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Research Article

Influence of Axle Load and Asphalt Layer Thickness on Dynamic Response of Asphalt Pavement

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Based on the test data of vehicle load test on asphalt pavement, the significance of dynamic response index of different asphalt pavement to axle load change of single and double rear axle trucks is analyzed. The changes of horizontal strain at the bottom of asphalt layer, vertical compressive stress at the top of subgrade, and vertical displacement of transition layer and bottom compressive stress before and after laying of middle and upper layers are revealed. The test results show that reducing the thickness of asphalt layer or increasing the vehicle axle load can lead to the more unfavorable stress-strain distribution in asphalt pavement under driving load. The influence of the fluctuation of truck axle load or asphalt layer thickness on the stress-strain distribution in asphalt pavement varies with the type of pavement structure, pavement response index, vehicle driving speed, vehicle type, and the horizon of the measuring point. The transverse strain at the bottom of the asphalt layer is more affected by the axle load and the thickness of the asphalt layer than the longitudinal strain at the bottom of the asphalt layer. The measured value of the dynamic response index of the semirigid asphalt pavement is more affected by the axle load than that of the inverted asphalt pavement. However, the measured value of the dynamic response index of the semi-rigid asphalt pavement is less affected by the thickness of the asphalt layer when the thickness of the asphalt layer changes within a certain range. The tensile strain part of the longitudinal strain at the bottom of the asphalt layer and the compressive strain part of the transverse strain at the bottom of the asphalt layer are greatly affected by the thickness of the asphalt layer. The sensitivity of fatigue life of asphalt pavement of inverted structure to driving speed and axle load is less than that of semirigid structure. The research results can provide reference for the analysis of the asphalt pavement disease mechanism and provide guidance for asphalt pavement structural design and service life analysis.

1. Introduction

Axle load has a significant influence on the response law and measured values (stress-strain field and displacement field) of asphalt pavement structure [1, 2], and the development and extension of pavement diseases are sensitive to the size of axle load and the number of load actions [3–6]. On the contrary, a larger thickness of asphalt layer can effectively improve the bearing capacity of asphalt pavement, increase the diffusion range of pavement load, and reduce the damage effect of overload on pavement. Therefore, the damage effect of driving load on pavement can be reduced by increasing the thickness of asphalt layer or reducing the axle load of vehicle.

Under small axle load or no-load, the vehicle has less static load on the pavement, but it is more prone to severe vertical vibration. Especially when the pavement flatness is poor, a large additional load will be generated on the road surface [7–9]. The comprehensive damage effect of the vehicle on the pavement under small axle load or no-load is not low. The damage effect of the vehicle on the pavement is the superposition of the static load and dynamic load of the vehicle on the pavement. Sargand et al. [10] relied on Ohio test track permanent asphalt road interview section WAY-30 to test the effects of speed, load (biaxial 179 kN and uniaxial 125 kN), and load offset on the dynamic response of asphalt pavement at high and low temperatures, but the axle load and pavement structure form are relatively single. Cao et al. [11, 12] analyzed the deflection and modulus characteristics of inverted asphalt pavement and semirigid asphalt pavement based on FWD measured deflection basin data. Assogba et al. [13] studied the strain response law of the bottom of each asphalt layer in the pavement structure by combining numerical simulation and field test, and overloading can lead to extremely unfavorable fatigue life of semirigid asphalt pavements. Wang [14] studied the regularity of reflective crack propagation of asphalt pavement under the coupling action of vehicle dynamic load and temperature. Heavy and overloaded vehicles will accelerate fatigue cracking. Liu et al. [15] analyzed the dynamic stress response of flexible asphalt pavement under multiwheel random dynamic load and moving constant dynamic load of heavy vehicles. Dong et al. [16] studied the strain response of asphalt pavement with semirigid base (5 different slopes) under the action of double rear axle truck and three different axle loads. Relying on the accelerated loading test equipment, Guan et al. [17] studied the dynamic response characteristics of indoor full-scale asphalt concrete pavement under moving load. However, the thickness of asphalt pavement used is too thin to completely reproduce the mechanical characteristics of common pavement structures. Guan et al. [18] studied the dynamic response characteristics of indoor full-scale asphalt concrete pavement in single-axle and dual-axle loading modes, and asphalt layer thickness did not change. The above research was mainly aimed at semirigid asphalt pavement or flexible base asphalt pavement. The inverted asphalt pavement was provided with graded crushed stone transition layer between cement stabilized crushed stone base and asphalt layer. The addition of nonlinear and granular graded crushed stone is made to more complex pavement structure and stress characteristics than semirigid base or flexible base asphalt pavement, and the graded crushed stone transition layer should be one of the key research layers. Dong et al. [19] solved the influence of axle load on the dynamic response law of inverted asphalt pavement by theoretical calculation method. Ai et al. [20] studied the influence of axle load on the bottom strain of asphalt layer of inverted asphalt pavement, but the author did not test the mechanical response index of graded crushed stone transition layer.

Under the action of driving load, increasing the thickness of asphalt layer can effectively reduce the measured value of dynamic response index of asphalt pavement structure. Guo et al. [21] used nonlinear numerical simulation method to analyze the internal response law of fully flexible base asphalt pavement under different thickness, but numerical simulation cannot fully characterize the actual response characteristics of more complex material and environmental conditions. Han et al. [22] studied the strain variation characteristics of the bottom of the combined asphalt pavement tested by 20 t double rear axle truck before and after the upper layer is paved, but the pavement structure and load form were relatively single. At the same time, there were few studies on the significance of the change of asphalt layer thickness based on the analysis of the response characteristics of inverted asphalt pavement based on the field test data.

In view of this, the dynamic response characteristics of semirigid asphalt pavement and inverted asphalt pavement under different axle loads are tested by single rear axle truck and double rear axle truck, and the effects of axle load on the vertical compressive stress top surface of subgrade, the vertical displacement and vertical compressive stress of transition layer, and the transverse or longitudinal strain at the bottom of asphalt layer are analyzed. Based on the test data of pavement mechanical response indexes under different asphalt layer thickness tested by single rear axle truck, the influence of thickness on the dynamic response characteristics of different asphalt pavement structures is revealed, and its fatigue life was analyzed.

2. Test Scheme Layout of Test Section

2.1. Pavement Structure Composition of Test Section. The asphalt pavement dynamic response test section of Suining Guangzhou expressway is paved with three pavement structures: structure S1 (semirigid asphalt pavement), structure S2 (inverted structure 1), and structure S3 (inverted structure 2). Its composition is shown in Figure 1. The flatness of the road section is tested by continuous flatness meter. The flatness of the upper layer is 0.5 mm, the middle layer is 0.7 mm, and the lower layer is 0.9 mm. The overall flatness is good.

2.2. Layout Scheme of Sensing Elements. The layout of sensing elements in the test section takes structure S3 as an example, as shown in Figure 2. The sensing elements were installed in the dynamic response test section of the asphalt road, including horizontal asphalt strain gauges (transversal and longitudinal), vertical large deformation strain gauges, earth pressure gauges, and temperature sensors.

2.3. Test Scheme. The damage to asphalt pavement is mainly caused by trucks. According to statistics, the two main types of loads on highways are single rear axle freight cars (type 12 freight cars) and double rear axle freight cars (type 15 freight cars), and they are selected in the test section to test the dynamic response of asphalt pavement (as shown in Figure 3). The wheel pressures of front and rear axles of single rear axle freight cars are 0.7 MPa and 1.1 MPa, respectively, and the wheel pressures of front and rear axles of double rear axle freight cars are 1.2 MPa. The dynamic data acquisition instrument (Model: TST3826F) has 60 channels in total, and the sampling frequency for field test is 1 kHz.

Considering that under the action of driving load, the longitudinal strain characteristics of the bottom of the asphalt layer show the alternating change of tension and pressure (as shown in Figure 4). While the fatigue fracture and fatigue life of the asphalt mixture are significantly different from those under the action of simple tensile stress under the alternating load of tension and pressure. The strain cycle amplitude shall be selected as the design parameter $\Delta\varepsilon$ in the process of dynamic design of asphalt pavement, and the number of strain cycles shall be selected for the design index. It should be pointed out that the strain amplitude of longitudinal or transverse strain at the bottom

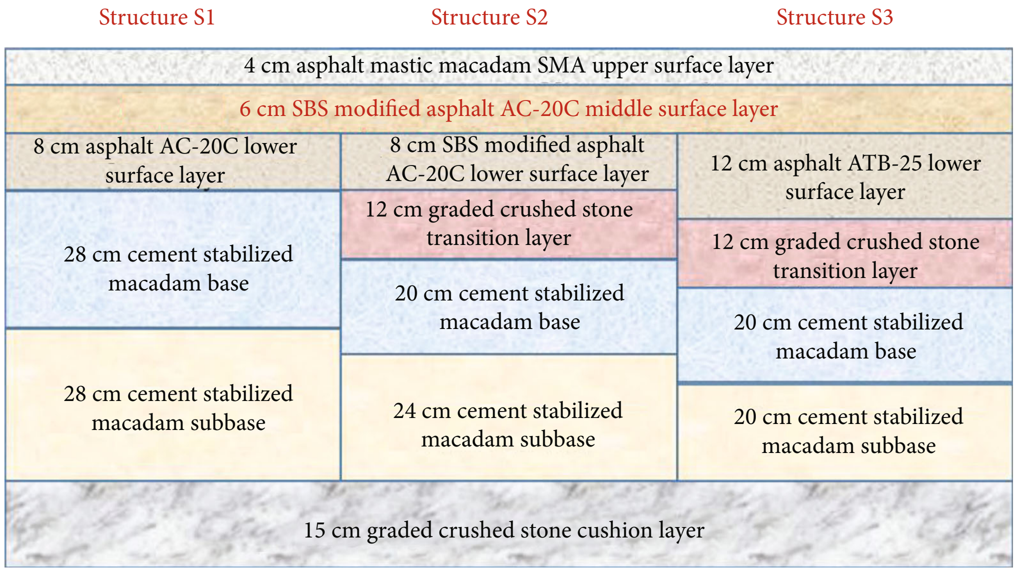


Figure 1: The test section pavement structure.

of asphalt layer is the sum of the absolute values of tensile and compressive strain [23, 24]. Unless otherwise specified, the strain or stress value used in the later analysis refers to the peak value of the corresponding axial position on the time history curve.

$$\Delta\varepsilon = \varepsilon_{max} - \varepsilon_{min}, \quad (1)$$

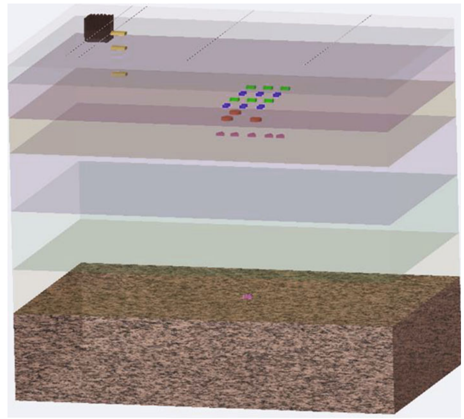
where $\Delta\varepsilon$ is the strain cycle amplitude ($\mu\varepsilon$), ε_{max} is the maximum tensile strain ($\mu\varepsilon$), and ε_{min} is the maximum compressive strain ($\mu\varepsilon$).

3. Influence of Axle Load on Dynamic Response of Asphalt Pavement

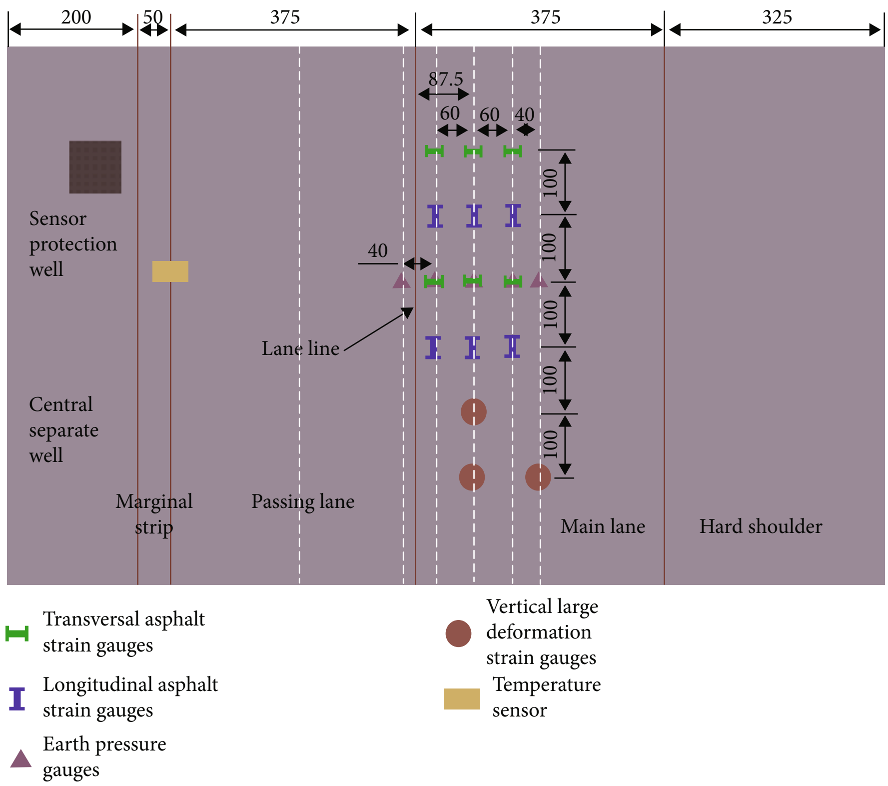
According to the characteristic mechanical index test data of asphalt layer, transition layer, and subgrade, the relationship between each index and axle load is established, as shown in Figures 5–9. From this, the following basic understanding can be obtained.

(1) The measured values of each asphalt pavement dynamic response index increase with the increase of axle load, but the increase range of different pavement dynamic response indexes is different. The causes include different sensitivity of different types of sensing elements, differences in the discreteness of on-site compactness and material properties at different locations, differences in the pavement structural characteristics or physical significance represented by each index (strain, stress, displacement, etc.), the test layer has different material characteristics (asphalt mixture has viscoelastic characteristics, and graded crushed stone has nonlinear characteristics), and the variation of temperature and humidity in the test process. Taking the response of the rear axle of the single rear axle truck of structure S2 (the driving speed is 20 km/h) as an example, when the axle load increases from 9.66 t to 16.38 t, the longitudinal and transverse strain at the bottom of the asphalt layer, the vertical compressive stress at the top of the subgrade, the vertical compressive stress at the bottom of the transition layer, and the vertical displacement at the top of the transition layer increase by 8.33%, 61.48%, 45.39%, 40.80%, and 17.01%, respectively. On the whole, the transverse strain at the bottom of the asphalt layer is more affected by the axle load than the longitudinal strain

(2) The amplitude of dynamic response index of each asphalt pavement with the increase of axle load varies with the type of pavement structure. Taking the load response of the rear axle of a single rear axle truck when the driving speed is 20 km/h as an example, when the axle load increases from 9.66 t to 16.38 t, the vertical compressive stress on the top surface of the subgrade of structure S1 and structure S2 increases by 87.6% and 45.39%, respectively; the longitudinal strain at the bottom of the asphalt layer of structure S1 and structure S2 increases by 81.78% and 8.33%, respectively, and the transverse strain at the bottom of the asphalt layer of structure S1 and structure S2 increases by 68.65% and 61.48%, respectively. Overall, the sensitivity of structure S1 to the influence of axle load is greater than that of structures S2 and S3. Under the asphalt layer of structures S2 and S3 is the granular graded crushed stone layer, which has a certain effect of absorbing stress, and the less the modulus of the graded crushed stone is than the cement stabilized crushed stone layer under the asphalt layer of structure S1, so the load sensitivity of inverted asphalt pavement is less than that of semirigid asphalt pavement

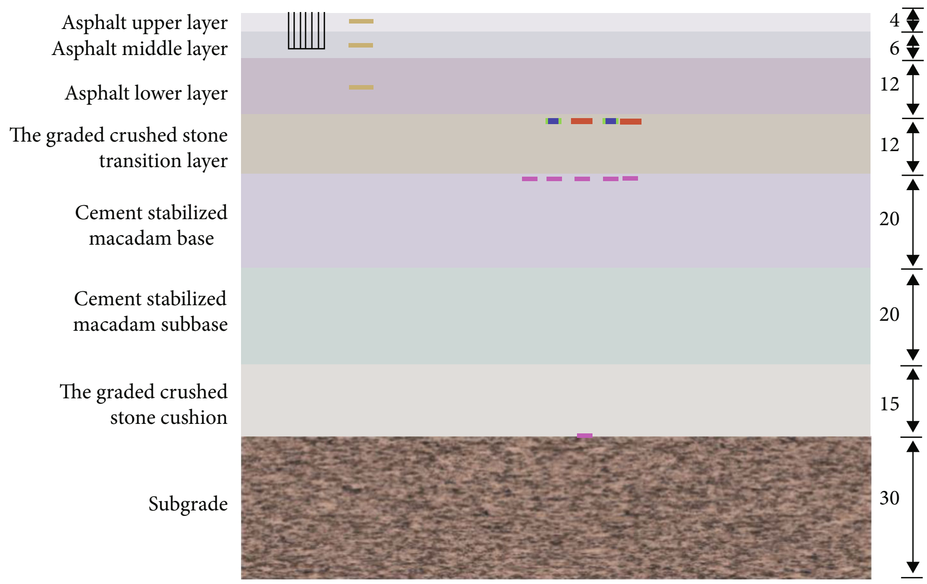


(a) Spatial arrangement of sensors



(b) Sensor layout

Figure 2: Continued.



(c) Schematic diagram of the transverse section of the sensor in the pavement structure

Figure 2: Schematic diagram of structure S3 sensing element (unit: cm).

(a) Single rear axle truck

(b) Double rear axle truck

Figure 3: Asphalt pavement dynamic response test.

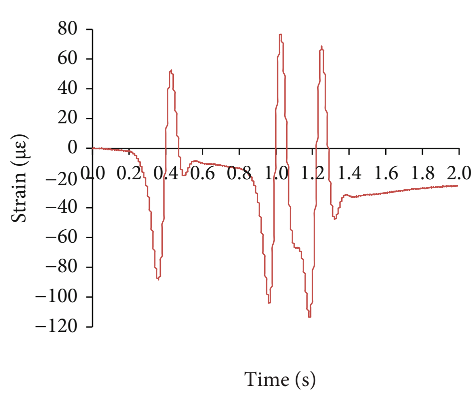
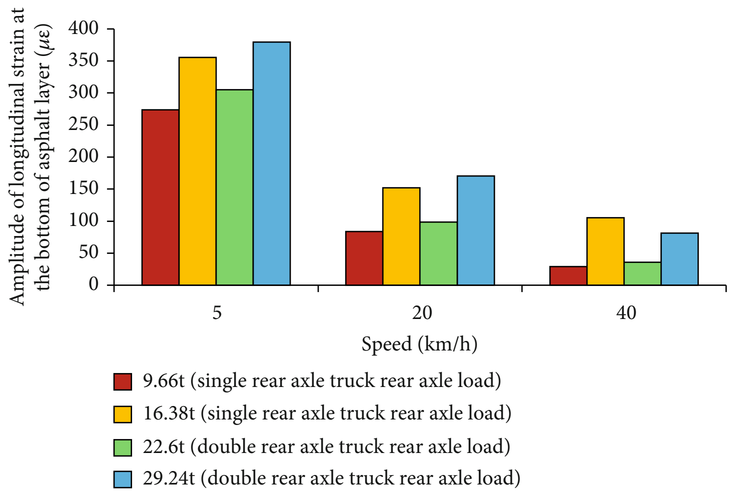


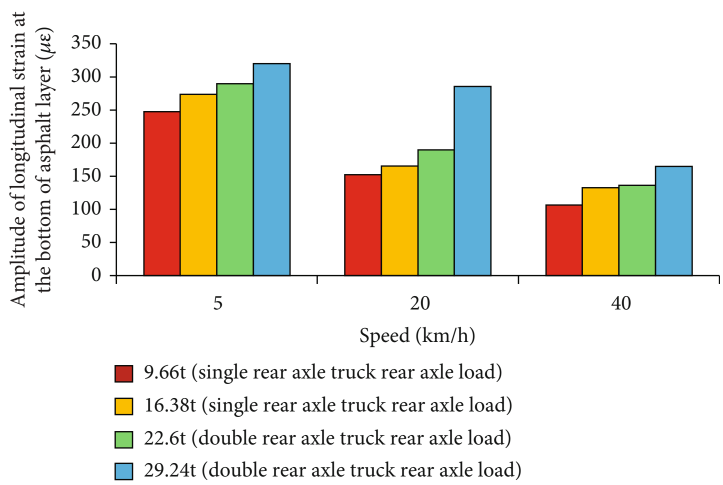
Figure 4: Truck loads move far away from the sensor location.

(3) The increment of the same axle load at different speeds has different effects on the dynamic response index. Taking the rear axle response of the single rear axle truck of structure S2 as an example, when the axle load increases from 9.66 t to 16.38 t and the driving speed is 5 km/h, 20 km/h, and 40 km/h, the longitudinal strain at the bottom of the asphalt layer increases by 10.57%, 8.33%, and 24.96%, respectively, the transverse strain at the bottom of the asphalt layer increases by 33.9%, 61.48%, and 83.83%, respectively, and the vertical compressive stress on the top surface of subgrade increases by 54.46%, 45.39%, and 44.33%, respectively. Vertical compressive stress on top surface of subgrade is less affected by dynamic load and speed, other indexes increase gradually with the increase of speed, and the measured value of pavement dynamic response index is greatly affected by axle load and speed. This is mainly related to the spread of the load

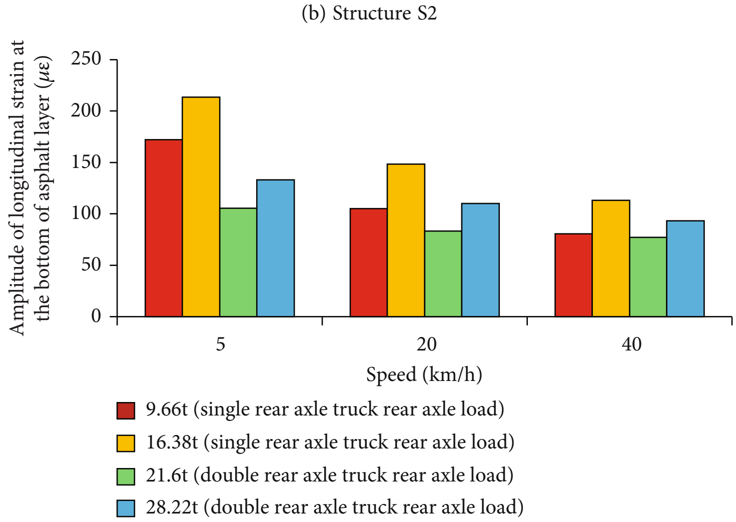
(4) In addition to the vertical compressive stress on the top surface of the subgrade, with the increase of the axle load of single rear axle and double rear axle trucks, the sensitivity of the measured value of the dynamic response index of the asphalt pavement is



(a) Structure S1



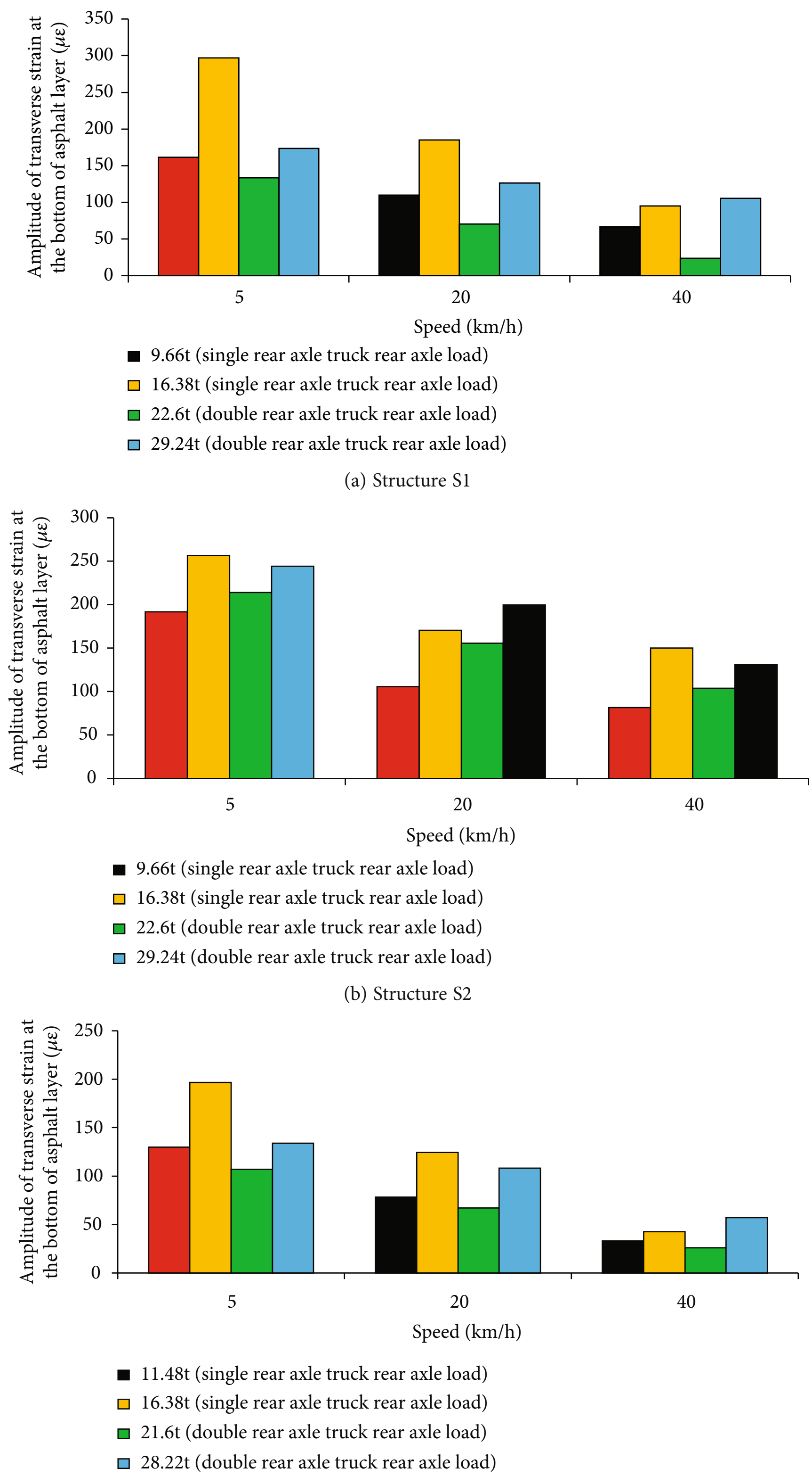
(b) Structure S2



(c) Structure S3

FIGURE 5: Relation between longitudinal strain amplitude at bottom of asphalt layer and axle load.

significantly different. Taking the response of structure S2 (the driving speed is 40 km/h) as an example, when the axle load of a single tire on the rear axle of the truck increases by about 70%, the longitudinal strain at the bottom of the asphalt layer produced by the rear axle of the single rear axle truck increases

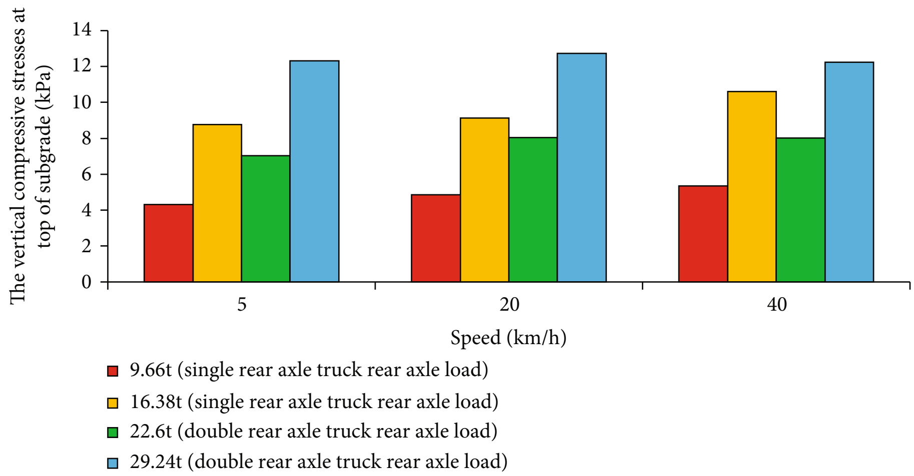


(a) Structure S1

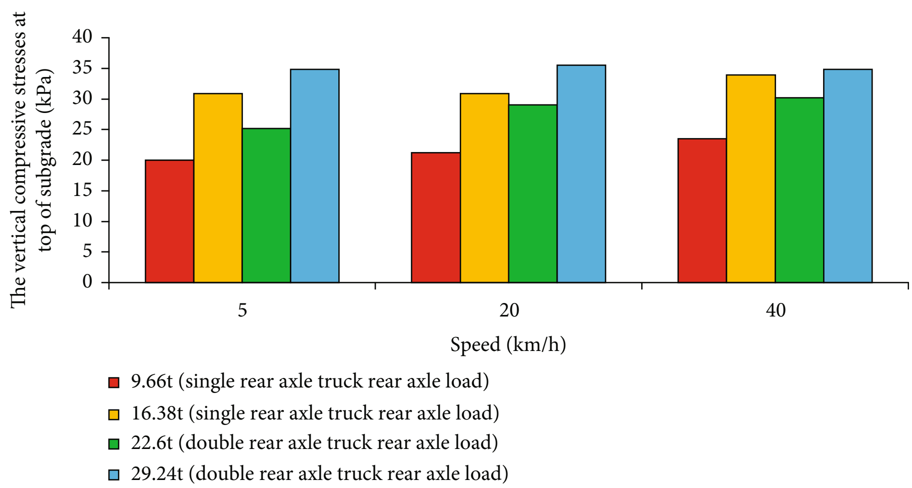
(b) Structure S2

(c) Structure S3

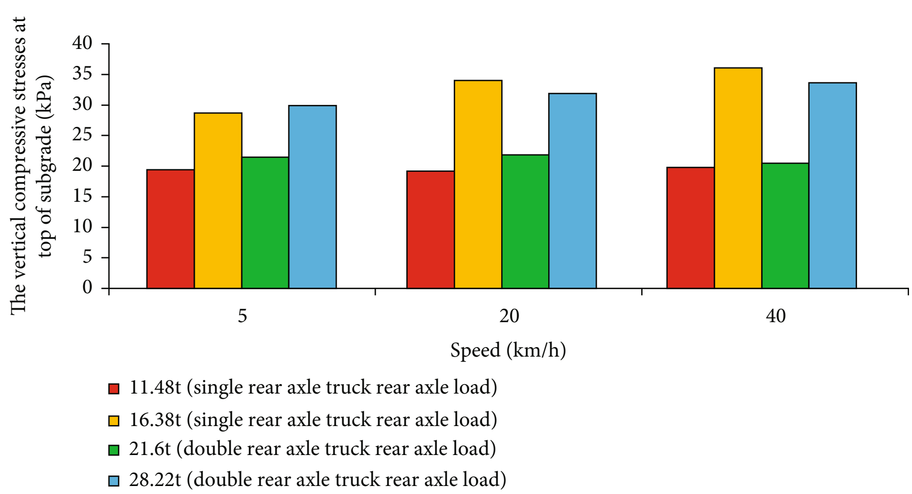
Figure 6: Relation between transverse strain amplitude at bottom of asphalt layer and axle load.



(a) Structure S1

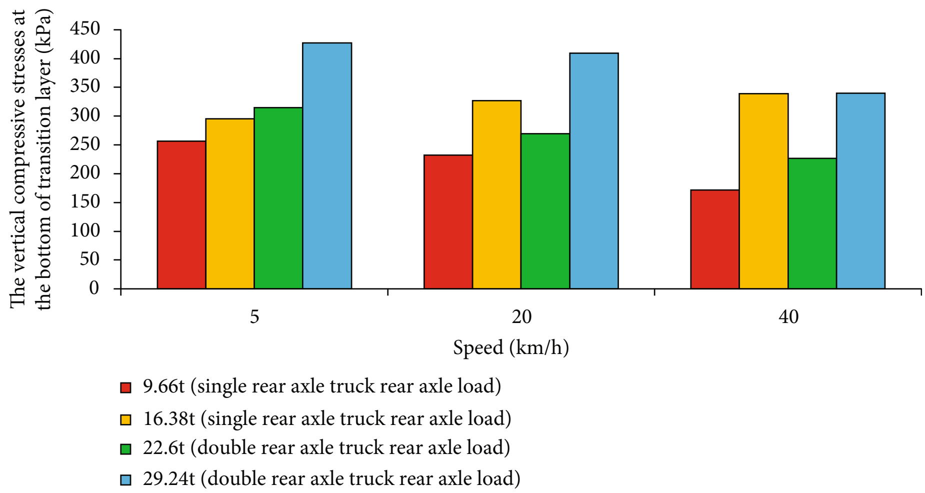


(b) Structure S2

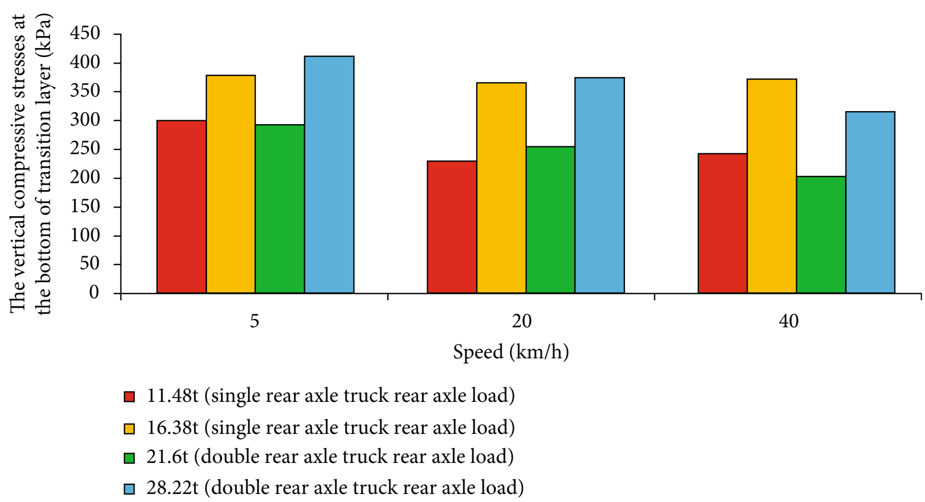


(c) Structure S3

Figure 7: Relation between vertical compressive stresses at top of subgrade and axle load.



(a) Structure S2



(b) Structure S3

Figure 8: Relation between vertical compressive stresses at the bottom of transition layer and axle load.

by 24.96%, which is much less than the increase of 49% (after linear conversion), and the fatigue damage of the double rear axle truck to the pavement is greater than that of the single rear axle truck. This is mainly due to the superposition effect of the dual rear axle truck loads

4. Effect of Asphalt Layer Thickness on Dynamic Response of Asphalt Pavement

Different asphalt mixture types are used for the upper middle and lower layers of asphalt in the test section, but according to the measured values of indoor dynamic modulus test, the dynamic modulus difference of each asphalt mixture is not significant. It can be considered that the modulus of asphalt mixture in different layers is approximately equal, that is, the factor affecting the measured value of asphalt pavement response index before and after the laying of middle layer or upper layer is the thickness of asphalt layer [25–27]. Therefore, in the test section, the vehicle loading test is used to test the dynamic response of the pavement before and after the laying of the middle or upper layer, to analyze the influence of the thickness of the asphalt layer on the dynamic response of the asphalt pavement. The rear axle load of the single rear axle truck used for the dynamic response test of the top surface of the middle and lower layers of the three pavement structures is 6 t, and the rear axle load of the single rear axle truck used for the top surface test of the upper and middle layers is 11 t and 16 t.

From Figures 10 and 11, it can be seen that a larger asphalt layer thickness can increase the resistance of the road to vehicle load, and the measured values of each mechanical response index show a decreasing trend, but the measured values of each mechanical index of structure S3 decrease more than that of structure S1 and structure S2. When the single rear axle truck is loaded at different layers of asphalt pavement, the compressive strain part of the longitudinal strain at the bottom of the asphalt layer is small, and its variation regularity is poor with the increase of the thickness, but the tensile strain part decreases with the increase of the thickness of the asphalt layer. The compressive strain part of the transverse strain at the bottom of the asphalt layer decreases greatly with the

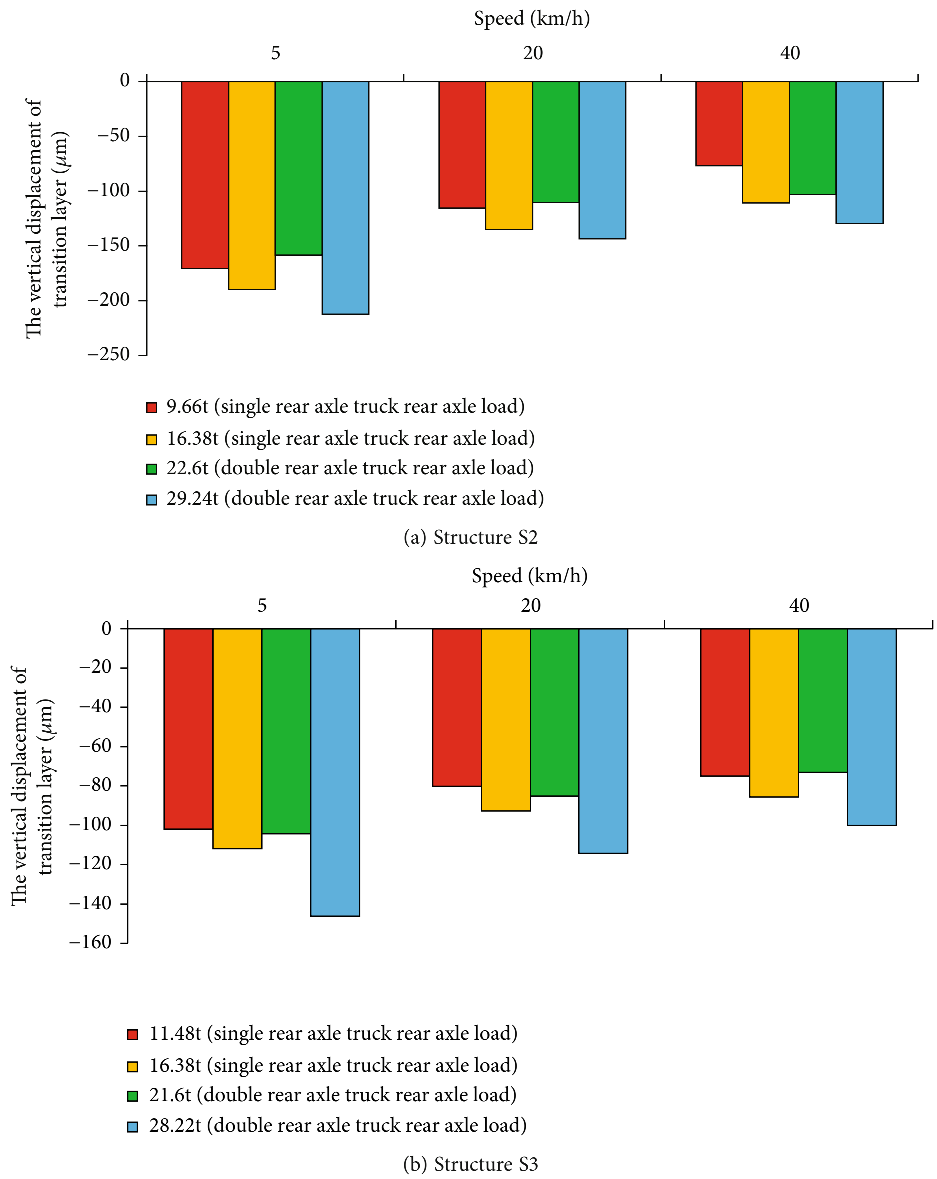
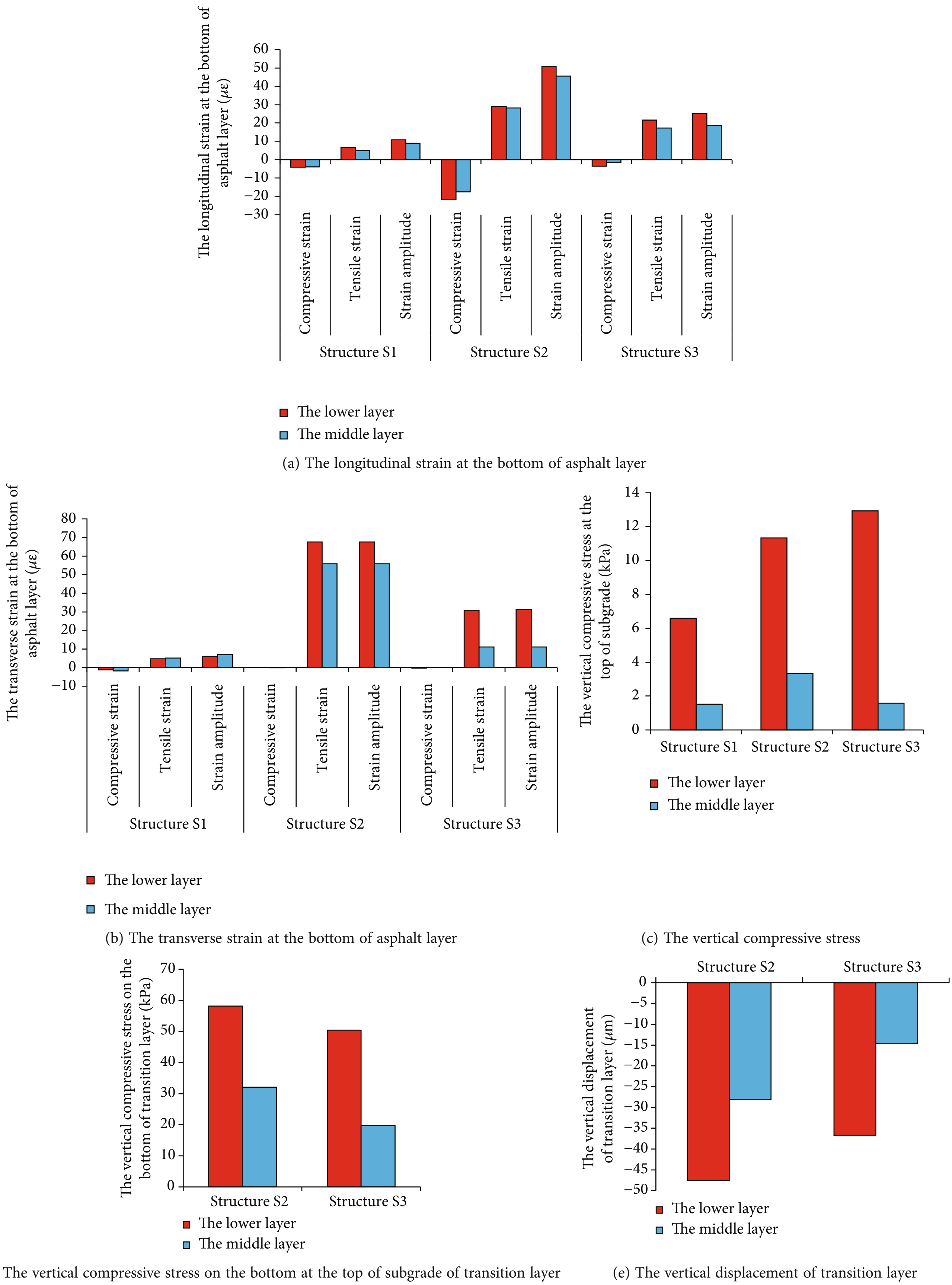


Figure 9: Relation between vertical displacement of transition layer and axle load.

increase of the thickness of the asphalt layer. After the upper layer is laid, the transverse strain at the bottom of the asphalt layer under most working conditions only has the tensile strain part, but the compression strain part. The influence of the thickness of inverted asphalt pavement on the longitudinal strain amplitude of the bottom of asphalt layer is less than that of the transverse strain amplitude of the bottom of asphalt layer, which is consistent with the conclusion of numerical simulation [17]. In addition, the vertical compressive strain on the top surface of the soil foundation decreases relatively greatly after the laying of the middle layer (70 ~90%), but it decreases slightly after the laying of the upper layer (3 ~ 16%). The vertical compressive strain at the bottom of the graded crushed stone transition layer and the vertical displacement of the transition layer decrease significantly after the laying of the middle layer and the upper layer, and the reduction range of the two layers is roughly the same (both between 30% and 60%), and the thicker asphalt surface layer has little effect on the improvement of subgrade deformation, but when the thickness of asphalt layer increases within a certain range, the thicker asphalt layer significantly improves the mechanical and deformation characteristics of graded crushed stone transition layer. With the increase of the axle load of the rear axle of the truck (11 t to 16 t), the response value of each mechanical index increases correspondingly. On the contrary, with the increase of the thickness (4 cm upper layer is laid on the middle surface layer), the response value of each mechanical index decreases correspondingly, but the influence degree of the thickness and axle load on the response value of the mechanical index is different from the layer, test index, and axle load of the test index. If the axle load of the rear axle is reduced from 16 t to 11 t, when the single rear axle truck is loaded on the top of the middle surface course, the longitudinal strain amplitude at the bottom of the asphalt surface course and the vertical compressive stress at the top of the subgrade are reduced by 18.78% and 31.05%, respectively.



(a) The longitudinal strain at the bottom of asphalt layer

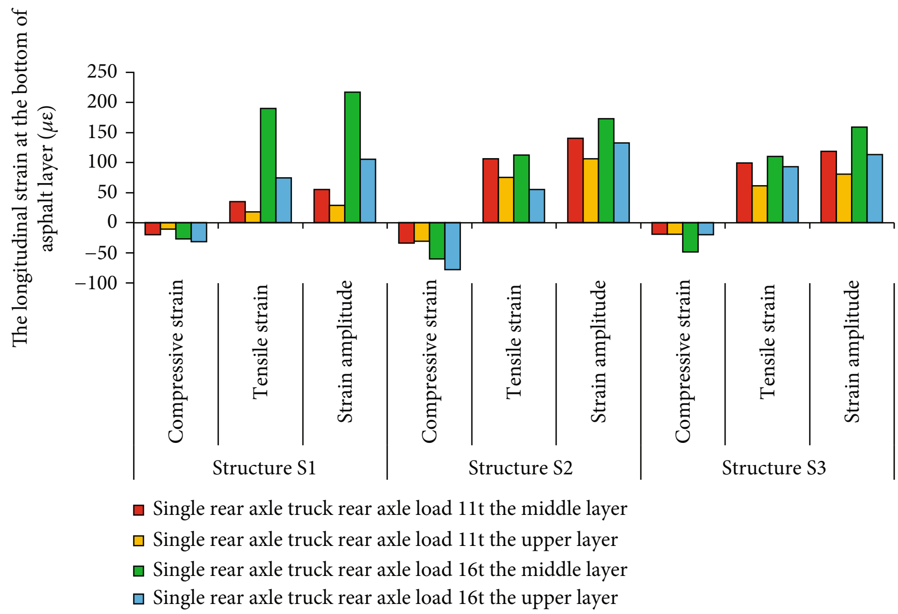
(b) The transverse strain at the bottom of asphalt layer

(c) The vertical compressive stress

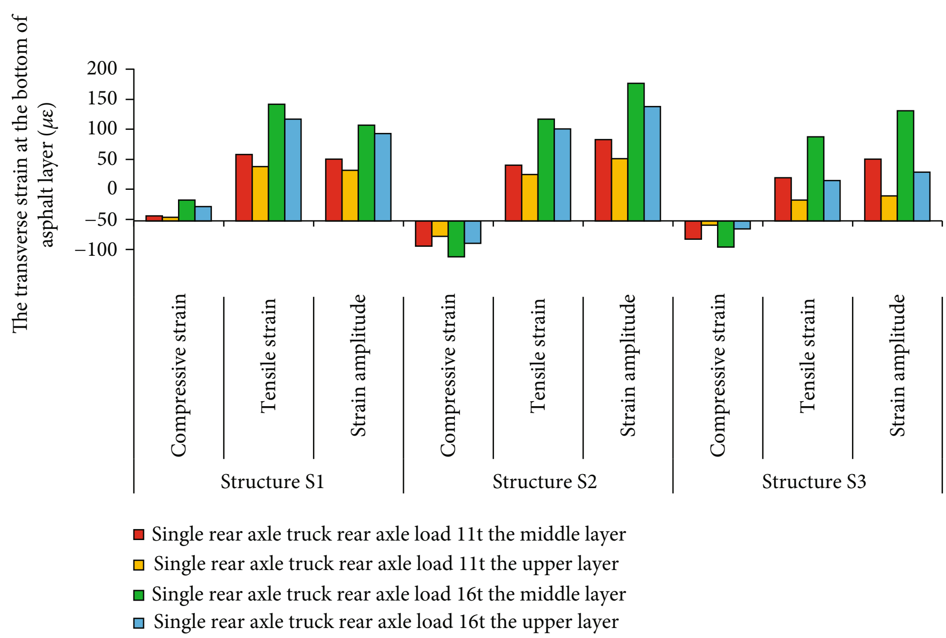
(d) The vertical compressive stress on the bottom at the top of subgrade of transition layer

(e) The vertical displacement of transition layer

FIGURE 10: Change of asphalt pavement response before and after middle layer laying.

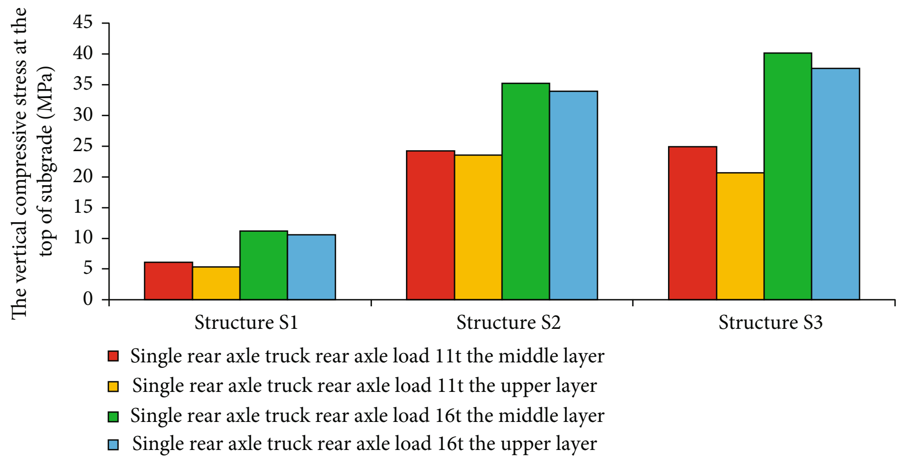


(a) The longitudinal strain at the bottom of asphalt layer

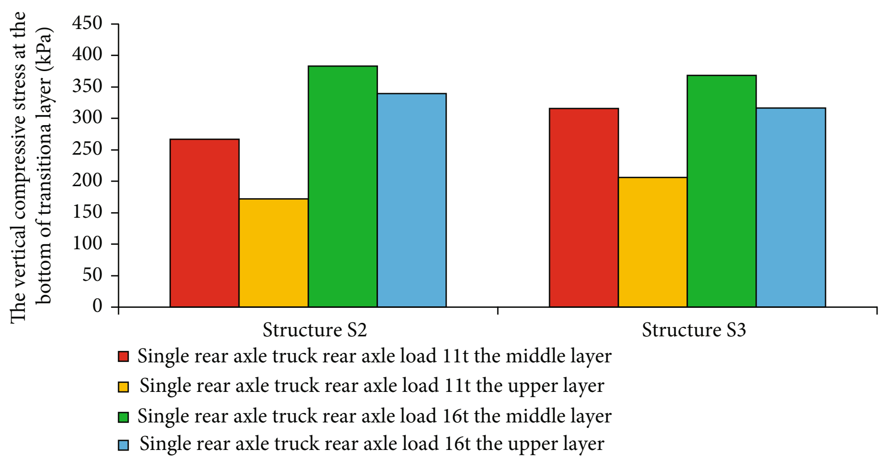


(b) The transverse strain at the bottom of asphalt layer

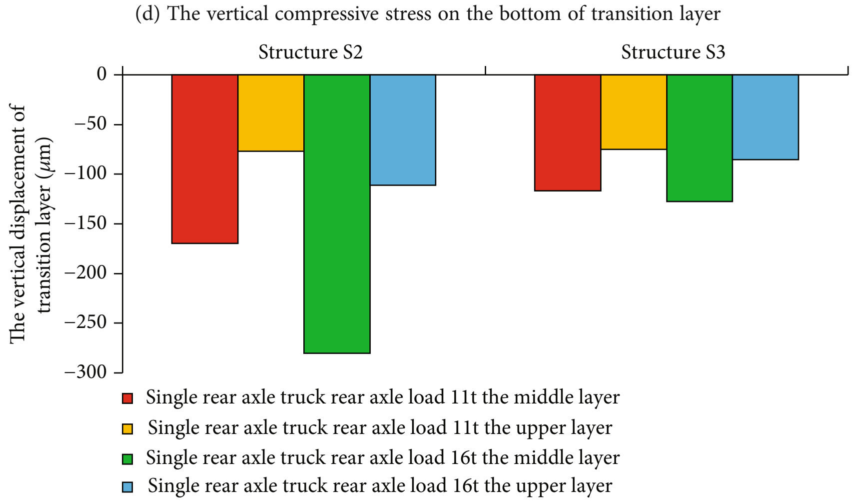
Figure 11: Continued.



(c) The vertical compressive stress at the top of subgrade



(d) The vertical compressive stress on the bottom of transition layer



(e) The vertical displacement of transition layer

FIGURE 11: Change of asphalt pavement response before and after top layer laying.

However, after the 4 cm upper layer is laid on the middle surface course, the longitudinal strain amplitude at the bottom of the asphalt layer and the vertical compressive stress at the top of the subgrade (the axle load of the rear axle is 11 t) are reduced by 24.17% and 3.02%, respectively.

In addition, there are significant differences in the location of the maximum tensile stress between semirigid and inverted asphalt pavement [28]. The former appears at the bottom of the middle layer, the crack first appears in the middle layer, and the latter often appears at the bottom of the lower layer [29, 30]. It is necessary to improve the crack resistance of the lower layer. It is suggested to use rich asphalt mixture or add rich asphalt layer to improve the crack resistance of the lower layer.

Table 1: Estimation fatigue life of asphalt surface.

Structure type	Single rear axle				Double rear axle			
	Rear axle load/t	Velocity/(km/h)	$N_{f1}/(10^6)$ Loading on upper layer	$N_{f1}/(10^6)$ Loading on middle layer	Rear axle load/t	Velocity/(km/h)	$N_{f1}/(10^6)$ Loading on upper layer	$N_{f1}/(10^6)$ Loading on middle layer
Structure S1	16.38	5	0.5	/	29.24	5	0.4	/
	16.38	20	14.9	/	29.24	20	9.5	/
	16.38	40	63.7	5.6	29.24	40	176.6	25.5
	9.66	5	1.4	/	22.6	5	0.9	/
	9.66	20	159.6	/	22.6	20	83.0	/
	9.66	40	11047.7	1302.8	22.6	40	4512.8	176.1
Structure S2	16.38	5	1.8	/	29.24	5	1.0	/
	16.38	20	13.5	/	29.24	20	1.5	/
	16.38	40	31.9	17.7	29.24	40	13.5	/
	9.66	5	2.7	/	22.6	5	1.4	/
	9.66	20	18.5	/	22.6	20	7.7	/
	9.66	40	77.2	40.3	22.6	40	28.7	/
Structure S3	16.38	5	2.1	/	28.22	5	13.6	/
	16.38	20	8.8	/	28.22	20	28.8	/
	16.38	40	25.9	15.7	28.22	40	55.6	/
	11.48	5	4.9	/	21.6	5	34.1	/
	11.48	20	34.8	/	21.6	20	87.0	/
	11.48	40	99.6	50.4	21.6	40	119.2	/

5. Damage Analysis of the Coupling Effect of Axle Load and Asphalt Layer Thickness on the Asphalt Layer

The fatigue characteristics of asphalt pavement are closely related to the bottom tensile strain of asphalt mixture layer. The bottom tensile strain of asphalt layer under different load conditions is measured on site to estimate the fatigue life of asphalt layer. (Code for design of highway asphalt pavement JTG D50-2017) Prediction of fatigue cracking life of asphalt mixture layer based on bottom tensile strain of asphalt layer is as in formula (2).

$$N_{f1} = 6.32 \times 10^{15.96-0.29\beta} k_a k_b {k_{T1}}^{-1} \left(\frac{1}{\varepsilon_a}\right)^{3.97} \left(\frac{1}{E_a}\right)^{1.58} (\text{VFA})^{2.72}, \quad (2)$$

$$k_b = \left[\frac{1 + 0.3E_a^{0.43}(\text{VFA})^{-0.85} e^{0.024h_a - 5.41}}{1 + e^{0.024h_a - 5.41}}\right]^{3.33}, \quad (3)$$

where N_{f1} is the fatigue cracking life of asphalt mixture layer (times). β as the target reliability index, the expressway is taken as 1.65. k_a is the adjustment coefficient of seasonally frozen soil area, and 1.0 is taken for hilly area in eastern Sichuan. k_b is the fatigue loading mode coefficient, calculate with formula (3). E_a is the dynamic compression modulus of asphalt mixture (MPa). Combined with the existing research results [31–33], the 46°C dynamic modulus of asphalt mixture under structure S1, structure S2, and structure S3 is 1447 MPa, 1212 MPa, and 992 MPa, respectively. VFA is the asphalt saturation (%) of the asphalt mixture. The asphalt saturation of the asphalt mixture under structure S1, structure S2, and structure S3 determined by the indoor test is 71.6%, 70.5%, and 62.8%, respectively. h_a is the thickness of asphalt mixture (mm). k_{T1} is the temperature adjustment coefficient, taken as 1.46. ε_a is the strain amplitude at the bottom of the asphalt mixture layer (10^{-6}), and field-measured values shall be adopted.

The fatigue life of asphalt pavement is determined by the longitudinal strain at the bottom of the asphalt layer. A comparative study of the fatigue life differences of three asphalt pavement structures under different axle loads and vehicle speeds (as shown in Table 1) shows that higher driving speed and lower axle load are helpful to improve the fatigue life of asphalt mixture, and under the condition that the axle load of a single shaft is similar, the fatigue life of asphalt surface course estimated by the longitudinal strain amplitude of asphalt layer bottom tested by single rear axle truck is greater than that estimated by double rear axle truck. At the same time, the fatigue life of asphalt pavement of semirigid structure is more sensitive to driving speed and axle load than that of inverted structure [34, 35]. Obviously, although the thickness difference of the asphalt layer when the top surface of the upper layer is loaded and the top surface of the middle layer is loaded is only 4 cm, there is a large gap between the fatigue life of the two. Among them, the fatigue life of the former semirigid asphalt pavement is nearly 10 times that of the latter, and the fatigue life of the former inverted asphalt pavement is nearly 2 times that of the latter. The fatigue life of the inverted asphalt pavement is less affected by the thickness than that of the semirigid asphalt pavement. But numerically, the calculated value of inverted fatigue life is lower than that of semirigid asphalt pavement.

6. Conclusion

(1) Under the action of driving load, increasing the thickness of asphalt layer or reducing the vehicle axle load can reduce the measured value of the internal dynamic response index of asphalt pavement structure, and the sensitivity of the longitudinal strain amplitude at the bottom of asphalt layer to the fluctuation of axle load is less than the transverse strain amplitude at the bottom of asphalt layer. The sensitivity of dynamic response characteristics of inverted asphalt pavement to axle load is less than that of semirigid asphalt pavement. The influence of axle load and asphalt layer thickness on the measured value of pavement dynamic response index is not equivalent

(2) The influence of axle load on the measured value of pavement dynamic response index is more significant under large driving speed. The effect of load fluctuation amplitude of single rear axle truck on asphalt pavement damage is less significant than that of double rear axle truck, and the damage effect of double rear axle trucks is more than twice that of single rear axle trucks

(3) The influence of asphalt layer thickness on the measured value of transverse strain at the bottom of asphalt layer is greater than its measured value of longitudinal strain, but the compressive strain part of the latter is less affected by the thickness of asphalt layer, the tensile strain part is more sensitive to the thickness of asphalt layer, and the compressive strain part of transverse strain at the bottom of asphalt layer decreases with the increase of asphalt layer thickness

(4) The fatigue life of semirigid asphalt pavement is more sensitive to driving speed and axle load than that of inverted structure, and the calculated value of the former is also much greater than that of the latter (more than 3 times under most axle loads and speeds). The key factors affecting the fatigue life of inverted asphalt pavement are the bearing capacity, load characteristics (axle load, axle load action times), and asphalt layer thickness of graded crushed stone in transition layer

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

No potential conflict of interest was reported by the authors.

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References

[1] R. Zhang, X. Liu, and X. Zhang, "Three-dimensional strain analysis of asphalt pavement based on vehicle–pavement model of interaction," *SN Applied Sciences*, vol. 3, no. 10, 2021.

[2] Y. Zhao, Y. Tan, and C. Zhou, "Determination of axle load spectra based on percentage of overloaded trucks for mechanistic-empirical pavement design," *Road Materials & Pavement Design*, vol. 13, no. 4, pp. 850–863, 2012.

[3] X. Chen, J. Zhang, and X. Wang, "Full-scale field testing on a highway composite pavement dynamic responses," *Transportation Geotechnics*, vol. 4, pp. 13–27, 2015.

[4] S. Liu, X. Li, D. Wang, and D. Zhang, "Investigations on the mechanism of the microstructural evolution of different coal ranks under liquid nitrogen cold soaking," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 2020, pp. 1–17, 2020.

[5] H. Wu, G. Zhao, and S. Ma, "Failure behavior of horseshoe-shaped tunnel in hard rock under high stress: phenomenon and mechanisms," *Transactions of Nonferrous Metals Society of China*, vol. 32, no. 2, pp. 639–656, 2022.

[6] X. Li, S. Chen, Q. Zhang, X. Gao, and F. Feng, "Research on theory, simulation and measurement of stress behavior under regenerated roof condition," *Geomechanics and Engineering*, vol. 26, no. 1, pp. 49–61, 2021.

[7] G. Yang, J. Zhang, H. Wang, X. B. Chen, and Y. Q. Huang, "Experimental research on dynamic response of road pavement under different loads and speeds of vehicles," *Rock and Soil Mechanics*, vol. 29, no. 11, pp. 3099–3103, 2008.

[8] Z. Dong, W. Yan, and P. L V, "Study on influence of axle load and tire pressure on dynamic wheel load," *Journal of Highway and Transportation Research and Development*, vol. 26, no. 3, pp. 27–32, 2009.

[9] G. Han, Y. Zhou, R. Liu, Q. Tang, X. Wang, and L. Song, "Influence of surface roughness on shear behaviors of rock joints under constant normal load and stiffness boundary conditions," *Natural Hazards*, vol. 112, pp. 367–385, 2022.

[10] S. M. Sargand, I. S. Khoury, and M. T. Romanello, "Seasonal and load response instrumentation of the Way-30 perpetual pavements," in *International Conference on Perpetual Pavements*, Columbus Ohio, 2006.

[11] M. Cao, W. Huang, Y. Zou, and G. Liu, "Modulus inversion layer by layer of different asphalt pavement structures," *Advances in Civil Engineering*, vol. 2021, Article ID 1928383, 2021.

[12] M. Cao, W. Huang, Y. Zou, and Z. Wu, "Equivalent resilient modulus inversion and calculation of different asphalt pavement structures," *Advances in Civil Engineering*, vol. 2021, Article ID 2620559, 2021.

[13] O. C. Assogba, Y. Tan, Z. Sun, N. Lushinga, and Z. Bin, "Effect of vehicle speed and overload on dynamic response of semi-rigid base asphalt pavement," *Road Materials and Pavement Design*, vol. 8, pp. 1–31, 2021.

[14] X. Wang, "Investigation of crack propagation in asphalt pavement under moving traffic and thermal coupled loads," *Dalian University of Technology*, 2020.

[15] D. Liu, Z. Dai, and H. Chen, "Dynamic stress response of flexible pavement under multiple wheel dynamic loads of vehicle," *China Journal of Highway and Transport*, vol. 30, no. 11, pp. 36–44, 2017.

[16] Z. Dong, P. Lv, and X. Liu, "Test on dynamic response of asphalt pavement at large longitudinal slope section," *Journal of Chang 'an University (Natural Science Edition)*, vol. 33, no. 4, pp. 7–11, 2013.

[17] Z. Guan, C. Zhang, and M. Liu, "Accelerated loading dynamic response of full-scale asphalt concrete pavement," *Journal of Traffic & Transportation Engineering*, vol. 12, no. 2, pp. 24–31, 2012.

[18] Z. Guan, C. Zhuang, and P. Zhang, "Asphalt pavement mechanical response of accelerated pavement testing in single-axle and dual-axle loading modes," *Advances in Civil Engineering*, vol. 2019, 11 pages, 2019.

[19] Z. Dong and P. L V, "Dynamic response of inverse structure asphalt pavement under moving load," *Journal of Chang 'an University (Natural Science Edition)*, vol. 28, no. 5, pp. 111–115, 2008.

[20] C. Ai, A. Rahman, C. Xiao, E. Yang, and Y. Qiu, "Analysis of measured strain response of asphalt pavements and relevant prediction models," *International Journal of Pavement Engineering*, vol. 18, no. 12, pp. 1089–1097, 2017.

[21] Y. Guo, L. Wang, A. Shen, and P. Gu, "Dynamic analysis of graded crushed stone as base of asphalt pavement," *Journal of Highway and Transportation Research and Development*, vol. 33, no. 1, pp. 27–33, 2016.

[22] W. Han, L. Zhu, J. Wei, and X. Yan, "Dynamic response analysis of asphalt pavement based on vehicle loading test," *Science Technology and Engineering*, vol. 18, no. 9, pp. 130–135, 2018.

[23] Z. Dong, Y. Zhang, and P. L V, "Fatigue performance of asphalt mixture under tensile-compressive alternatin loading," *China Journal of Highway and Transport*, vol. 26, no. 2, pp. 15–19, 2013.

[24] Z. Dong, Z. Zheng, and P. L V, "Experiment study on the influence of the vehicle velocity on the asphalt pavement dynamic response," *Journal of Zhengzhou University (Engineering Science)*, vol. 29, no. 2, pp. 123–126, 2008.

[25] C. Xiao, *Research on Dynamic Behavior and Structure Optimization for Typical Asphalt Pavement*, Southwest Jiaotong University, 2014.

[26] X. Tian, S. Zhang, B. Huang, and J. Liang, "Study on influence factors of dynamic modulus of asphalt stabilized macadam," *Journal of China & Foreign Highway*, vol. 29, no. 6, pp. 221–223, 2009.

[27] L. Qiu, Y. Zhu, D. Song et al., "Study on the nonlinear characteristics of EMR and AE during coal splitting tests," *Minerals*, vol. 12, no. 2, 2022.

[28] Y. Yang, Z. Liu, Y. Xin, H. Liu, and X. Ju, "Evolution of strain response of semi-rigid asphalt pavement under dynamic loading," *Journal of China & Foreign Highway*, vol. 2017, pp. 51–55, 2017.

[29] S. Chen and X. Zhang, "Mechanical behavior analysis of asphalt pavement structure with an inverted base layer," *Journal of Building Materials*, vol. 17, no. 4, pp. 644–648, 2014.

[30] D. Pan, K. Hong, H. Fu et al., "Numerical simulation of nano silica sol grouting for deep tunnels based on the multifield coupling mechanism," *Geofluids*, vol. 2021, Article ID 3963291, 2021.

[31] Y. You, *The Research on the Dynamic Modulus of Asphalt Mixture*, Shandong Jianzhi University, 2017.

[32] J. Liang, *Study on Dynamic Modulus and Crack Propagation of the Asphalt Pavement*, Chang 'an University, 2016.

[33] X. Shu and B. Huang, "Dynamic modulus prediction of HMA mixtures based on the viscoelastic micromechanical model," *Journal of Materials in Civil Engineering*, vol. 20, no. 8, pp. 530–538, 2008.

[34] W. Huang, M. Cao, and H. You, "Test and analysis on dynamic response of different asphalt pavement structures under traffic load," *Journal of Highway and Transportation Research and Development*, vol. 37, no. 4, pp. 1–8, 2020.

[35] D. Pan, K. Hong, H. Fu, J. Zhou, and G. Lu, "Influence characteristics and mechanism of fragmental size of broken coal mass on the injection regularity of silica sol grouting," *Construction and Building Materials*, vol. 269, p. 121251, 2021.