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Study on the Asphalt Pavement Response in the Accelerated Pavement Testing Facility

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Abstract Accelerated pavement testing (APT) is an effective method in evaluating pavement performance by applying wheel loading and speed under controlled conditions. This study aims to investigate the effects of wheel loading, speed and ambient temperature on the pavement responses at different directions and depths of pavement structure. A two-layer asphalt pavement structure was constructed on a base layer constructed 10 years ago. Strain gauges were installed both in the transversal and longitudinal directions of motion on the bottom of both layers. The response of the asphalt layers was monitored and the developed strains were recorded. The results show that maximum compressive strain increases with wheel load. In contrast, the maximum tensile strain decreases as load increases; this is probably due to the high confining pressure that occurs within the pavement structure when higher wheel load is applied. The maximum compressive and tensile strains decrease with wheel speed, because the asphalt mixture becomes stiffer at high wheel speed (frequency). The maximum compressive and tensile strains in the transversal direction increase with ambient temperature, because of the low stiffness of asphalt materials at high temperature, which appears to be the cause of rutting.

Keywords Asphalt · Accelerated pavement test · Cyclic Indirect Tensile Test · Mechanical response

1 Introduction

Accelerated Pavement testing (APT) was first introduced to the world in the United Kingdom in 1910s. It came to the forefront in the late 1950s with the AASHO (American Association of State Highway Officials) road test in United States and

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since then has played an important role in the advancement of road construction to a largely rational process (Hugo and Ebbs 2004). APT fills the important gap between mechanistic-empirical design models using laboratory materials testing characterization and real, long-term pavement performance monitoring and data analysis. Nowadays APT is used for full-scale pavement testing, which refers to an application of the controlled wheel loading on a prototype or actual, layered, structural pavement system to determine pavement response and performance (Metcalf 1996).

To study the negative impacts of the environment and traffic on the condition and performance of pavement structures can take years under true field conditions. APT utilizes special full-scale mobile or fixed testing apparatus to simulate these effects in a shorter time period. In the early studies of APT, most of the work focused on the visible pavement performance such as fatigue cracking or permanent deformation (Xu and Meng 2004; Khan et al. 2013). Based on the test results, pavement materials and structure design was highly developed to improve the anti-fatigue and anti-rutting performance (Zhang et al. 2005; Plessis et al. 2018). New materials, epoxy asphalt, rubber asphalt, bridge deck etc. (Qian et al. 2019; Tian et al. 2017), were also evaluated and validated based on APT results.

The primary objective of this study is to investigate the effects of wheel loading, speed and ambient temperature on the mechanical responses pavement structure at different directions and depths based on APT testing. To accomplish this objective three tasks, as listed below, were performed and discussed in the following sections: 1. A series of APT tests were conducted on a porous pavement section to capture the mechanical response of the pavement structure by applying various wheel loads and speeds at two different ambient temperatures. 2. Field core samples were taken from the first and second layers of APT test sections and tested by the Cyclic Indirect Tensile Test (IT-CY) test in the laboratory. 3. The effect of wheel load, speed and ambient temperature on the transverse and longitudinal strains were discussed.

2 Test Section and Experimental Method

2.1 *Overview of the Test Section*

The construction phase of the test section started with the removal of the existing old pavement surface, which had 10 cm thickness. After the milling process, a bitumen emulsion tack coat layer was sprayed on the surface. Then the 6 cm thickness new stone asphalt concrete (STAC) layer was laid first, and on top of it a 5 cm thickness porous asphalt (PA) layer was placed. PA and STAC are commonly used as the top and base layers of pavements in the Netherlands. All layers were compacted using a roller compactor, respectively. The construction of the test sections was done in October 2014. The profile of the new pavement structures is shown in Fig. 1, in which the old STAC (17 cm thickness) and cement bound asphalt granulate base layers (AGRAC, 25 cm thickness) exist more than 10 years.

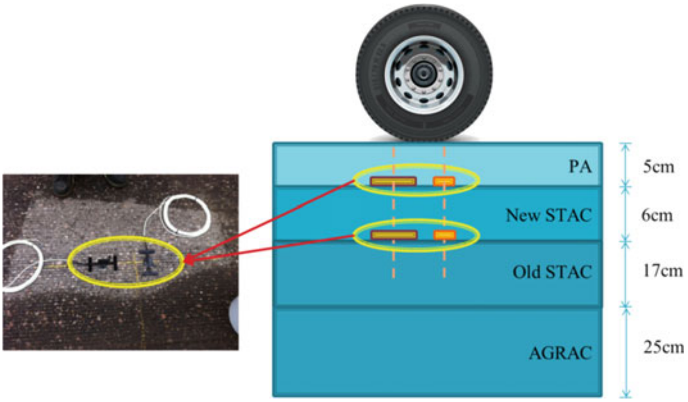

Fig. 1 Profile of test section and strain gauges instrument

In order to measure the mechanical response of pavement structure under wheel load, the test sections were instrumented with strain gauges in longitudinal and transversal directions of motion on the bottom of PA and new STAC layers, as shown in Fig. 1. The coding system in Table 1 is used for the strain at various directions and depths: X_1X_2 or $X_1X_2X_3$.

Both PA and STAC mixtures were designed using the same type of aggregate, Norwegian sandstone, with a nominal maximum size of 16 mm. Norwegian sandstone is a type of crushed stone with density 2740 kg/m^3. The aggregate gradations of both mixtures are given in Fig. 2. The target air void content was 16 and 5% for the PA and SMA mixtures, respectively. The same type of PEN 70/100 bitumen was used for both mixtures. The binder content was 5.0 and 4.6% for the PA and the STAC mixture, respectively. Table 2 shows the main physical and rheological properties of the PEN 70/100 bitumen. Moreover, a factory filler, i.e. Wigro 60K filler (with

Table 1 Coding system

Code	X_1	X_2	X_3
Indication	Capital	Number	Capital
Meaning	Direction	Depth	Maximum strain
Possibilities	T = Transversal direction L = Longitudinal direction	5 = 5 cm depth 11 = 11 cm depth	T = Tensile strain C = Compressive strain

Examples
L11 = Longitudinal direction, 11 cm depth
T5T = Transversal direction, 5 cm depth, Maximum tensile strain

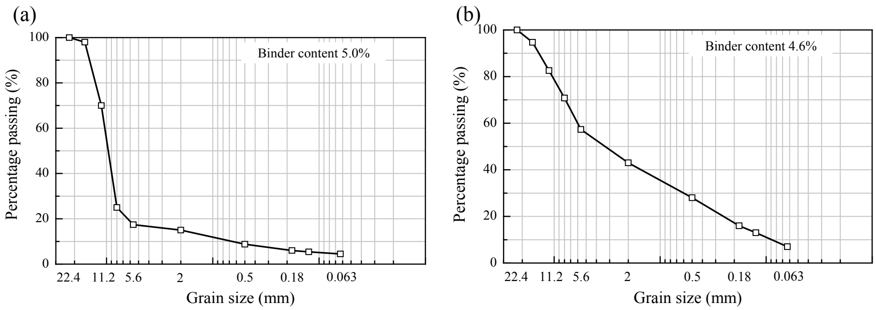

Fig. 2 Aggregate gradation of asphalt mixtures **a** PA mixture **b** STAC mixture

Table 2 Specifications of PEN 70/100

Property	Unit	PEN 70/100
Penetration at 25 °C	0.1 mm	70–100
Softening point	°C	43–51
Dynamic viscosity at 60 °C	Pa s	160
Complex shear modulus at 1.6 Hz & 60 °C	kPa	1.8
Phase angle at 1.6 Hz & 60 °C	°	88

density 2780 kg/m^3) was used for both mixtures. Wigro 60K is a limestone filler which contains 25% calcium hydroxide.

2.2 Accelerated Pavement Test

The accelerated pavement tests were performed using a linear facility, LINTRACK, at the Section of Pavement Engineering at Delft University of Technology. The facility was commissioned in 1991. In this study, the accelerated pavement tests were conducted at 5 kN single wheel load intervals in the range of 20–50 kN, at 2 km/h varying speed in the range of 5–19 km/h. Tire inflation pressure is 900 kPa. These tests were conducted in the month of February 2015 (Test-I) and August 2015 (Test-II). Ambient temperature was recorded to be 4 °C during Test-I and 22 °C during Test-II. Table 3 summarizes the testing conditions that were considered.

Table 3 Accelerated testing conditions

Test name	Wheel load (kN)	Speed (km/h)	Ambient temperature (°C)
Test-I	20, 25, 30, 35, 40, 45	5, 7, 9, 11, 13, 15, 17, 19	4
Test-II			22

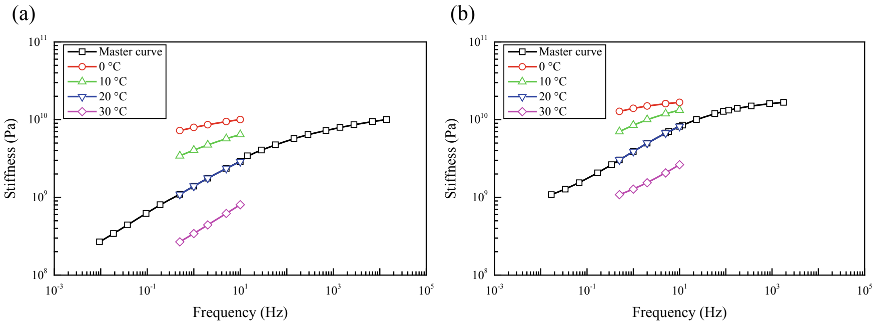

Fig. 3 Stiffness of asphalt mixtures at various temperatures **a** PA mixture **b** STAC mixture

2.3 Cyclic Indirect Tensile Test

Six samples with a diameter of 100 mm and a thickness of 50 mm were cored from the PA and the STAC layers in February 2015. The dynamic modulus of each core was determined by means of Cyclic Indirect Tensile Test (IT-CY) according to NEN-EN 12697-26. The tests were performed using the Universal Testing Machine (UTM) at five frequencies i.e. 0.5, 1, 2, 5 and 10 Hz and four testing temperature i.e. 0, 10, 20 and 30 °C. The conditioning time before testing was 4 h and three replicates were tested.

3 Results and Discussion

3.1 Cyclic Indirect Tensile Test

The stiffness of the PA and STAC mixtures at various temperatures is presented in Fig. 3. As expected, the stiffness of the mixtures significantly increases with increasing frequency and decreases as temperature rises. Moreover, the stiffness of STAC mixture is higher than that of PA mixture. To obtain the visco-elastic behavior in a wider range of frequencies, stiffness master curves were generated on the basis of the Time-Temperature Superposition (TTS) principle at a reference temperature of 20 °C and shown in Fig. 3.

3.2 Accelerated Pavement Test

The longitudinal and transversal strains at various depths were recorded during the accelerated pavement tests. Figure 4 shows the results of strain gauges at various

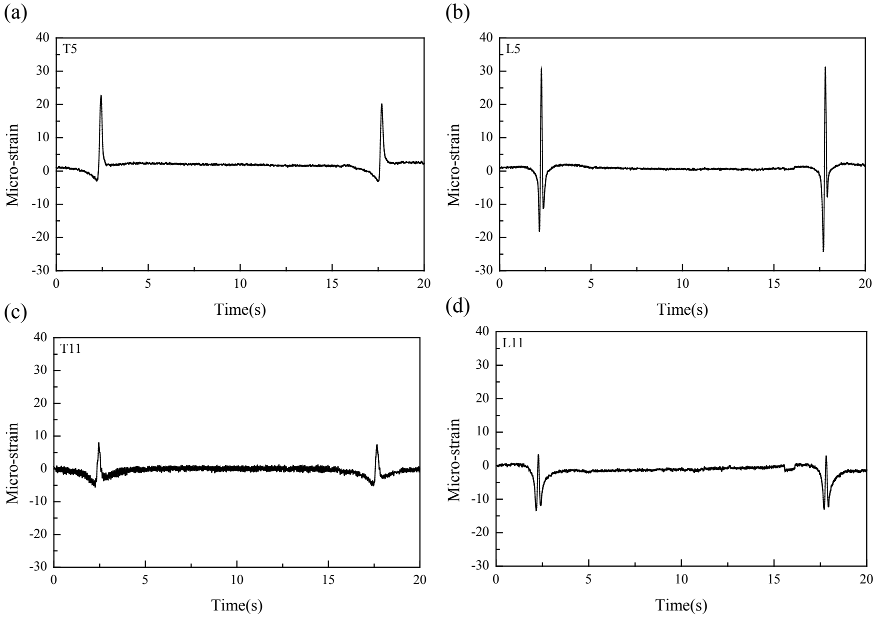

Fig. 4 Measurement of strain gauges at various directions and depths **a** T5 **b** L5 **c** T11 **d** L11 (Wheel load is 20 kN, speed is 15 km/h and ambient temperature is 4 °C)

directions and depths, when the wheel load is 20 kN, the speed is 5 km/h and the ambient temperature is 4 °C. In this figure, positive values represent tensile strains and negative values represent compressive strains.

Overall, all strain gauges experienced compression-tension-compression during the movement of the wheel load, this was true, especially for the strain gauges on the longitudinal direction, Fig. 4b, d. High tensile strains occurred when the wheel load passed, and high compressive strains occurred before and after the wheel load passed. The maximum tensile strain at the 5 cm depth (Fig. 4a, b) is higher than that at 11 cm depth (Fig. 4c, d) due to the higher stiffness of the STAC mixture. In addition, the high tensile strains exist at 5 cm are also caused by the stiffer base layer and subgrade, since they have been over compacted in the past 10 years' APT tests. A high tensile strain at the bottom of the top layer is one of the main causes of pavement cracking. From the measurement of strain data, the maximum compressive and tensile strains of each strain gauge were extracted during the tests. The effect of wheel load on strain at various both and depths is illustrated in Fig. 5.

Figure 5 shows that maximum compressive strain increases with wheel load as expected. However, the maximum tensile strain decreases with wheel load. It is probably because high confining pressure occurred in the pavement structure when heavy wheel load passed, which led to a lower measured tensile strain. In addition, it has been found that both the maximum compressive and tensile strain decrease with increasing wheel speed at the transverse and longitudinal direction for both

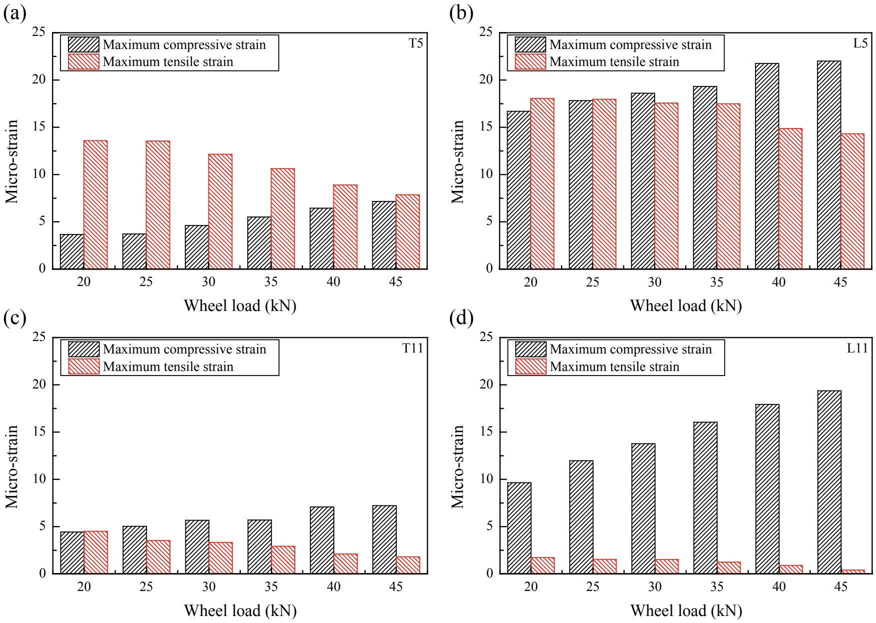

Fig. 5 Effect of wheel load on maximum compressive and tensile strains at various directions and depths **a** T5 **b** L5 **c** T11 **d** L11 (Speed is 15 km/h and ambient temperature is 4 °C)

depth locations, as shown in Fig. 6. The reason for this increases is related to the viscoelastic nature of the materials, higher speed denotes higher loading frequency and consequently higher stiffness of the mixtures, Fig. 3.

The effect of ambient temperature on the maximum compressive and tensile strains is illustrated in Fig. 7. It can be seen that the maximum compressive and tensile strain in the transversal direction increase as temperature rises, as shown in Fig. 7a, c. This is a reasonable observation considering that the material stiffness decrease with increasing temperature, Fig. 3. The occurrence of high strains in the transversal direction can lead to the accumulation of permanent deformation and significantly contribute to the rutting distress in asphalt pavements. However, the maximum compressive and tensile strain in the longitudinal direction decrease with ambient temperature. A possible reason is that the confining pressure in the longitudinal direction is higher than that in transversal direction, because the length of the pavement is much larger than its width, thus leading to the maximum compressive and tensile strains in the longitudinal direction to become smaller.

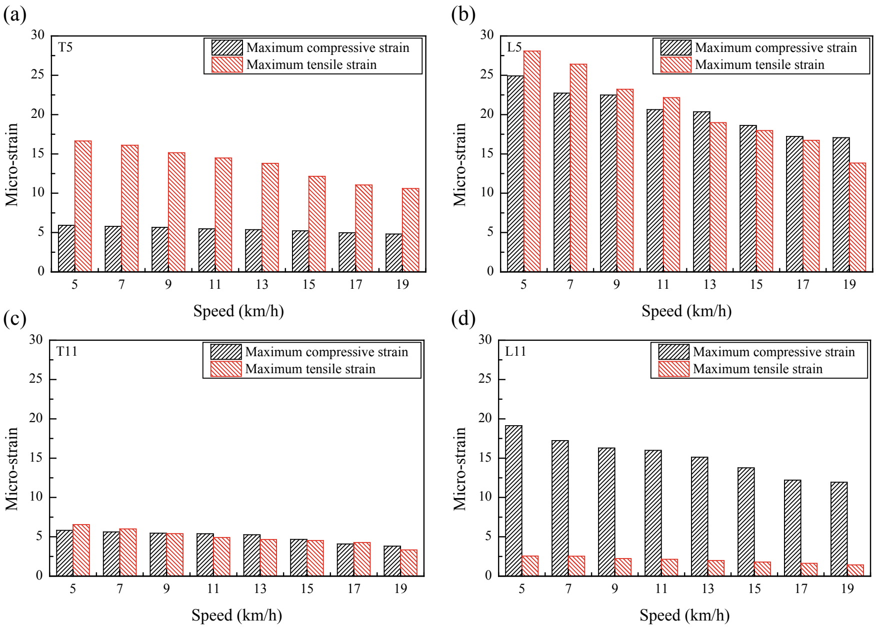

Fig. 6 Effect of speed on maximum compressive and tensile strains at various directions and depths **a** T5 **b** L5 **c** T11 **d** L11 (wheel load is 30 kN and ambient temperature is 4 °C)

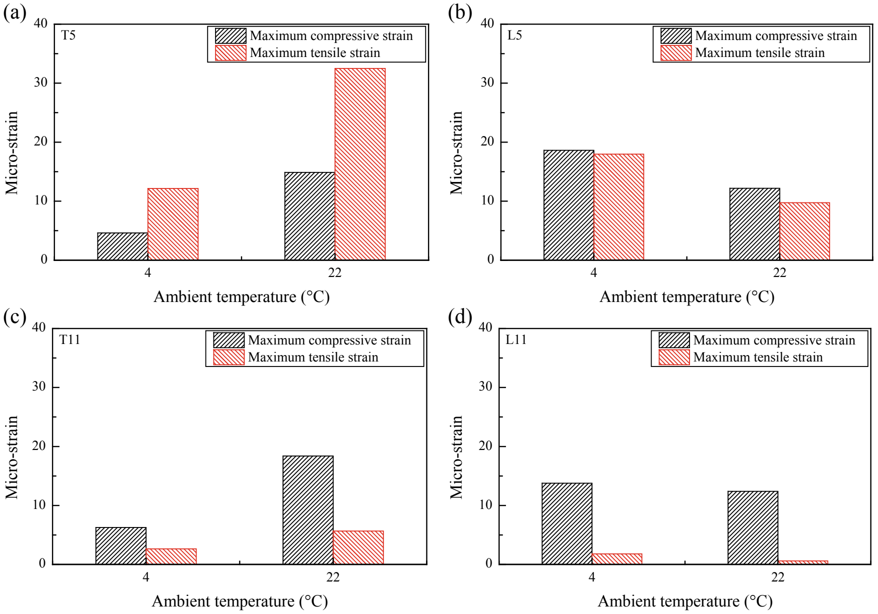

Fig. 7 Effect of temperature on maximum compressive and tensile strains at various directions and depths **a** T5 **b** L5 **c** T11 **d** L11 (wheel load is 30 kN and Speed is 15 km/h)

Table 4 between stains and loading conditions

Test		Cor_Load	Cor_Speed	Cor_Temp
APT	T5C	+	–	+
	T5T	–	–	+
	L5C	+	–	–
	L5T	–	–	–
	T11C	+	–	+
	T11T	–	–	+
	L11T	+	–	–
	L11T	–	–	–

3.3 Effect of Wheel Load, Speed and Ambient Temperature on the Transverse and Longitudinal Strains

According to the above results, the influence of wheel load, speed and ambient temperature on the transverse and longitudinal strains are concluded in Table 4. The symbols '+' and '−' denote increase and decrease in correlation. The highlight blocks denote that the mechanical behavior of the pavement structure is the same with that of laboratory evaluation results (Bayat and Knight 2012; Korkiala and Dawson 2007). To be specific, the transverse strain increases with wheel speed and decreases with wheel speed, and the longitudinal strain decreases with wheel speed as well. However, as the high confining pressure occurs within the pavement structure when higher wheel load is applied, the compressive strain increases and tensile strain decreases as wheel load increases. In addition, due to the fact that the confining pressure in the longitudinal direction is higher than that in the transversal direction, the transverse strain increases and the longitudinal strain decreases with ambient temperature. In other words, laboratory evaluation of asphalt materials cannot fully describe the field behavior of pavement structure due to the effect of confining pressure and other factors in the field pavement (Loulizi et al. 2006; Mazari et al. 2014). For example, when applying an indirect tension test or direct compression test in laboratory, the confining pressure related to the loading and the size difference at each directions normally are not considered.

4 Conclusions

The study presented in this paper shows the preliminary results of a broad study on accelerated pavement tests. To be specific, the changes in the mechanical response of pavement structure were investigated under various combinations of wheel load, speed at two different ambient temperatures. Moreover, core samples were taken from the test sections and their stiffness was determined under various combinations of frequency and temperature.

The APT results show that the maximum compressive strain increases with load amplitude, the maximum tensile strain decrease with frequency, and the maximum tensile/compressive strain in the transversal direction increase with temperature. The high compressive strain that occurs at heavy wheel loads increases the risk of pavement permanent deformation. On the other hand, the high tensile/compressive strains that occurs in the transverse direction at high temperature indicates a high risk of pavement rutting. In other words, high wheel loads, low speeds and high ambient temperatures make pavement susceptible to damage.

To fully characterize the mechanical behavior of pavement structure, a proper experimental protocol (for instance considering confining pressure) in laboratory and more verification from field measurements seem necessary.

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References

Bayat A, Knight M (2012) Field evaluation and analysis of flexible pavement structural responses under dynamic loads. Road Mater Pavement Des 13:26–37

Hugo F, Ebbs A (2004) NCHRP synthesis 325: significant findings from full-scale accelerated pavement testing. Transportation Research Board, Washington DC

Khan S, Nagabhushana MN, Tiwari D, Jain PK (2013) Rutting in flexible pavement: an approach of evaluation with accelerated pavement testing facility. Procedia Soc Behav Sci 104:149–157

Korkiala L, Dawson A (2007) Relating full-scale pavement rutting to laboratory permanent deformation testing. Int J Pavement Eng 8:19–28

Loulizi A, Alqadi I, Elseifi M (2006) Difference between in situ flexible pavement measured and calculated stresses and strains. J Transp Eng 132:574–579

Mazari M, Navarro E, Abdallah I, Nazarian S (2014) Comparison of numerical and experimental responses of pavement systems using various resilient modulus models. Soils Found 54:36–44

Metcalf JB (1996) NCHRP synthesis of highway practice 235: application of full-scale accelerated pavement testing. Transportation Research Board, Washington DC

Plessis L, Ulloa CA, Harvey JT, Coetzee NF (2018) Accelerated pavement testing efforts using the heavy vehicle simulator. Int J Pavement Res Technol 11:327–338

Qian J, Chen K, Tian Y, Zeng F, Wang L (2019) Performance evaluation of flexible pavements with a lateritic gravel base using accelerated pavement testing. Constr Build Mater 228:116790

Tian Y, Lee J, Nantung T, Haddock JE (2017) Development of a mid-depth profile monitoring system for accelerated pavement testing. Constr Build Mater 140:1–9

Xu Q, Meng S (2004) Study on accelerated pavement testing on flexible base asphalt pavement. In: Proceedings on symposium about road engineering, pp 205–210

Zhang X, Chen J, Kong F (2005) The research on heavy traffic anti- rut bituminous pavement. J Petrol Asphalt 19(6):7–11