points fluctuate greatly, with the water content between 10 and 35%, and the peak value can reach nearly three times of that of the test section, which is caused by many cracks in the waterproof layer of fiber concrete and rainwater infiltration.

4.4.2 Temperature. Figure 7 shows the temperature monitoring data in the test section and contrast section from December 29, 2015 to July 7, 2017. Compared the temperature

Oblique cracks in the corner of structure bearing

(a)

Map cracking

(b)

Plate 6.
The partial cracking mode of fiber concrete in contrast section

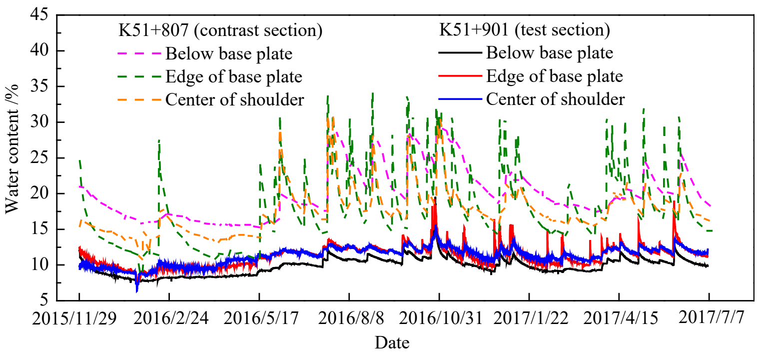
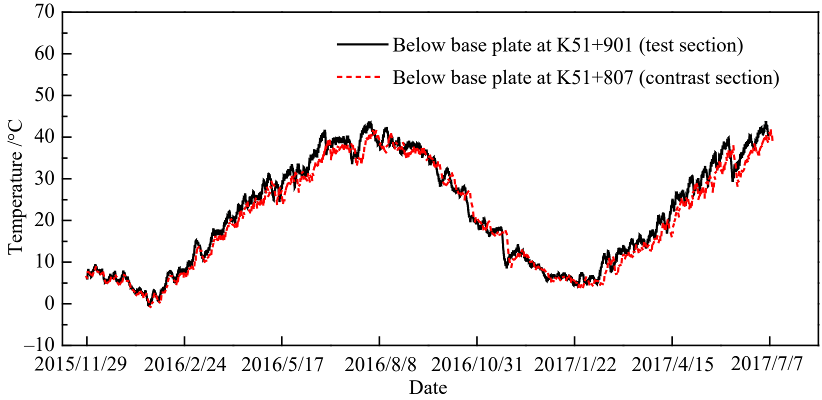
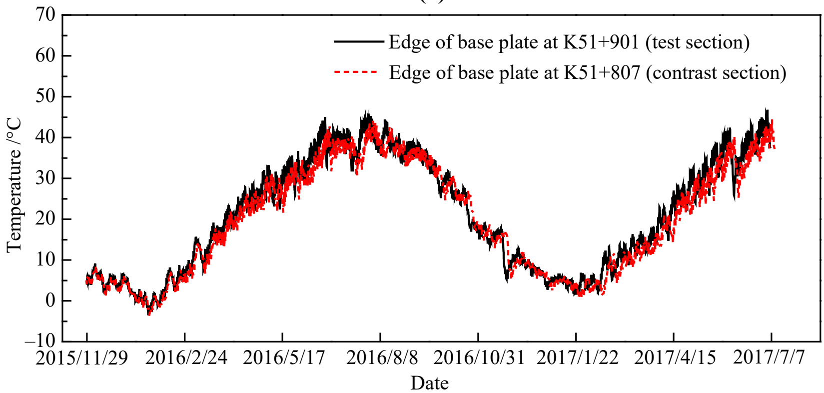


Figure 6.
The monitoring value of water content



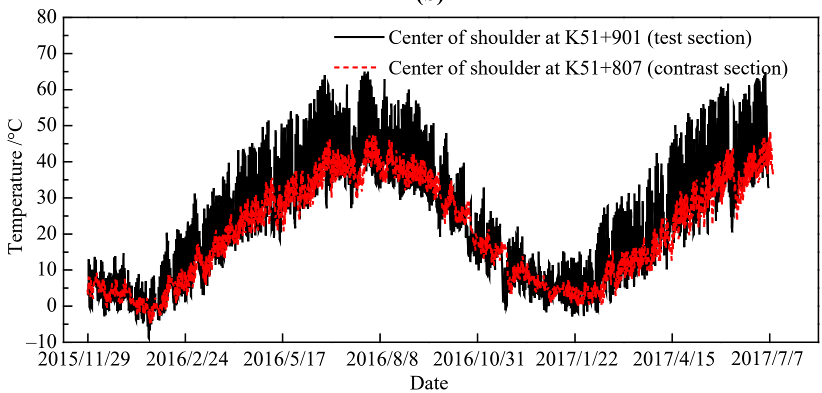
Below the base plate

(a)



Edge of the base plate

(b)



Center of the shoulder

(c)

Figure 7.
Temperature monitoring values at different positions of profile

monitoring data in Figure 7c, it can be seen that as the heat absorption capacity of asphalt concrete is stronger than that of ordinary fiber concrete, the temperature amplitude of asphalt concrete layer at the shoulder center is greater than that of fiber concrete; the highest temperature of the two in summer is about 65 ℃ and 50 ℃, respectively, with a difference of 15 ℃, and the fluctuation of asphalt concrete temperature with air temperature is obviously greater. However, the asphalt concrete (Figure 7b and c) at the edge of and below the base plate is covered by the superstructure, so the temperature difference is not significant. It can be inferred that the asphalt concrete below the base plate is less affected by the environment and has better weather resistance.

4.4.3 Deformation. Figure 8 shows the monitoring results of the horizontal displacement of the base plate from December 29, 2015 to July 7, 2017. It can be seen from Figure 8 that the horizontal displacement amplitude of base plate perpendicular to track alignment at the K51 + 901 profile of test section is about −1.15 mm (negative value indicates that the base plate moves towards the direction between tracks). The horizontal displacement amplitude of base plate perpendicular to track alignment at K51 + 807 profile of contrast section is about 0.78 mm (the positive value indicates that the base plate moves towards the direction of shoulder).

Figure 9 shows the monitoring results of vertical displacement of asphalt concrete in the test section/surface layer of subgrade bed in the contrast section during the monitoring period. It can be seen from Figure 9 that the asphalt concrete/surface layer of subgrade bed below and at the edge of the base plate at different profiles are vertically deformed under the long-term action of train load; the vertical deformation amplitudes below and at the edge of the base plate at K51 + 901 of the test section are −0.5 mm and −2.3 mm, respectively. The vertical deformation amplitudes below and at the edge of the base plate at K51 + 807 are −1.2 mm and −0.4 mm, respectively. On the whole, the long-term deformation of the asphalt concrete test section is greater than that of corresponding position of the fiber concrete contrast section, which may be caused by the weakening of base plate in the design, but they all meet the requirements in the regulations.

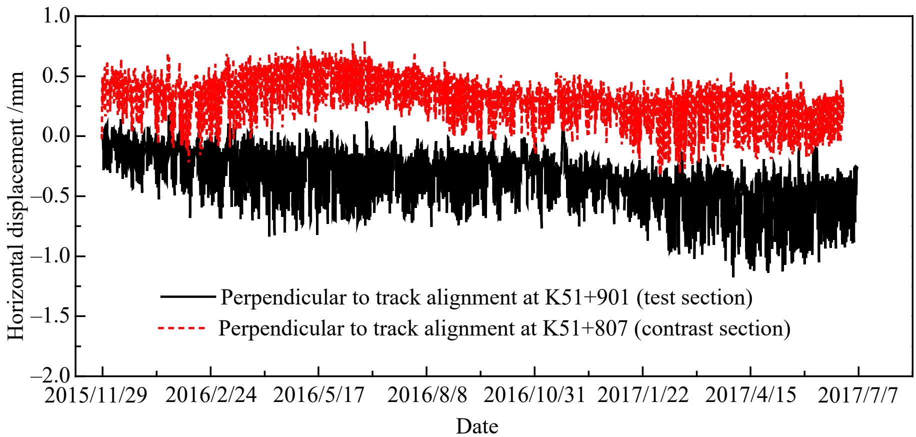


Figure 8.
Horizontal displacement monitoring values of the base plate in each profile perpendicular to track alignment

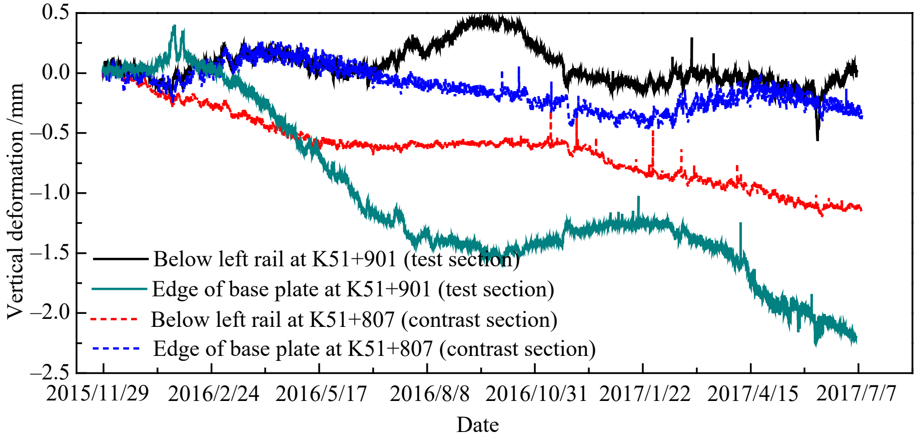


Figure 9.
The monitoring value of vertical deformation at different positions of each profile

5. Conclusions

(1) Based on the working environment of FSACWSS, the technical characteristics and functional requirements of the structure were analyzed, and the roller-compacted HEMAC was designed. The waterproof sealing performance, bearing capacity, low temperature crack resistance, structural safety and durability of the material were evaluated through laboratory tests, and the results showed that all the properties of the material could meet the use requirements.

(2) The dynamic test results of track and subgrade showed that the stress and deformation of track structure in asphalt concrete test section were equivalent to those in typical subgrade section, and both met the stability indicator of train operation; in the test section, the dynamic deformation amplitude of embankment subgrade bed surface was 0.20 mm, and the peak value of vibration acceleration of embankment subgrade bed is 0.54 $m \cdot s^{-2}$, which met the limit requirements in the regulations.

(3) The field investigation results showed that the overall contact among the test section, base plate and the structure was in good condition, the surface was compact and intact, and there were no diseases such as looseness, spalling and subgrade bed softening; there were several cracks with irregular distribution at the temperature expansion joint of the base plate, which could be repaired by asphalt potting and had high maintainability; there were many lateral cracks, map cracking and corner cracks on shoulders and between tracks at the fiber concrete contrast section, which seriously affected its waterproof sealing performance.

(4) The long-term monitoring results of water content, temperature and deformation showed that the fluctuation of water content of the subgrade bed in the test section is small with rainfall, which was basically maintained between 8 and 18%, while the water content of the subgrade bed in the contrast section was significantly affected by rainfall, which was as high as 10–35%, and the peak value was about 3 times of that of the test section. The temperature amplitudes of the sealing layer on shoulders and at the edge of the base plate of the test section were larger than that of the contrast section, but there was no significant difference between the two under the track. The horizontal displacement monitoring value of the base plate in the test section was

equivalent to that in the contrast section, and the vertical deformation value was slightly larger than that in the contrast section, which all met the settlement requirements.

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