Analysis of Pavement Mechanical Properties under Different Parameters of Asphalt Materials

Liu Feng1, 2, Li Hao1, 2, Liu Gui1, 2 and Zhou Yong1, 2

1 Guangdong Hualu Transport Technology Co., LTD, Guangzhou 510420, Guangdong, China
2 Research and Development Center on Road Transport Safety and Emergency Support Technology & Equipment, Ministry of Transport, PRC, Guangzhou 510420, Guangdong, China

Abstract. In view of the differences between the 2006 Chinese version of the asphalt pavement design specification and the 2017 version of the asphalt pavement design specification, taking the road structure of Renxin Expressway in Guangdong Province as an example, the finite element analysis method was used to establish the finite element model of the road structure. The mechanical response of asphalt pavement with different surface materials is analyzed. Then the mechanical response of asphalt pavement to asphalt pavement structure with different thickness is analyzed under the condition that the asphalt pavement remains unchanged in both the base layer and the subgrade. Finally, according to the above analysis results, the problems that need attention in asphalt pavement design are obtained.

Keywords: Road Engineering, Material Parameters, Mechanical Properties.

Unlike the full-thickness asphalt pavement structure in developed countries, the development of China's highways was more based on the semi-rigid base of the stable grade and gravel of inorganic binder because of the constraints of high-quality asphalt resources and economic conditions in the early China [1]. The previous research shows that the mechanical response law of the full-thickness asphalt pavement structure is very different from that of the semi-rigid asphalt pavement structure [2]. Through the continuous monitoring of the test section of Yunluo Expressway in Guangdong Province, the research team can see that the asphalt pavement on the semi-rigid base layer designed with strong foundation, thin surface and stable soil foundation can realize the long life of asphalt pavement [3,4]. The road surface condition is shown in Figure 1. However, the monitoring results also show that the dynamic response law of asphalt pavement under vehicle load is different from that of asphalt pavement under static load [5]. Therefore, in order to consider this difference, the 2017 Chinese asphalt pavement design specification changes the static modulus of the material to a dynamic modulus. This is a major step in the design of Chinese asphalt pavement. However, with the change of material parameters, whether the mechanical response law of asphalt pavement structure under the action of the original static parameters will change with the different material parameters is worth studying.
1. Renxin Highway Overview

Xinbo expressway is one of the sections of the Wushen expressway. The starting point of the project is located in Xinfeng County, Shaoguan City, and is connected to Boshen expressway in Boluo County. From the south to the north, the Guanghui expressway, the Guanghe expressway and the Daguang expressway are connected in series, and the northbound direction of Hunan is connected to the Renxin Expressway through the Daguang expressway. The basic structure of Renxin expressway pavement is shown in Figure 2. In order to test the influence of aggregates with different mechanical properties on the asphalt surface layer and the overall pavement structure, the research team paved four test roads. And the corresponding theoretical analysis was carried out before the paving of the test road. The theoretical analysis part mainly consists of two aspects. Firstly, the overall mechanical response of asphalt pavement under different surface layers is analyzed. Secondly, Based on the basic structure of Renxin expressway, the mechanical response of pavement structure under different asphalt layer thickness is studied under the premise of the same thickness of base and subgrade.

![Fig. 2 Schematic diagram of asphalt pavement structure of Renxin highway](image)

2. Finite Element Model of Road Structure

2.1. Structure model

In the mechanical analysis of road structures, the basic assumptions are as follows:

1) The materials of each structural layer are assumed to be linear elastic materials and all conform to the generalized Hooke theorem.

2) The thickness of each structural layer of the road is limited. According to the relevant literature, when the ground structure is subjected to static load and dynamic load analysis, when the thickness of
the foundation is greater than 6m and greater than 12m, the measured results are close to the simulation results and can meet the calculation requirements.

3) Complete contact between the structural layers of the road.

4) The load acts perpendicular to the pavement surface layer, and the stress, strain and displacement of the road structure at the infinite depth of the load are zero.

The asphalt pavement was analyzed using ANSYS finite element analysis software. In the ANSYS analysis, the foundation and each structural layer are blocky. However, the size of the foundation model is larger than the size of each structural layer above the foundation. The specific foundation size is 16m×9m×10.5m (ie. x×y×z, where x is the driving direction; y is the depth direction; z is the cross-sectional direction). The planar dimensions of each structural layer other than the foundation are 10m × 4.5m. Before dividing the grid, the solid subgrade and the structure layers are connected using the GLUE command. Ensure continuous contact between the soil subgrade and each structural layer and each structural layer. SOLID 45 element is used to divide the solid model grid in soil subgrade and each structure layer. And establish the finite element model as shown in Figure 3. The selection of the calculated points is shown in Figure 4.

Fig. 3 Finite element model of Renxin highway asphalt pavement structure under double circular load

![Fig. 3 Finite element model of Renxin highway asphalt pavement structure under double circular load](image)

Fig. 4 Double circular load contact surface parameter setting

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2.2. Material Parameters

Before carrying out the structural structural response analysis of the road, the material parameters and structural parameters of the asphalt pavement structure are determined according to Table 1.
Table 1. Material parameters of Renxin expressway for analysis of mechanical properties of asphalt pavement

| NO. | Material Name       | Thickness /mm | Elastic Modulus / MPa | Cracking strength /MPa | Poisson's ratio |
|-----|---------------------|--------------|-----------------------|------------------------|----------------|
|     |                     |              | Version 06[6]         | Version 17[7]          |                |
| 1   | GAC-16              | 50           | 1200~1800             | 8000~12000             | 1.2            |
| 2   | GAC-20              | 60           | 1200                  | 10000                  | 1.0            |
| 3   | GAC-25              | 80           | 1000                  | 9000                   | 0.8            |
| 4   | Cement stabilized  | 190+190+180  | 1600                  | 9000                   | 0.5            |
| 5   | Graded gravel       | 150          | 350                   | 350                    | --             |
| 6   | Soil base           | --           | 70                    | 70                     | --             |

3. Analysis of Law of Road Mechanics Response

3.1. Analysis of the Variation of Mechanical Response Components with the Modulus of the Upper Layer

Because different materials are used in the surface layer in Renxin expressway, this part will analyze the mechanical response law of asphalt pavement structure when the elastic modulus of the upper layer changes under the condition that the base modulus, the middle layer modulus and the lower layer modulus remain unchanged. Analyze according to 06 edition specification and 17 edition specification respectively. Calculation parameters as shown in table 1. The calculation point is taken as point C of Fig. 4. Among them, the results of the deflection calculation are shown in Figure 5. The results of stress and strain response at the bottom of each structural layer are shown in Table 2.

Table 2. Analysis results of the mechanical response components of Renxin expressway with the change of the elastic modulus of the upper layer
As can be seen from Figure 5 and Table 2. ① As the elastic modulus of the upper layer increases, the deflection value of the road surface shows a downward trend. ② The stress and strain at the bottom of the upper layer are both negative. The bottom layer is subjected to compressive stress and compressive strain. ③ The stress of the middle layer and the bottom layer is consistent with the upper layer. But the strain at the bottom of the two layers is in a pull state. The three layers above the graded rock layer are subjected to tensile strain or tensile stress. The stress and strain at the base of the upper layer increase with the increase of the elastic modulus of the upper layer. However, the stress and strain of the lower and upper basement layers decrease slightly with the increase of the elastic modulus of the upper layer. However, the reduction is not large, and the strain value of the upper basement layer is the largest.

3.2. Analysis of the Variation of Mechanical Response Components with the Thickness of the Surface Layer

This section will take the existing pavement structure of Renxin expressway as the benchmark, change the thickness of the surface layer, and investigate the mechanical response laws of the pavement structure after the thickness increases or decreases. The material composition is shown in Table 1. The surface layer structure is divided into the following five types. ① 4+5+7(Upper layer + Middle layer + Lower layer). This structure is abbreviated as S1. ② 5+6+8(Upper layer + Middle layer + Lower layer, Renxin expressway structure). This structure is abbreviated as S2. ③ 5+8+8(Upper layer + Middle layer + Lower layer). This structure is abbreviated as S3. The total thickness of the top layer is 21cm. ④ 5+6+8+6(Upper layer + Middle layer + Lower layer + ATB-25). This structure is abbreviated as S4. The total thickness of the top layer is 25cm. ⑤ 5+6+8+9(Upper layer + Middle layer + Lower layer + ATB-25). This structure is abbreviated as S5. The total thickness of the top layer is 28cm.

Table 3. Analysis Results of the Mechanical Response Components of Renxin Expressway with the Variation of the Thickness of the Surface Layer

| Mechanical response parameters | structure type | Upper Layer | Middle Layer | Lower Layer | ATB-25 | Upper base | Upper sub-base |
|-------------------------------|---------------|-------------|--------------|------------|--------|-----------|----------------|
| Structural bottom strain/με   | S1            | -39.62      | 27.78        | 26.84      | --     | 21.82     | 38.59          |
|                               | S2            | -20.04      | 38.86        | 27.82      | --     | 20.23     | 36.03          |
|                               | S3            | -20.32      | 43.57        | 28.39      | --     | 19.24     | 34.46          |
|                               | S4            | -19.00      | 42.57        | 40.91      | 25.03  | 17.39     | 31.74          |
|                               | S5            | -18.63      | 43.53        | 43.39      | 23.04  | 16.18     | 29.88          |
| Structural bottom stress/MPa  | S1            | -0.1310     | -0.0544      | -0.0418    | --     | 0.0059    | 0.0767         |
|                               | S2            | -0.1105     | -0.0357      | -0.0332    | --     | 0.0073    | 0.0718         |
|                               | S3            | -0.1103     | -0.0237      | -0.0287    | --     | 0.0081    | 0.0688         |
|                               | S4            | -0.1077     | -0.0290      | -0.0173    | -0.0225 | 0.0089    | 0.0635         |
|                               | S5            | -0.1067     | -0.0271      | -0.0136    | -0.0187 | 0.0094    | 0.0598         |
It can be seen from Table 3 and Figure 6. ① The pavement structure with different surface thickness shows a decreasing trend with the increase of surface thickness. ② The surface layer stress of the five asphalt pavement structures (including the ATB-25 structural layer, the same below) are compressive stresses, which have little effect on the structure. It can be ignored. ③ In addition to the upper layer, the bottom strain of other asphalt-containing structural layers is tensile strain. However, the pull strain of the bottom layer increases with the increase of the total thickness of the road surface layer. ④ The strain law of the upper base, lower base and upper base layer is more obvious. Both decrease with the increase of the total thickness of the surface layer. It can be seen that with the increase of the total thickness of the surface layer, the asphalt layer bears more loads. The load of the inorganic composite material layer has been reduced. This is also more consistent with the concept of durable asphalt pavement. ⑤ At the same time, by analyzing the bottom layer stress data of the base layer and the sub-base layer in the table, it can be known that the stress at the bottom of the lower base layer and the upper base layer decreases as the total thickness of the asphalt pavement structure increases. However, the case of the upper base layer is opposite to that of the upper base layer, indicating that as the total thickness of the surface layer increases, the upper base layer will be a weak layer of the entire structural layer, which may crack under the load before the other layers. In short, the increase in the thickness of the asphalt surface layer is beneficial to the force of the inorganic composite material layer. But it will also have a negative impact on the asphalt layer. However, from the point of view of easy maintenance of the entire pavement structure, it is advantageous to increase the thickness of the asphalt layer to the overall force of the pavement.

4. Conclusion
According to the results of the analysis above, whether the asphalt pavement is designed with static parameters or the asphalt pavement is designed with dynamic parameters, the road surface bending of asphalt pavement is consistent with the stress and strain laws of each structure. However, there are certain differences in the calculation values. In the structure of three layers of asphalt, the middle layer is most unfavorable, and its strain value is about 1 times higher than the strain value of the lower layer. The inorganic binder layer is the most unfavorable for the upper base layer. It is subjected to tensile stress and tensile strain and has a large value. The above descriptions show that in the asphalt pavement design, in the three-layer asphalt pavement structure on the semi-rigid base layer, the middle surface and the upper base are the most unfavorable layers. The corresponding mechanical indexes should be controlled, otherwise it is easy to shorten the overall life of the asphalt pavement structure.

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