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Study on Dynamic Response of Saturated Asphalt Pavement Under Multi Factor Interaction

Yanping Song [1, a] *, Danfeng Hu [1], Zhang Zhu [2], Tuanwei Sun [3, 4], Wei Zhan [3, 4]

[1] Hangzhou Transportation High Level Highway Maintenance Co., Ltd, Hangzhou 310024, China;

[2] Hangzhou Traffic Engineering Group Co., Ltd, Hangzhou 310013, China;

[3] Zhejiang Scientific Research Institute of Transport, Hangzhou 310023, China;

[4] Research and Development Center on A New Generation of Artificial Intelligence Technology for Transport Industry Ministry of Transport, Hangzhou 310023, China.

[a] stw19940414@163.com

Abstract. In order to solve the water damage phenomenon of asphalt pavement in humid, hot and rainy areas, the mechanism of dynamic water pressure on asphalt pavement was studied. Firstly, a model of the relationship between frequency, air void, permeability coefficient and modulus were established according to the measured asphalt mixture parameters. Then, according to the model, the parameter values of asphalt mixture multi parameter interaction are estimated. Based on this, combined with Biot's consolidation theory, the finite element software was used to simulate the dynamic response results of pavement structure with and without considering the change of parameter linkage. At the same time, the law of the effect of air void and driving speed on hydrodynamic pressure under the action of multi-parameter linkage was studied. The results show that the pore water pressure of the pavement structure is overestimated by 329.68 kPa, the vertical stress is underestimated by 91.43 kPa, and the shear stress is overestimated by 24.79kPa without considering the multi-parameter linkage change; The pore water pressure of pavement surface is the largest, and the pavement surface is the most unfavorable position where water damage occurs; The research is of great significance for accurately evaluating the water damage resistance of asphalt pavement.

Keywords: asphalt pavement; multi-parameter linkage; water damage; pore water pressure

1. Introduction

There are many factors leading to the early damage of highway asphalt pavement, among which water damage is the main reason [1-3]. The water infiltrating into the asphalt pavement structure will cause erosion and extrusion to the pavement structure under the repeated action of vehicle load. The frequent dynamic water erosion and extrusion in the pores lead to the physical separation of aggregate and asphalt pavement binder film, resulting in pavement damage [4-6]. Therefore, Therefore, the researchers have carried out a lot of research on the water damage of asphalt pavement. The research shows that the pore water pressure of saturated asphalt pavement structure is the largest, and the water transmission analysis under dynamic stress conforms to the real situation of dynamic water pressure response of pavement structure [7-8].

In the past, scholars studied the factors that affect the dynamic water pressure of asphalt pavement from the perspectives of theory and test. Combined with previous research results, Dan et al. [9-10], based on Biot consolidation theory, used finite element simulation software to study and analyze the variation law of permeability coefficient and driving speed on pore water pressure. Based on the finite element software, scholars at home and abroad have conducted a lot of research on the factors affecting the pore water pressure of asphalt pavement. J Huang et al. studied and analyzed the influence of permeability coefficient, thickness and modulus on the pore water pressure [11-12]. Xie et al.

In this paper, based on Biot's consolidation theory [13], a three-dimensional finite element model of asphalt pavement under dynamic load is established to study and analyze the change law of mechanical response of asphalt pavement under the action of multi factor linkage, and reveal the

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mechanism of water damage of asphalt pavement, thus providing theoretical basis and technical guidance for asphalt pavement design.

2. Methods and Materials

2.1 Establishment of Frequency and Modulus Equations

Due to the viscoelastic properties of asphalt materials, loading time is an important parameter for dynamic performance testing. The research shows that under the same temperature and within a certain range of loading frequency, the dynamic modulus of asphalt mixture gradually increases with the increase of loading frequency . In order to obtain the relationship between the dynamic modulus of asphalt mixture and the loading frequency, the rebound modulus values of SMA-10, AC-13 and AC-20 were measured by the uniaxial compression dynamic modulus test of asphalt mixture. The dynamic modulus values of three asphalt mixtures measured at different frequencies are shown in Table 1.

Table 1. Dynamic modulus values of three asphalt mixtures at different frequencies

modulus（MPa） frequencies（HZ）	SMA-10	AC-13	AC-20
0.1	764	816	1242
0.5	1049	1202	1847
1	1245	1486	2198
5	2028	2671	3428
10	2515	3417	4106
25	3333	4640	5134

The origin software is used to regression fit the test data of the three types of asphalt mixtures in Table 1, and the regression equation between the dynamic modulus of the three types of asphalt mixtures and the loading frequency is obtained. The fitting degree R2 is above 0.98. The dynamic modulus and frequency regression equation of three asphalt mixtures are as follows:

SMA-10 frequency and modulus relationship:

$$E = -2600.7 \times e^{-\frac{f}{9.1}} + 3471.2 \tag{1}$$

Relation between AC-13 frequency and modulus:

$$E = -3912.7 \times e^{-\frac{f}{9.2}} + 4860.7 \tag{2}$$

Relation between AC-20 frequency and modulus:

$$E = -3684.4 \times e^{-\frac{f}{7.0}} + 5167.1 \tag{3}$$

Where: f is the loading frequency, in HZ; E is the dynamic modulus of asphalt mixture, in MPa.

2.2 Establishment of Void Ratio and Modulus Equations

The dynamic modulus of asphalt mixture varies with the loading frequency, and the change of porosity will affect the dynamic modulus. Therefore, the dynamic modulus of asphalt mixture is affected by many factors, which varies with the loading frequency and porosity. Based on the frequency and modulus equations, the void fraction and modulus equations at the same frequency are established.

In terms of this research object, in the same mixture type, the other parameters are basically the same except the void content, which can be considered as the main reason for the change of mixture modulus. Finally, the relationship between void fraction and modulus (1) is given. At the same time,

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according to the formula (4), the void fraction increases by 1% and the modulus decreases by about 5%.

$$E' = E_0 \times 10^{-0.0208(VV'-VV)} \tag{4}$$

In the formula:

E'—The dynamic modulus corresponding to the target porosity, MPa;

E_0—The measured dynamic modulus of the specimen, MPa;

VV'—Target porosity;

VV—Actual measured porosity.

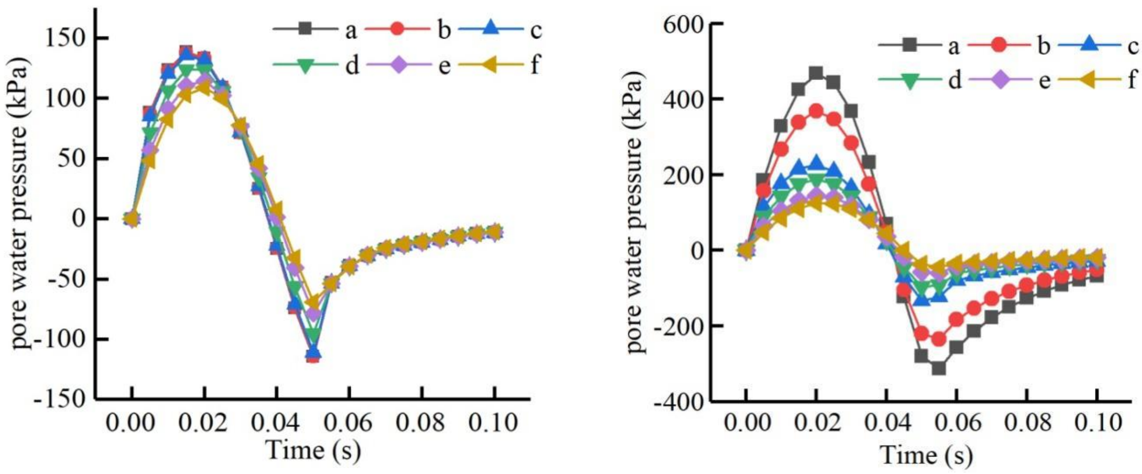
2.3 Permeability Coefficient and Porosity Model

Void ratio is the key factor affecting the dynamic water pressure of asphalt pavement structure. Void ratio not only affects the dynamic modulus of asphalt mixture, but also is the most important parameter controlling the permeability coefficient of asphalt mixture. Therefore, void ratio plays an intermediate role in the prediction of material parameters. For the same asphalt mixture, the permeability coefficient is different with different porosity, and the permeability coefficient directly affects the dynamic water pressure of pavement structure. Chongqing Jiaotong University [14] used the vacuum sealing method to measure the test data of a large number of specimen porosity and permeability coefficient to obtain the relationship between porosity and permeability coefficient.

3. Results and Analysis

3.1 Hydrodynamic Pressure Comparison

In fact, the void fraction is the key factor to determine the dynamic modulus and permeability coefficient of asphalt mixture, while the interaction of multiple parameters is often ignored in previous studies of hydrodynamic pressure. Therefore, the calculation results of hydrodynamic pressure considering multi parameter linkage change and not considering multi parameter linkage change are compared and analyzed. The load form is half sine wave, the peak load is standard axle load of 100kN, the driving speed is 80km/h, and the voidage of asphalt mixture is 6%.



(a) Consider multi parameter linkage (b) Multi parameter linkage is not considered

Fig. 1 Time history curve of pore water pressure

It can be seen from Figure 1 that the peak value of positive and negative pore water pressure appears at different depths of the pavement with the action of wheel load and driving away,

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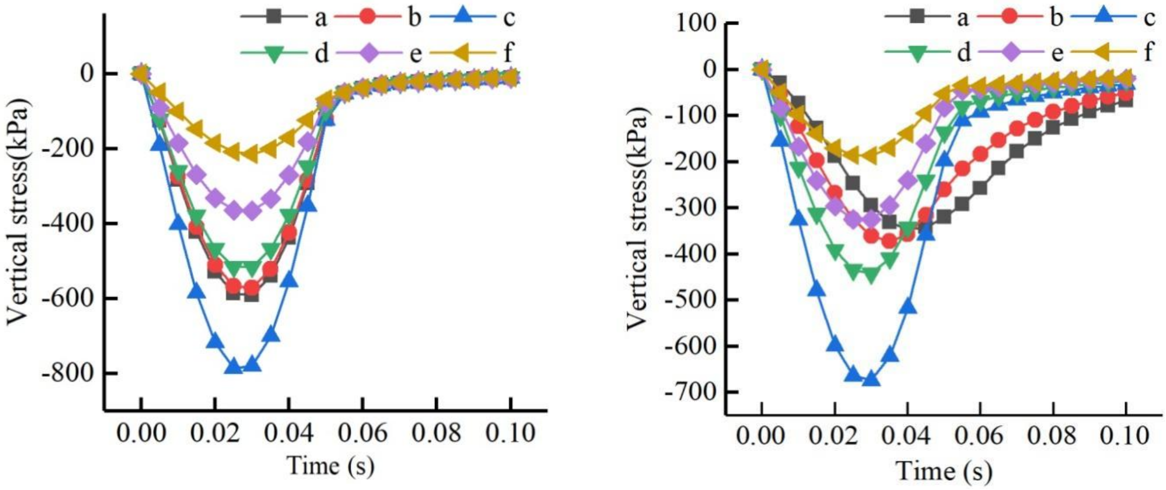
regardless of whether the multi parameter linkage change is considered or not. When the wheel load just acts on the pavement structure, the positive pore water pressure inside the pavement structure gradually increases. With the wheel load reaching the peak value, the positive pore water pressure also reaches the peak value; When the wheel load gradually drives away, the positive pore water pressure gradually decreases to a negative value, the negative pore water pressure gradually increases to the peak value, and finally the pore water pressure gradually dissipates to near zero.

It can be seen from Figure 1 (a) and (b) that the maximum pore water pressure without considering the multi parameter linkage change is 468.11kPa, and the maximum pore water pressure with considering the multi parameter linkage change is 138.43kPa, the former is about 3.38 times of the latter, and the pore water pressure without considering the multi parameter linkage change is obviously greater than the pore water pressure with considering the multi parameter linkage change. It shows that the pore water pressure of pavement structure was overestimated without considering the multi parameter linkage change in the past. Therefore, it is necessary to consider the multi parameter linkage change of material parameters. The variation range of pore water pressure at different depths of pavement structure considering multi parameter linkage change is small, while the variation range of pore water pressure at different depths of pavement structure not considering multi parameter linkage change is large and discrete.



(a) Consider multi parameter linkage (b) Multi parameter linkage is not considered

Fig. 2 Time history curve of vertical stress

It can be seen from Figure 2 that the vertical stress of the pavement structure at different depths gradually reaches the peak value with the vehicle load. When the vehicle load drives away, the vertical stress gradually decreases until it dissipates to zero. The vertical stress varies with the depth of the pavement structure. The maximum vertical stress appears on the middle surface of the pavement and the minimum vertical stress occurs on the lower surface of the pavement.

It can be seen from Figure 2 (a) and (b) that the maximum vertical stress of pavement structure considering multi parameter linkage change is -779.09kPa, and the maximum vertical stress of pavement structure without considering parameter linkage change is -687.66kPa, the former is about 1.13 times of the latter. The material parameter modulus directly determines the internal stress of the pavement structure. The reason for the difference between the two models is the porosity. The calculation results show that the vertical stress inside the pavement structure is underestimated without considering the parameter linkage change model. In fact, the vertical stress inside the pavement structure is larger.

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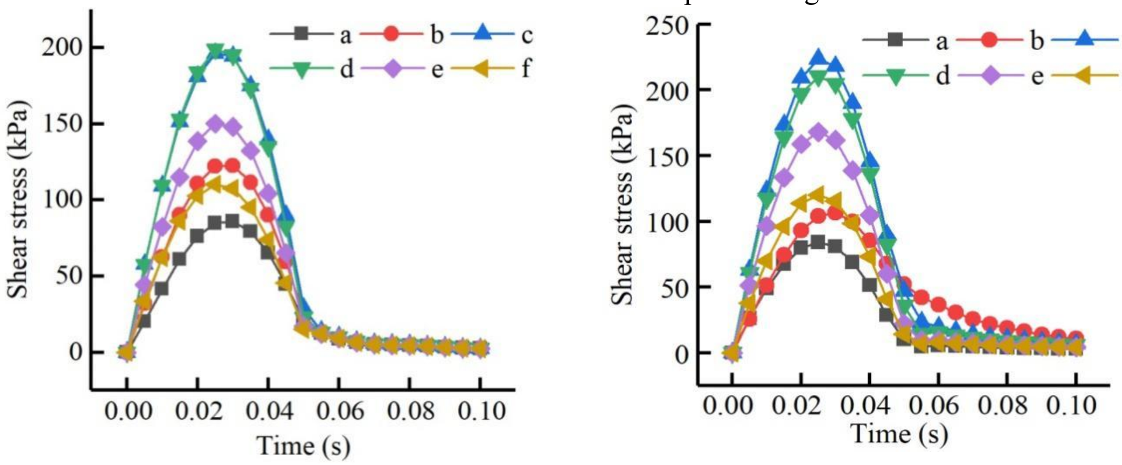

(a) Consider multi parameter linkage (b) Multi parameter linkage is not considered

Fig. 3 Time history curve of shear stress

It can be seen from Figure 3 that the shear stress at different depths of the pavement structure gradually increases to the peak value with the increase of the vehicle load acting time. When the vehicle load drives away, the shear stress gradually decreases until it dissipates to zero. The shear stress is different at different depths of the pavement structure. The maximum shear stress at points c and d occurs in the middle surface layer of the pavement structure, and the minimum shear stress occurs in the upper layer of the pavement.

It can be seen from Figure 3 (a) and (b) that the maximum shear stress of pavement structure considering the parameter linkage change is 198.82kPa, and the maximum shear stress of pavement structure without considering the parameter linkage change is 223.61kPa, the former is about 0.89 times of the latter. The reason why the shear stresses of the two models are different is also due to the consideration of the influence of parameter linkage changes on the modulus, which leads to different shear stresses in the pavement structure.

4. Conclusion

The hydrodynamic pressure inside the pavement structure is the result of the interaction of many factors, such as material modulus, void ratio and permeability coefficient, among which there are interactions and influences. In this study, by measuring the material parameter values of different asphalt mixtures, the equation of frequency and modulus, the equation of void fraction and modulus, and the model of permeability coefficient and void fraction are established. The material parameter results of multi parameter linkage change are brought into Comsol finite element software to calculate and analyze the dynamic water pressure change law and distribution characteristics of multi parameter linkage change, and the following conclusions are drawn:

(1) The pore water pressure value without considering the multi parameter linkage change is obviously larger than the pore water pressure value considering the multi parameter linkage change, the former is about 3.38 times of the latter, indicating that the pore water pressure of pavement structure was overestimated without considering the multi parameter linkage change in the past.

(2) The variation range of pore water pressure at different depths of pavement structure considering multi parameter linkage change is small, while the variation range of pore water pressure at different depths of pavement structure not considering multi parameter linkage change is large and discrete. The pore water pressure values at different pavement structure depths are different. The closer to the pavement surface, the greater the pore water pressure value is. The maximum pore water pressure is 138.43kPa. The road surface is the most unfavorable location for water damage.

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(3) The calculation results of vertical stress and shear stress show that the model without considering the parameter linkage changes underestimates the vertical stress inside the pavement structure and overestimates the shear stress inside the pavement structure. The vertical stress is underestimated by 11.74%, and the shear stress is overestimated by 11.09%. The maximum value of vertical stress and shear stress appears in the middle surface layer of the pavement structure.

(4) In the range of 4%~8% void fraction, the pore water pressure decreases with the increase of void fraction, and the vertical stress and shear stress increase with the increase of void fraction; Within the range of 40km/h~120km/h, the pore water pressure increases with the increase of driving speed. Although the vertical stress and shear stress show an increasing trend, the increasing amplitude is very small. The influence of driving speed on the vertical stress and shear stress can be ignored.

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