Mechanical Analysis of Preventing Reflection Cracks Based on Stress Absorbing Layer

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After asphalt concrete overlay, the reflection crack in the old pavement remains a great challenge. In order to overcome this problem, here, we report the effect of stress absorbing layer on the reflection crack. First, the concrete measures to prevent and reduce reflection cracks at home and abroad are analyzed. Then, the mechanism of the generation and development of reflection cracks is studied, the functional characteristics of stress absorbing layer are analyzed, and the principle of antireflection crack is clarified. Further, the effects of modulus thickness and porosity of stress absorbing layer on the stress of pavement structure layer are discussed. Finally, the effect of the stress absorbing layer on preventing reflective cracks is analyzed by numerical simulation. The analyses show that the stress absorbing layer is a thin asphalt concrete layer with good fatigue resistance and low modulus between the old pavement and asphalt pavement, which delays the expansion of pavement reflection cracks. The stress absorbing layer should have high elasticity and low temperature flexibility, water damage resistance, and interlayer bonding. The simulation results suggest that the modulus of the stress absorbing layer should be 400 MPa ~ 600 MPa, and the thickness should be 1 cm ~ 2.5 cm. When the thickness of the stress absorption layer is 2.5 cm, the values of tensile stress $\sigma_X$, equivalent stress $\sigma_{\text{Mises}}$ and maximum shear stress $\tau_{\text{Max}}$ are 31.7%, 29.2%, and 25.7% lower than those of the layer without addition, respectively. The results demonstrate that the effect of stress reduction is obvious, which plays an important role in preventing or reducing the occurrence of reflective cracks. The designed void ratio of the mixture is between 1% and 2.5% for the indoor permeability resistance test. We believe that these findings have certain guiding significance for theoretical analysis and engineering application of stress absorbing layer.

1. Introduction

The asphalt concrete overlay on the old pavement not only improves the performance of the old cement concrete pavement, but also improves the driving comfort. At the same time, it makes full use of the residual strength of the old pavement and has little impact on traffic and environment [1, 2]. However, after adding the new asphalt surface, due to the crack defects of the old pavement in the structure, the new pavement is prone to produce reflection cracks under the combined action of external load and environment [3, 4]. Reflection cracks will not only lead to the deterioration of pavement performance, but also affect the beauty of pavement. Once the surface water infiltrates, the strength and stability of subgrade and pavement will be seriously reduced, and the surrounding cracks will expand rapidly, greatly shortening the service life of asphalt overlay [5–8].

To reduce or prevent the occurrence of reflective cracks, many experts and scholars at home and abroad have done a lot of relevant research. Gu [9] and others conducted fatigue tests on cement concrete pavement with asphalt overlay, analyzed the influence of asphalt overlay thickness on the crack resistance of pavement structure, and concluded that when the asphalt overlay thickness is less than 10 cm, the fatigue life increases significantly with the increase of thickness, and there is an approximate linear relationship between them. However, when the thickness exceeds 10 cm, the fatigue life increases significantly with the increase of thickness, and there is an approximate linear relationship between them. However, when the thickness exceeds 10 cm, the growth rate of the antifatigue load slows down, and when the thickness exceeds 15 cm, the thickness resistance performance is unaffected. Zhang and others [10–12] carried
out crack prevention tests using glass fiber grille, geotextile, and geogrid. The research shows that this material can better prevent the occurrence of reflection cracks, and the crack prevention effect of glass fiber grille is better than that of geotextile and geogrid. If the old cement concrete slab has high damage rate, large damage area, and uneconomical replacement or grouting repair, the old cement concrete slab can be cracked and stabilized, and then the asphalt surface layer can be added to reconstruct the old road [13–18].

Compared with the method of thickening asphalt overlay, the stress absorbing layer can achieve the same antireflection crack effect, and the economic benefits of the stress absorbing layer are higher. Compared with geotextile method, the geotextile mainly plays the role of stirrup at the bottom of the asphalt layer, and the stress absorbing layer plays the role of “absorbing” the stress of base cracking through its own flexibility. Compared with the isolation layer method, the asphalt macadam or graded gravel uses its larger void ratio to make the reflection not reflect upward. The stress absorption layer can achieve the same effect, but it will also cause waterproof damage. Compared with the crushing method, the construction of the crushing method is difficult, the crushing particle size is uneven, resulting in environmental pollution, the remaining life of the old plate is not fully utilized, and the construction of the stress absorption layer is as simple as that of the ordinary asphalt surface layer.

How to effectively prevent the occurrence of reflection cracks and make the pavement continue to bear the repeated action of traffic load after the overlay is a prominent problem to be solved urgently in the asphalt overlay of old pavement. Therefore, this paper summarizes and analyzes the research on preventing reflection cracks at home and abroad and then explores the characteristics of the stress absorbing layer and the principle of reflection crack prevention according to analyzing the mechanism of reflection cracks. It secondly discusses the influence of finite element stress absorbing layer modulus, thickness, and void ratio on the stress of pavement structure layer. Finally, the effect of stress absorbing layer on preventing reflection crack is analyzed through numerical simulation. In this paper, the effect of the stress absorbing layer on the old pavement is systematically studied, which has important practical value for theoretical research and engineering application in the future.

2. Mechanism of Reflection Crack Generation and Development

According to the existing research basis, in the professional field, the formation of reflection cracks is usually divided into two stages: the first stage is the generation stage of reflection cracks; the second stage is the expansion stage of reflection cracks [19].

2.1. Mechanism of Reflection Crack Formation. The sudden change of temperature will cause two kinds of deformation of the pavement structure: one is the cracking of the cement concrete pavement in the asphalt surface: when the temperature rises, the cracks in the old pavement will increase the opening deformation due to temperature shrinkage, resulting in additional stress on the asphalt surface and cracks on new asphalt surface; second, the temperature distribution of each structural layer of the pavement is uneven, resulting in different shrinkage and warping deformation of different materials. Under the cyclic action of temperature difference, the cracks produce large stress, resulting in further cracking.

When the driving load repeatedly acts on the pavement cracks, its impact on the surface layer can be divided into three stages, as shown in Table 1.

When the driving load approaches and leaves, the surface will produce shear stress in the opposite direction. When the driving load acts on the upper surface of the original crack, the surface will be subjected to bending tensile stress. The above two forces increase the cracking of the crack.

2.2. Reflection Crack Propagation. From its generation to expansion, the reflection crack will undergo a crack propagation stage, that is, the reflection crack along the asphalt overlay in the direction of longitudinal extension and transverse extension of the surface.

2.2.1. Longitudinal Propagation of Reflection Cracks. Temperature stress leads to cracking; driving load mainly leads to open type and shear-type cracks. When the wheel is driven directly above the cracks, it is easy to produce open cracks. The driving passing through the crack side is shear-type. For the gap-type reflection cracks generated under the positive load of the vehicle, they usually appear at the bottom of the cover layer and expand vertically upward through the repeated action of the load. Shear reflection cracks appear in the asphalt overlay, extending from the bottom of the overlay to the top at an angle of about 45°.

2.2.2. Transverse Propagation of Reflection Cracks. Once cracks appear, they will inevitably expand to both sides. Usually, reflection cracks often appear on one side of the road surface. The comprehensive action of environment and load will accelerate the crack propagation. The main cause of reflection crack is the coupling effect of temperature and load.

Reflection cracks are mainly transverse cracks, and their spacing depends on factors such as climatic and hydrological conditions, overlay thickness, and crack resistance of surface materials. When the temperature difference between day and night is large, the thickness of the surface layer is thin, and the crack resistance of the surface layer material is poor, and the spacing generated by the reflection crack is small; otherwise, it is large.

3. Influencing Factors of Structure and Material Design of Stress Absorbing Layer

3.1. Functional Characteristics of Stress Absorption Layers. According to the antireflection crack mechanism of the stress absorption layer, it must have the following functional characteristics [20–23]:
High elasticity: the greater the recoverable elastic deformation of the structural layer, the better the performance of relieving load stress, which is conducive to reducing the vertical deformation of the overlay and improving the fatigue resistance of the surface layer.

Strong flexibility: the low temperature flexibility of stress absorption layer can alleviate temperature stress. When the temperature stress is generated on the old road surface, the stress absorbing layer with high flexibility will produce large plastic deformation, so as to weaken the additional stress.

Water loss resistance: stress absorbing layer should have the ability to resist water damage. The stress absorbing layer forms asphalt film on the asphalt pavement, which can prevent the filtration of rainwater; that is, it has good waterproof performance, cuts off the penetration of surface water into the old road surface, ensures the stability of the original road base, and prolongs the service life of the road surface.

Interlayer bonding: the stress absorbing layer should have high viscosity, which can bond each structural layer well and provide transition and connection for the structural layers of two different materials. Good bonding performance can not only dissipate and alleviate the stress concentration caused by cracks, but also improve the overall strength and stability of the structure.

3.2. Principle of Preventing Reflection Crack by Stress Absorption Layer. The stress absorption layer is a functional layer with good fatigue resistance and low modulus added between the old pavement and the asphalt concrete surface layer. It can delay the extension of the road surface reflection crack, focus on the stress diffusion, reduce the peak stress, and slow speed of crack propagation and the deviation from the position of the cracks on the surface at the grass-roots level [23], as shown in Figure 1.

4. Influence of Modulus and Thickness of Stress Absorbing Layer on Pavement Stress

In this paper, the stress of pavement structure layer will be simulated by the three-dimensional finite element method, and the influence of the thickness and modulus of stress absorption layer on asphalt surface layer will be studied [24–30]. A reasonable range of modulus and thickness of stress absorption layer is proposed to weaken the stress to the greatest extent, so as to prevent and reduce the generation of reflection cracks.

4.1. Model Building. Taking the asphalt overlay of old cement concrete pavement as an example, the three-dimensional model of asphalt pavement structure of stress absorbing layer is established by using the ABUQUS finite element program, as shown in Figures 2 and 3. The influence of the change of modulus and thickness of stress absorbing layer on the stress distribution and change of asphalt pavement structure layer is analyzed [30].

The size of cement concrete pavement board is 5.0 m × 4.5 m × 0.24 m, and the expanded foundation size is 16.01 m × 15.5 m × 9 m. The three-dimensional structure of the stress absorbing layer of the asphalt pavement structure layer is shown in Figure 2. X is the driving direction, Y is the cross section direction of the road, Z is the depth direction of the road, and Figure 3 is the meshing of the finite element calculation of the model.

4.2. Influence of Modulus on Road Surface. Standard single axle and double wheel axle loads are used to calculate the load. According to the research, when the load acts on one side of the original crack, the damage to the overlay is the
greatest. Therefore, partial load is selected as the load position for the calculation in this paper [30]. Figures 4 and 5 show the position of partial loads applied on the overlay road surface and the overlay road surface with stress absorbing layer.

In this paper, the modulus of asphalt concrete surface layer is 1200 MPa, and the thickness is 10 cm. The modulus range of stress absorption layer is 200 MPa – 1200 MPa, and the thickness range is 1 cm – 3 cm. The calculation parameters of pavement structure layer are shown in Table 2.

In order to analyze the influence of the modulus of the stress absorbing layer on the overlay pavement, finite element numerical analysis method is used to calculate the stress on the top and bottom of the overlay layer and the bottom of the stress absorbing layer with different modulus of stress absorbing layer. The relationships between the tensile stress σX, first principal stress σ1, equivalent stress σMises, maximum shear stress τMax and the modulus of stress absorption layer are shown in Figures 6–8.

As can be seen from Figure 6, the values of tensile stress σX, first principal stress σ1, equivalent stress σMises and maximum shear stress τMax decrease with the increase of the modulus of the stress absorption layer, but they are not obvious. It can be concluded that the change of the modulus of the stress absorption layer has little effect on the stress of the top surface of the overlay layer.

As can be seen from Figure 7, the stress at the bottom of the overlay layer is greatly affected by the modulus of the stress absorbing layer. With the increase of the modulus of the overlay layer, the values of tensile stress σX, first principal stress σ1, equivalent stress σMises and maximum shear stress τMax increase. When the modulus increases from 200 MPa to 600 MPa, the increasing trend is very fast. From 600 MPa to 1200 MPa, the growth trend slows down.

As can be seen from Figure 8, the modulus of the stress absorbing layer has an important effect on the stress at the bottom. With the increase of the modulus, the bottom tensile stress σX, the first principal stress σ1, the equivalent stress σMises and the maximum shear stress τMax also increase. Therefore, it is necessary to set up a low modulus stress absorption layer to benefit the overlay layer and its own structural layer.

Therefore, in order to determine the reasonable modulus range of the stress absorbing layer, the relationships between the tensile stress σX, the first principal stress σ1, the equivalent stress σMises, the maximum shear stress τMax and the vertical shear stress τXZ and the pavement depth are calculated by finite element numerical values, as shown in Figures 9–12.

As can be seen from Figures 9–12 that the maximum shear stress τXZ increases obviously with the increase of the modulus of stress absorbing layer when the layer depth is less than 6 cm. At the depth of 6 cm, the modulus of the stress-absorbing layer is 200 MPa, and τXZ is -0.019 MPa, while at 1200 MPa τXZ is
−0.018 MPa, and the stress decreased by about 4.9%. Figures 10–13 also have the same rule. When the depth of the overlay is less than 2 cm, the tensile stress decreases gradually with the increase of the modulus. When the depth of overlay is less than 4 cm, the maximum shear stress decreases with the increase of modulus. Therefore, the modulus of the stress absorbing layer should not be too low.

It can be seen from Figures 9–13 that when the pavement depth is greater than 6 cm, all stresses should decrease with the decrease of modulus, which is more prominent in Figures 10 and 11. Therefore, the stress absorbing layer with low modulus is reasonable.

Table 2: Calculation parameters of asphalt pavement structure layer.

<table>
<thead>
<tr>
<th>The structure layer</th>
<th>The thickness of the (cm)</th>
<th>Modulus of elasticity $E$ (MPa)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt overlay</td>
<td>10</td>
<td>1200</td>
<td>0.25</td>
</tr>
<tr>
<td>Stress absorbing layer</td>
<td>1~3</td>
<td>200~1200</td>
<td>0.30</td>
</tr>
<tr>
<td>Old cement concrete pavement layer</td>
<td>24</td>
<td>30000</td>
<td>0.15</td>
</tr>
<tr>
<td>The foundation</td>
<td></td>
<td>100</td>
<td>0.35</td>
</tr>
</tbody>
</table>

In conclusion, when the modulus of stress absorption layer is between 400 MPa and 600 MPa, it can play an important role in dissipating stress and can also have flexibility. The overall strength of pavement structure will not be reduced because the modulus is too low.

4.3. Analysis of the Influence of Stress Absorbing Layer Thickness on Overlay Layer. The thickness of the stress absorbing layer is 0 cm, 1 cm, 1.5 cm, 2.5 cm, and 3 cm (where the thickness is 0, meaning that no stress absorbing
layer is added). According to the finite element calculation results, the relationships between the tensile stress $\sigma_X$, first principal stress $\sigma_1$, equivalent stress $\sigma_{Mises}$ and maximum shear stress $\tau_{Max}$ at the bottom of the stress absorbing layer with the thickness of the stress absorbing layer are plotted, as shown in Figures 14 and 15.

Figures 14 and 15 show that when the modulus is 400 MPa and 600 MPa, the tensile stress $\sigma_X$, the first principal stress $\sigma_1$, the equivalent stress $\sigma_{Mises}$ and the maximum shear stress $\tau_{Max}$ decrease with the increase of the thickness of the stress absorbing layer, indicating that the thickness of the stress absorbing layer has little influence on the change of the stress on the top of the layer.

It can be seen from Figures 16 and 17 that the changes of 400 MPa and 600 MPa are similar. The tensile stress $\sigma_X$, first principal stress $\sigma_1$, equivalent stress $\sigma_{Mises}$ and maximum shear stress $\tau_{Max}$ decrease with the increase of stress absorption layer thickness. From the unpaved stress absorbing layer to the overlaying stress absorbing layer with the thickness of 1 cm, the stress value is greatly reduced, indicating that the effect of the applied stress absorbing layer is remarkable. When the thickness changes from 1.0 cm to 2.5 cm, the trend of stress reduction is weaker than that of 0-1 cm. When the thickness changes from 2.5 cm to 3 cm, the trend of stress reduction is weaker than that of 1-2.5 cm.

As can be seen in Figures 18 and 19, when the thickness of the stress absorbing layer increases from 1.0 cm to 2.5 cm, the tensile stress $\sigma_X$, the first principal stress $\sigma_1$, the equivalent stress $\sigma_{Mises}$ and the maximum shear stress $\tau_{Max}$ decrease with the increase of the thickness of the stress absorbing layer.
Figure 14: The top surface stress of the layup layer varies with thickness (the modulus of the stress absorbing layer is 400 MPa).

Figure 15: The top surface stress of the layup changes with thickness (the modulus of the stress absorbing layer is 600 MPa).

Figure 16: The stress on the bottom surface of the plus layer varies with thickness (the modulus of the stress absorbing layer is 400 MPa).

Figure 17: Stress at the bottom surface of the stress absorption layer varies with thickness (the modulus of the stress absorbing layer is 600 MPa).

Figure 18: Stress at the bottom of the stress absorption layer varies with thickness (the modulus of the stress absorbing layer is 400 MPa).

Figure 19: Stress at the bottom surface of the stress absorption layer varies with thickness (the modulus of the stress absorbing layer is 600 MPa).
decrease significantly. When the thickness changes from 2.5 cm to 3 cm, the stress value of the stress absorbing layer tends to decrease.

In conclusion, the increase of the thickness of the stress absorbing layer has a significant impact on stress reduction, and the effect is the most obvious when the thickness changes from 1.0 cm to 2.5 cm. When the thickness changes from 2.5 cm to 3 cm, the stress reduction effect decreases. The greater thickness of the stress absorption layer will cause the vertical deformation of the pavement structure and reduce the overall strength of the pavement. Therefore, it is suggested that the thickness of the stress absorption layer should be 1 cm–2.5 cm.

### 4.4 Voidage of Mixture in Stress Absorbing Layer

According to the function requirement of the stress absorbing layer to prevent water damage, a reasonable index is raised on the mixture voidage of the stress absorbing layer [31]. When the old road surface adds the asphalt surface, the infiltration of moisture will lead to loose and peeling mixture particles. When water enters the pavement structure, the mechanical strength of pavement structure will be reduced. The water damage of asphalt surface is related to the voidage of mixture. The larger voidage of mixture compaction will lead to the damage of asphalt surface. In a certain range of voidage, the influence of voidage change on antwater damage performance is not obvious. Therefore, this paper selects four kinds of different grades and then uses the water seepage meter to test the water seepage situation under different void rates in indoor according to the requirements of highway asphalt pavement construction technical specifications, as shown in Table 3.

The test result shows that the water permeability coefficient of asphalt mixture with different grades is different under the same void ratio. When the void ratio is greater than a certain quantitative value, the water permeability coefficient will increase sharply, and there is a good correlation between the water permeability coefficient and the void ratio. It is generally considered that when the water seepage coefficient exceeds 400 mL/min, it is not acceptable. At this time, the asphalt pavement will produce serious water seepage and increase the generation of water damage. However, the water seepage coefficient of stress absorption layer asphalt mixture is less than 10 mL/min, which is far less than the requirement of 200 mL/min in the specification.

It can be inferred that the stress absorbing layer has a good waterproof and pervasive function compared with asphalt mixture from Table 3. The stress absorbing layer prevents the rain from the surface layer from the old concrete plate to the original base, avoids the base to produce new water damage, and ensures the stability of the base. So, according to the impermeability test of stress absorbing layer, it is feasible to design the void ratio of the stress absorption layer mixture between 1.0% and 2.5%.

### 5. Add Numerical Simulation of Stress Absorbing Layer

In this paper, the modulus is set as 600 MPa, and the stress changes on the top and bottom of the stress absorbing layer...
of asphalt surface with a thickness of 2.5 cm and the stress absorbing layer of asphalt surface without the stress absorbing layer are calculated. The calculation results are shown in Table 4.

It can be seen from Table 4 that the addition of 2.5 cm stress absorbing layer has little effect on the stress on the top of asphalt layer, which is basically consistent with the previous analysis. When the stress absorbing layer of the asphalt layer is not laid, the tensile stress $\sigma_X$, the equivalent effect force $\sigma_{\text{Mises}}$, and the maximum shear stress $\tau_{\text{max}}$ values are $-0.085, 0.065$, and $0.070$, respectively. After laying 2.5 cm stress absorption layer, the values become $-0.058, 0.046$, and 0.052, which are 31.7%, 29.2%, and 25.7% lower than the original values, respectively. The stress reduction effect is obvious, which can prevent or reduce reflection cracks.

(5) According to the indoor impermeability test of stress absorption layer, it is proposed that the design void ratio of stress absorption layer mixture is between 1.0% and 2.5%.

### Data Availability

The data used to support the findings of this study are included within the article.

### Conflicts of Interest

The authors declare that they have no conflicts of interest.

### References


