Analysis of Design Index and Mechanical of Asphalt Pavement Structure in the Northwest Desert Areas

San-qiang Yang¹, Shuai Zjiang² and Li-jun Sun³

¹Vice Director, College of Civil Engineering, Hebei University, No.180. Wusi EAST Road, Baoding, China 0312-5079374; ysq0999@163.com
²Master, College of Civil Engineering, Hebei University, No.180. Wusi East Road Baoding, China; 835773981@qq.com
³Director, College of Transportation Engineering, Tongji University, No.1239. Siping Road, Shanghai, China 021-69583810;ljsun@tongji.edu.cn

Abstract: In this paper, pavement performance index PCI, road surface deflection and pavement rutting are proposed as the design indexes of pavement structure by analyzing the desert region of bad natural environment under heavy load traffic asphalt pavement condition and using finite element analysis. The stress distribution of durable asphalt pavement structure in desert area was obtained. The results showed that it is an approximate linear relationship between maximum vertical deformation of road surface and wheel load under different wheel load. With the increase of axial load, the maximum vertical deformation increases gradually. The maximum tensile stress of the road surface is symmetrical distribution with the wheel axis. The shear stress in the pavement structure increases with the increase of depth, and the shear stress reaches the peak value in the distance from the road surface 5cm. The results of the research can be a scientific theoretical support and a technical guidance for the selection and structural design of the asphalt pavement in the desert region.

INTRODUCTION

The damage types of asphalt pavement are so various that it is difficult for us to control it. The different types of damages also have different effects on the performance of asphalt pavement. Therefore, when doing the structure design of Asphalt Pavement, it can not be like some other structural design, the selection of a single critical state and design indicators. In the design of pavement structure in China, the pavement deflection is often used as a design index, but the pavement deflection is a comprehensive quality index, which can not accurately reflect the level or damage type. It is generally believed that the deflection of the road surface mainly comes from the roadbed, but the road is measured and found that this statement is not practical. Based on this, the structural design index and structural mechanics analysis of asphalt pavement is of great significance.

1 Structural model parameter selection of durable asphalt pavement

Based on the combination of asphalt pavement structure in desert area, refer to the relevant provisions of the modulus and thickness of the structural layer in the design code of Asphalt Pavement. The structural parameters of the selected durable asphalt pavement are shown in Table 1.
Table 1. Structural parameters of asphalt pavement.

<table>
<thead>
<tr>
<th>Road grade</th>
<th>Structure layer</th>
<th>Thickness(cm)</th>
<th>Modulus of resilience (MPa)</th>
<th>Poisson ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban main road Or</td>
<td>Asphalt upper layer</td>
<td>4</td>
<td>1500</td>
<td>0.35</td>
</tr>
<tr>
<td>express way</td>
<td>Asphalt middle layer</td>
<td>5</td>
<td>1200</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Asphalt under layer</td>
<td>6</td>
<td>1000</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Semi-rigid base</td>
<td>35</td>
<td>1500</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Subbase</td>
<td>20</td>
<td>700</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Subgrade</td>
<td>—</td>
<td>40</td>
<td>0.4</td>
</tr>
</tbody>
</table>

The basic parameters of durability asphalt pavement structure model are as follows: x direction presents the vehicle direction, and y is the road surface, the Z direction is perpendicular to the road surface, and the length, width and depth of the model are taken 6m. By using the finite element theory, use 8 node hexahedral elements, and assume that only Z direction exists displacement in the bottom surface of the unit body, surface is free and the contact state between layers is continuous. As shown in Figure 1,2.

![Figure 1. Structural model of asphalt pavement.](image1)

![Figure 2. Finite element model of asphalt pavement structure after meshing.](image2)

2 ANALYSIS OF MECHANICAL RESPONSE OF PAVEMENT UNDER DIFFERENT AXLE LOAD

2.1 Analysis of vertical deformation of road surface

2.1.1 Maximum vertical deformation analysis of road surface

The deflection of pavement refers to the sum of the vertical deformation in the subgrade and pavement structure. The vertical deformation of asphalt pavement under different axle load is analyzed, and we can get the curve of pavement under different axle loads. As shown in Figure 3.
From the figure 3, with the increase of the axial load, the maximum vertical deformation of the road also showed an upward trend. When the axial load is 276.8KN, the maximum vertical deformation of road surface is 2.73 times the standard axle load. The axial load and the maximum vertical deformation of the road can be approximated as a linear relationship. Under the same axial load, maximum vertical deformation appears in the role of wheel load. Pavement deflection is the characterization of the structural strength of asphalt pavement. With the increase of deflection value, the stiffness of pavement structure will be reduced and the service life of the pavement will be shortened.

2.1.2 Trend of vertical deformation of pavement

Figure 4-Figure 5 shows the trend of vertical load under different pavement deformation along the transverse and longitudinal change.

It can be seen from the figure 4-figure 5, maximum vertical deformation of asphalt pavement surface appears at the position of the load, and spread around in the same proportion. The size of the vertical deformation is a symmetric distribution in wheel axis or the vertical symmetry.
2.2 Tensile stress analysis of pavement structure

2.2.1 Analysis of maximum tensile stress in pavement structure

There are many factors that cause fatigue damage of pavement structure layer. Tensile stress and strain are the most important factors in the pavement structure. Therefore, it is very necessary to analyze the maximum tensile stress and tensile strain of pavement structure layer under different axle load. The variation of maximum tensile stress and tensile strain of pavement structure layer under different axle load are studied. As shown in Figures 6-7.

The maximum tensile stress and maximum tensile strain increase with the increase of the axial load in the pavement structure, as shown in figure 6- Figure 7, and the trend of change is similar. When the axial load is 276.8KN, the maximum tensile stress within the pavement is 2.83 times the standard axle load.

2.2.2 Pavement tensile stress distribution

Position coordinates of maximum tensile stress in pavement structure, as shown in Table 2.
Table 2. Maximum tensile stress appears position.

<table>
<thead>
<tr>
<th>Axle load/KN</th>
<th>Maximum tensile stress</th>
<th>Position (X-Pavement transverse, Y-Pavement longitudinal, Z-Depth direction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.078</td>
<td>(0.13713, 0.24023, 0.0000)</td>
</tr>
<tr>
<td>103.6</td>
<td>0.092</td>
<td>(0.13296, 0.23038, 0.0000)</td>
</tr>
<tr>
<td>130</td>
<td>0.113</td>
<td>(0.13681, 0.24051, 0.0000)</td>
</tr>
<tr>
<td>149.2</td>
<td>0.122</td>
<td>(0.13798, 0.24152, 0.0000)</td>
</tr>
<tr>
<td>167.6</td>
<td>0.173</td>
<td>(0.11985, 0.23465, 0.0000)</td>
</tr>
<tr>
<td>276.8</td>
<td>0.221</td>
<td>(0.13941, 0.25398, 0.0000)</td>
</tr>
</tbody>
</table>

Table 2 analysis shows the maximum tensile stress occurs at the surface position on the road, and the loads is in the edge position. As shown in Figure 11, the tensile stress in the wheel axis or the vertical symmetry distribution and the maximum tensile stress appeared at A:

2.3 Analysis of shear stress in pavement structure layer

2.3.1 Analysis of maximum shear stress in pavement structure layer

As shown in Figure 9, with the gradual increase of the axial load, the maximum shear stress in the asphalt pavement layer also shows an upward trend. So it can be concluded that when the road is under the action of heavy duty vehicles, it is easy to occur shear stress failure.
2.3.2 The position of the maximum shear stress of pavement

The position coordinates of the maximum shear stress in the pavement structure are shown in Table 5.

Table 3. Position of maximum shear stress.

<table>
<thead>
<tr>
<th>Axle load/KN</th>
<th>Maximum tensile stress</th>
<th>Position (X-Pavement transverse, Y-pavement Longitudinal, Z-Depth direction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.234</td>
<td>(0.0000, -0.19925, -0.050000)</td>
</tr>
<tr>
<td>103.6</td>
<td>0.283</td>
<td>(0.0000, -0.20675, -0.050000)</td>
</tr>
<tr>
<td>130</td>
<td>0.339</td>
<td>(0.0000, 0.21325, -0.050000)</td>
</tr>
<tr>
<td>149.2</td>
<td>0.361</td>
<td>(0.0000, 0.21875, -0.050000)</td>
</tr>
<tr>
<td>167.6</td>
<td>0.531</td>
<td>(0.0000, 0.21425, -0.050000)</td>
</tr>
<tr>
<td>276.8</td>
<td>0.654</td>
<td>(0.0000, 0.22925, -0.050000)</td>
</tr>
</tbody>
</table>

From table 3, it is known that, with the increase of wheel load, asphalt pavement structure layer shear stress increases. When the axial load is larger shear stress influence range greater.

2.3.3 Pavement shear stress distribution

In Figure 10, the variation curves of shear stress with its changes of depth direction under different axial loads are given. In Figure 11, diffusion of the shear stress along the depth direction.

Figure 9. Maximum shear stress of pavement structure under different axle loads.
Analysis figure 10-11 can be obtained, the shear stress in the pavement structure layer first increases with the increase of the depth. And the maximum shear stress occurs at the 5cm depth of the road surface, and then, it begins to decrease.

CONCLUSION

Based on the investigation of typical asphalt pavement structure diseases in desert region and the analysis of typical asphalt pavement structure performance, by using the field road load data analysis and finite element simulation analysis, put forward structure design index of durability asphalt pavement in northwest desert region. The mechanical distribution law of durability asphalt pavement structure in desert area was obtained. The results of the study are as follows:

(1) Through the comparative analysis of the traditional mechanics experience method and the single road performance design concept, the thoughts of According to the performance design and the mechanical check are proposed. The performance based approach and the mechanics based approach are combined. Pavement performance index PCI, road surface deflection and pavement rutting are proposed as the design index of the durability of asphalt pavement structure in the northwest desert region.

(2) Get analysis, the maximum vertical deformation of road surface and wheel load is a linear relationship under different vehicle load, and along with the increase of the axial load, the maximum vertical deformation increases linearly. Wheel load at the position of the maximum vertical displacement is the biggest under the same axial load. When the axial load is 276.8KN, the maximum vertical deformation of road surface is 2.73 times the standard axle load.

(3) Research shows, the maximum tensile stress of the pavement appeared on the surface of the pavement, and appears on the edge of the load, and the tensile stress is a symmetric distribution in wheel axis or the vertical symmetry.

(4) It is found that the maximum shear stress in the asphalt pavement is increasing with the increase of axial load, and it shows that the shear stress is easily destroyed when the pavement is under the action of heavy duty vehicle.
(5) In the study, the shear stress in the pavement structure is first increased with the increase of the depth, and the maximum shear stress occurs at the 5cm depth of the road surface, and then, it begins to decrease.

REFERENCES