Research on Asphalt Mechanics based on Subgrade Stiffness

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Abstract

Asphalt pavement has the characteristics of high comprehensive strength, good plate performance, strong rigid foundation bearing capacity, and high strength and transportation capacity. Compared with ordinary cement pavement, asphalt pavement smooth, seamless, more comfortable driving, soft structure, small vibration, good driving stability; The cars and roads look great. Short engineering cycle, fast engineering molding, fast delivery, easy maintenance and other advantages. However, with the development of economic society and the change of traffic structure, some serious defects hidden in asphalt pavement are gradually exposed, which has become the cause of early damage of asphalt pavement. In order to better study the mechanical properties of asphalt pavement, this paper proposes a study on the mechanical properties of asphalt pavement based on subgrade stiffness. Through different subgrade stiffness levels, the mechanical properties of asphalt are explored, and it is concluded that increasing the subgrade modulus can not only improve the overall stiffness of pavement structure, but also improve the compressive and shear capacity of vehicles under driving load. It can also reduce the cracking and reflection cracks at the base caused by tensile stress and improve the durability of pavement structure.

Keywords

Asphalt Pavement; Subgrade Stiffness; Elasticity Modulus; Tensile Stress.

1. Introduction

At present, it is generally believed that the design life of highway subgrade should be considered as permanent subgrade [1], so as to avoid pavement structure renovation and reconstruction. In the process of subgrade construction, resilience modulus is an important mechanical parameter to characterize the deformation resistance of subgrade and pavement structure design, and plays a decisive role in the strength, stiffness, stability, service performance and life of pavement structure. Its value directly affects the design thickness and construction quality of pavement structure layer[2-4].

The mechanical properties of asphalt refer to the compressive strength, shear strength and tensile strength of asphalt (including bending strength and tensile strength). In general, asphalt mixtures have high compressive strength, but low shear and tensile strength. Therefore, asphalt pavement damage is often due to cracks or slippage and gradually expand.

The asphalt pavement has small stiffness and low flexural tension string. The common pavement structure in China is semi-rigid base asphalt pavement, which mainly relies on compressive strength and shear strength to bear the vehicle load on the pavement. Due to the relatively small thickness of the asphalt surface layer and the large stiffness of inorganic binder stabilized particles, the base of the pavement structure mainly bears the tensile stress when it is subjected to the upper load. The asphalt surface will not produce tensile stress and tensile strain, this kind of structure needs to check the tensile stress of semi-rigid base layer, which is the main factor leading to pavement cracking. [5]

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Through finite element software, the mechanical properties of asphalt pavement structure are simulated and analyzed, and the mechanical properties of asphalt pavement based on subgrade stiffness are studied. The analysis shows that under the load of overloaded vehicles, fatigue load will cause shear failure of the surface. Under the standard load, the pavement bending value decreases with the increase of subgrade stiffness. The shear stress of the base and surface decreases with the increase of subgrade stiffness. In the mechanics of materials, the product of the elastic modulus and the corresponding section is expressed as various types of stiffness. Therefore, we change the subgrade stiffness by changing the elastic modulus (Young's modulus in finite element method), so as to obtain the relationship between the mechanical properties of asphalt.

2. Experimental Study

In this chapter, the asphalt pavement structure is modeled by SOLIDWORK2016. ANSYS19.2 finite element software is used to analyze the mechanical properties of asphalt pavement structure under different subgrade stiffness and different load forms.

2.1 Construction of Asphalt Pavement Structure Model

In the use of finite element software analysis, the asphalt concrete pavement is simplified into 6 layers, from bottom to top are: soil base, lime soil, cement stabilized gravel, coarse-grained asphalt concrete, medium-grained asphalt concrete, fine-grained asphalt concrete. In this study, the pavement structure is assumed to be carried out on the basis of elastic layered system, and each structure adopts three-dimensional solid unit SOLID2016 unit for simulation.

The unit contains U_x , U_y, U_z , 3 degrees of freedom and 8 nodes,Where the translational displacement along the axis is U_z .The unit characteristics include creep, plasticity, stress strengthening, etc. So there is no need for additional parameter setting. Just the elastic modulus of the material E_0 , Poisson's ratio is defined by μ.

2.2 Calculate Parameters and Mesh Partitioning

The pavement structure adopted in engineering calculation is as follows: the surface layer adopts fine grained asphalt concrete with a thickness of 6cm; Medium grained asphalt concrete with a thickness of 9cm; Coarse-grained asphalt concrete of 17cm; The base adopts cement stabilized gravel with thickness of 28cm. Calcareous soil with a thickness of 35cm; The roadbed adopts 5.2m soil foundation. According to the test measurement and "Code for Design of Highway Asphalt Concrete Pavement" (JTGD50-2017), finally obtained the structural layer parameters of asphalt concrete pavement as shown in Table 1.

Table 1. Structural parameters of asphalt concrete pavement

Pavement structure	Layer thickness/m	Elasticity modulus/MPa	Poisson's ratio	Density/kg·m^{-3}	Damping ratio
Fine grained asphalt concrete	0.06	1680	0.25	2320	0.05
Medium grained asphalt concrete	0.09	1464	0.25	2351	0.05
Coarse-grained asphalt concrete	0.17	1280	0.25	2376	0.05
Cement-stabilized crushed stone	0.28	18200	0.35	2240	0.05
limestone soil	0.35	3460	0.35	1965	0.05
soil matrix	5.2	50	0.4	1785	0.05

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In this study, the structure is divided into hexahedral elements using a mapping network.

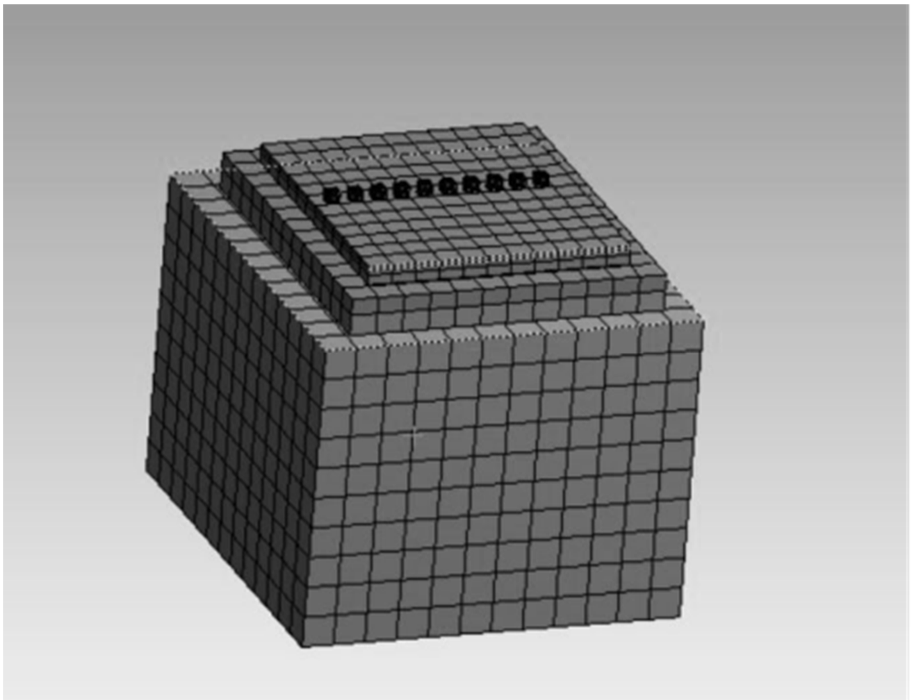

Figure 1. Model division

2.3 Analysis of Mechanical Performance of Asphalt Pavement

The loads in this study include vehicle dead weight loads. The control variable method is used to study the relationship between subgrade stiffness and mechanical properties by improving subgrade elastic modulus and controlling compressive stress, tensile stress and pavement structural parameters, since subgrade stiffness is related to subgrade elastic modulus. This paper mainly analyzes the stiffness of subgrade, tensile stress, compressive stress and bending value of asphalt pavement. Pressure is applied through vehicle model loads. As for the action area, this paper idealizes the contact area of road surface and tire into a square of 20cm×20cm, wheel spacing of 0.1m, contact area of each tire of 0.040m^2, and gap spacing between wheels on both sides of the vehicle body of 1.8m. Figure 2 is a simplified diagram of vehicle load.

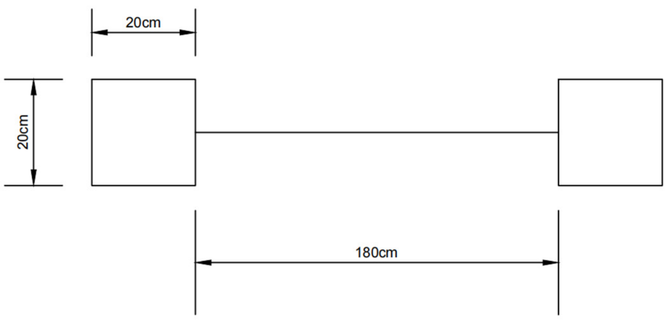

Figure 2. Simplified diagram of vehicle load

When the load acts on the road surface, the road surface will undergo vertical deformation, that is, the road surface bending value, which is the comprehensive result of the deformation of all the structural layers of the road surface (including the foundation). The surface bending value can represent the overall bearing capacity of pavement structure, and reflects the mechanical properties of foundation soil and pavement structure layer to some extent. Fig 1-2 shows the variation of pavement deflection under different coaxial loads. It can be seen from Fig 1-2 that the road deflection value increases with the increase of the overloading value. When the excess load is twice of the standard load, the road deflection value is 1.66 times of the standard load. This indicates that the greater the excess load is, the more the cumulative equivalent number of pavement axes is reduced, thus shortening the service life of the road.

3. Numerical Investigation

When the elastic modulus of subgrade is 50MPa, other parameters are the same as the above table. Five static vehicles are simultaneously loaded on the asphalt pavement structure, and the compressive stress of each tire and pavement is 50000N. It is concluded that when the elastic modulus is 50MPa, the pavement bending value is 1.5284m, and the compressive stress is 12.30MPa.

When the elastic modulus of subgrade is changed to 70MPa, other parameters are the same as the above table, and the vehicle loading remains unchanged. In this case, the bending value of road table is 1.1836mm, and the compressive stress under subgrade is 12.255MPa.

When the stiffness and elastic modulus of subgrade is changed to 90MPa, other parameters are consistent with the above table, and the vehicle loading is unchanged. In this case, the bending value of road surface is 0.98303mm, and the compressive stress is 12.219MPa.

When the roadbed stiffness elastic modulus is changed to 110MPa, other parameters are consistent with the above table, and the vehicle loading is unchanged. At this time, the road surface bending value is 0.85014mm, and the compressive stress is 12.189MPa.

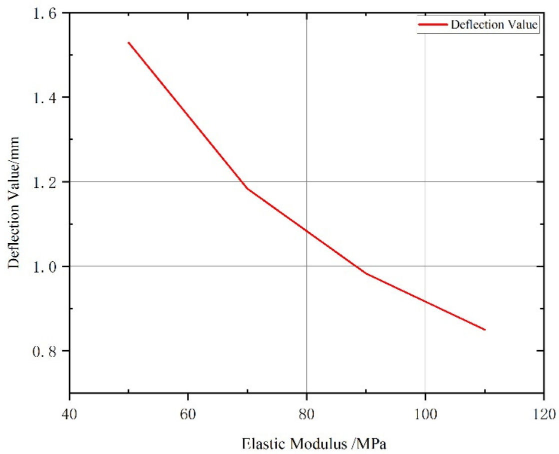

Figure 3. Diagram of deflection value changing with subgrade elastic modulus

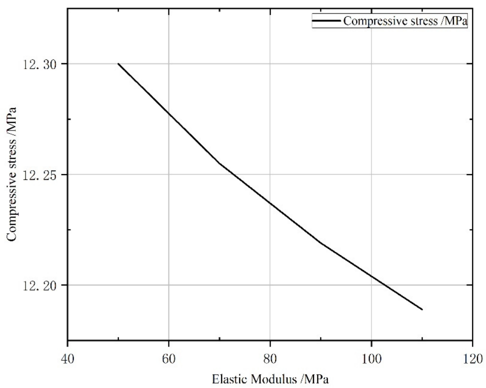

Figure 4. Change diagram of compressive stress when elastic modulus of subgrade changes

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It can be seen from the table above that the compressive stress and bending value of asphalt pavement decrease with the increase of roadbed stiffness.

When the elastic modulus of subgrade is 50MPa, other parameters are the same as the above table. Five static vehicles are simultaneously loaded on the asphalt pavement structure, and the compressive stress of each tire and pavement is 50000N. It is concluded that when the elastic modulus is 50MPa, the shear stress is the average value of each structural layer of asphalt pavement, and the shear stress is 310.46Pa.

When the elastic modulus of subgrade is changed to 70MPa, other parameters are the same as the above table, the vehicle loading remains unchanged, and the shear stress is 265.48Pa.

When the subgrade stiffness elastic modulus is changed to 90MPa, other parameters are consistent with the above table, and the vehicle loading remains unchanged, the shear stress is 223.89Pa.

When the elastic modulus of roadbed stiffness is changed to 110MPa, other parameters are consistent with the above table, the vehicle loading is unchanged, and the shear stress is 186.29Pa.

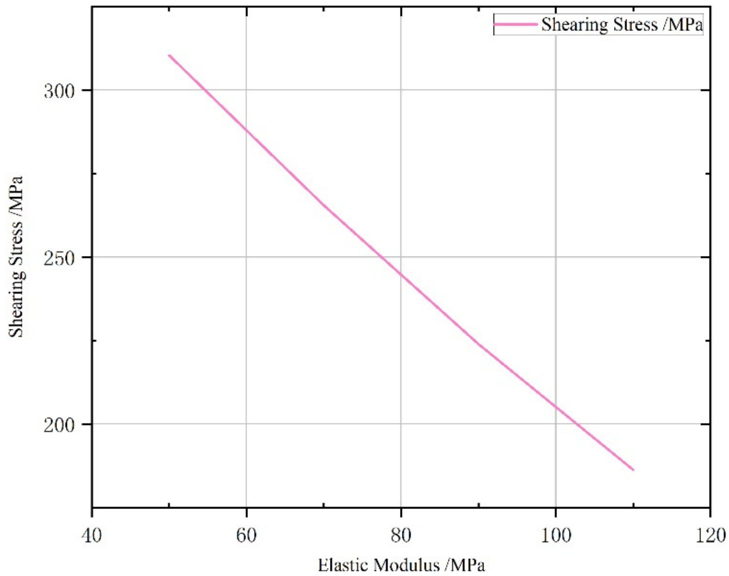

Figure 5. Change diagram of shear stress when elastic modulus of subgrade changes

It can be seen from the above table that the shear stress decreases gradually with the increase of the elastic modulus of the subgrade, which is consistent with the conclusion of the formula method in the previous chapter. Therefore, the larger the subgrade stiffness is, the smaller the shear stress the asphalt pavement receives under the same load.

The relationship between tensile stress and subgrade stiffness is analyzed and studied by applying tensile stress to the whole asphalt surface.

When the elastic modulus of subgrade is 50MPa and other parameters are the same as the above table, 500000N is applied to the asphalt surface layer. Based on the elastic modulus of 50MPa, the pavement tension is 3.0841mm and the tensile stress is 136.71Mpa.

When the elastic modulus of the subgrade is changed to 70MPa, other parameters are the same as the above table, and the tensile force is unchanged. At this time, the tensile value of the road surface is 2.5942mm, and the compressive stress of the subgrade is 136.5MPa.

When the subgrade stiffness elastic modulus is changed to 90MPa, other parameters are consistent with the above table, and the tension is unchanged. At this time, the road surface tensile value is 2.295mm, and the tensile stress is 136.35MPa.

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When the subgrade stiffness elastic modulus is changed to 110MPa, other parameters are consistent with the above table, and the tension is unchanged. At this time, the road surface tensile value is 2.0901mm, and the tensile stress is 136.22MPa.

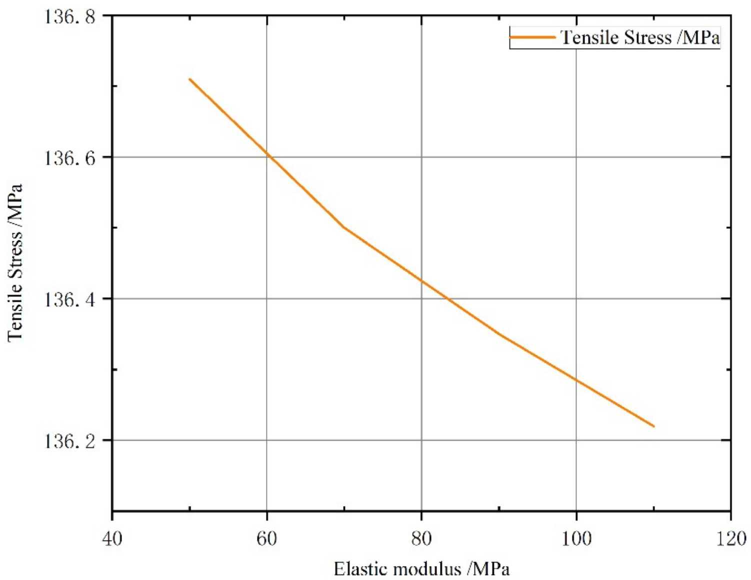

Figure 6. Change diagram of tensile stress when elastic modulus of subgrade changes

With the increase of equivalent elastic modulus of subgrade, the bending of pavement structure gradually decreases and the overall stiffness increases. When the equivalent rebound modulus increases from 50 MPa to 70 MPa, the overall stiffness increases by 22.6%. When the equivalent elastic modulus reaches 110 MPa, the overall stiffness increases by 44.4%. The maximum tensile stress at the bottom of the bed decreases with the increase of the equivalent resilience modulus of subgrade, which increases from 50 MPa to 70 MPa, and the tensile stress at the bottom of the bed decreases by 0.15%. When the equivalent rebound modulus reaches 120 MPa, the tensile stress decreases by 0.36%.

It can be seen that the increase of subgrade modulus can not only improve the overall stiffness of pavement structure, but also improve the compressive and shear capacity of vehicles under driving load, and reduce the cracking and reflection cracks at the bottom of the base caused by tensile stress, so as to improve the durability of pavement structure.

4. Conclusion

In this chapter, the mechanical properties of asphalt pavement structure are simulated and analyzed through finite element software, and the mechanical properties of asphalt surface of subgrade stiffness are studied, and the following conclusions are drawn.

Increasing the subgrade modulus can not only improve the overall stiffness of pavement structure, but also improve the compressive and shear capacity of vehicles under driving load, and reduce the cracking and reflection cracks at the bottom of the base caused by tensile stress, so as to improve the durability of pavement structure.

Improving the subgrade stiffness can effectively reduce the bending of the road surface, and the tensile stress of the base and subbase, which can effectively improve the tensile capacity of the asphalt pavement structure. In this chapter, the subgrade stiffness is changed by changing the elastic modulus. In practical engineering, the subgrade stiffness is improved by adding ash to the subgrade.

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