Research on Asphalt Pavement Design Method Based on Analysis of the Most Unfavorable Point and Layer Function

Feng Liu 1, 2, a,*, Yong Zhou 1, 2, Chupeng Chen 1, 2, Hao Li 1, 2, Gui Liu 2

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

*a Corresponding Author E-mail: whlfok@126.com

Abstract. In order to improve the mechanical design method of the current semi-rigid base asphalt pavement structure, taking BISAR3.0 software as the mechanical response analysis method of pavement structure, the corresponding mechanical response analysis of two asphalt pavement structures in the durability test section of Yunluo Expressway in Guangdong Province was carried out. By applying double circular loads to the two asphalt pavement structures, the most unfavorable points among the many calculation points of the two asphalt pavement structures were obtained. Then, the most unfavorable point was used to analyze the laws of mechanical response parameters such as shear stress, horizontal tensile stress and horizontal tensile strain of pavement structure with the depth of pavement structure, so as to master the functional requirements of different structural layers. Based on the above analysis rules, the design of the semi-rigid base asphalt pavement structure needs to first analyze the layer function of the structure, and clarify the position of the main anti-high temperature rut function layer and the main anti-fatigue functional layer. Thereby, the material design of different structural layers could be guided, and the integrated design of structure and material could be realized.

Keywords: Road Engineering, Design Methods of Asphalt Pavement, Most Unfavorable Point, Layer Function

1. Introduction
At present, the design methods of asphalt pavement mainly included empirical design methods, mechanics-experience method and performance-based design method [1]. Various design methods were produced in different eras and had different characteristics. However, with the gradual improvement of the theory of elastic layered mechanics analysis system of road structure, the design of asphalt pavement structure based on the results of mechanical analysis had been greatly developed, and it had occupied a dominant position in the design specifications of the asphalt pavement in various countries [2-3]. Throughout the various mechanical design methods, the points selected by the mechanics check were basically located at the bottom of the corresponding structural layer. However, the asphalt pavement structure was greatly affected by traffic loads, geological conditions and environmental factors. Its
structure was diverse, and the force characteristics would also be different. It was still necessary to study whether the mechanical verification of the structural layer bottom was reasonable according to the specifications. Therefore, this paper will take the two kinds of asphalt pavement structure types of Yunluo highway durability test road as an example, the corresponding mechanical response analysis and research were carried out, so as to provide theoretical support for improving the design of the asphalt pavement structure.

2. Typical Asphalt Pavement Structure
At present, the asphalt pavement structure types of high-grade highways mainly included semi-rigid base asphalt pavement, rigid base asphalt pavement and fully flexible base asphalt pavement. This paper would take the structure 1 and structure 2 of the Yunluo highway durability test road as an example to analyze the mechanical characteristics of the two pavement structures and their similarities and differences in design methods [4]. Fig. 1 show the asphalt surface material and structural parameters of two pavement structures. However, there were differences in the base layer. Structure 1 was composed of cement-stabilized gravel semi-rigid materials, while structure 2 was composed of compacted concrete, graded gravel and cement-stabilized gravel. The material parameters corresponding to each structural layer were shown in table 1.

![Fig. 1 A schematic diagram of two typical asphalt pavement structures](image)

| NO. | Material Name                  | Elastic Modulus / MPa | Poisson's Ratio |
|-----|--------------------------------|-----------------------|-----------------|
| 1   | Asphalt Top Layer              | 1400                  | 0.25            |
| 2   | Asphalt Layer                  | 1000                  |                 |
| 3   | Cement Bound Granular          | 1600                  | 0.25            |
| 4   | RCC                            | 20000                 |                 |
| 5   | Graded Bound Granular          | 350                   | 0.40            |
| 6   | Solid Subgrade                 | 45                    | 0.35            |

3. Establishment of Theoretical Analysis Model
According to the structural form and material parameters of the two asphalt pavement in Figure 1 and Table 1, the statics response analysis of the two asphalt pavement structures was carried out by using BISAR software [5-6]. In the mechanical response analysis of the two types of asphalt pavement structures, the calculation scheme shown in Figure 2 was used. The X was the cross-sectional direction. The Y was the driving direction. According to the right approach, the Z-Axis direction was determined. Double circular load was used in the calculation. The load radius was 10.65 cm, the center distance of the load circle was 31.95 cm, and the load size was 0.707
Two-dimensional calculation diagram of mechanical response analysis of asphalt pavement structure

At the same time, it was assumed that the structure layers were continuous. The final calculation data were respectively extracted from 30 calculation points in two directions along the x-axis and Y-axis. Its coordinates were shown in Table 2. Both road structure types used the same calculation pattern, the difference was the structure type of the two road surfaces.

| Serial number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---------------|---|---|---|---|---|---|---|---|
| Coordinates   | 0 | 0.0266 | 0.0533 | 0.0799 | 0.1065 | 0.1331 | 0.1598 | 0.1864 |
| Serial number | 9 | 10 | 11 | 12 | 13 | 15 | 16 | 17 |
| Coordinates   | 0.2130 | 0.2397 | 0.2663 | 0.2929 | 0.3195 | 0.3728 | 0.3994 | 0.4260 |
| Serial number | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| Coordinates   | 0.4526 | 0.4793 | 0.6 | 0.9 | 1.2 | 1.5 | 1.8 | 2.1 |
| Serial number | 26 | 27 | 28 | 29 | 30 | -- | -- | -- |
| Coordinates   | 2.4 | 2.7 | 3.0 | 3.3 | 3.6 | -- | -- | -- |

4. The Most Unfavorable Point Analysis of Asphalt Pavement Structure

4.1. Road Surface Deflection Analysis

Through the comprehensive analysis of the two pavement structures under static load, the comparative analysis data of the mechanical properties of the two asphalt pavement structures could be obtained, as shown in Tables 3 and 4. It could be seen from Table 3 that the road surface deflection of the two types of asphalt pavement structures was the same, and the maximum deflection in the cross-sectional direction appears in the single-wheel load center. The maximum deflection in the driving direction appears in the two-wheel gap center, but the maximum deflection value in the cross-sectional direction was larger than the maximum deflection value of the road surface in the driving direction.
### Table 3. Contrast results of the road surface deflection of two asphalt pavement structures

| Structure type | Coordinate plane | Direction                | Position                   | Numerical value /μm |
|----------------|------------------|--------------------------|----------------------------|---------------------|
| Structure1     | XZ               | the cross-sectional      | the single-wheel load      | 203.3               |
|                |                  | direction                | center (0.1598, 0), Point 7|                     |
|                | YZ               | the driving direction    | the two-wheel gap center   | 179.5               |
|                |                  |                          | (0.0), Point 1             |                     |
| Structure2     | XZ               | the cross-sectional      | the single-wheel load      | 201.0               |
|                |                  | direction                | center (0.1598, 0), Point 7|                     |
|                | YZ               | the driving direction    | the two-wheel gap center   | 178.0               |
|                |                  |                          | (0.0), Point 1             |                     |

### 4.2. Analysis of Stress and Strain Law of Pavement Structure

Through the analysis of Table 3 and Table 4, it could be seen that the two asphalt pavement structure types are the most unfavorable calculation points under the static load, and the basic laws were as follows:

1. The top of the soil foundation was subjected to compressive strain, and the compressive strain value of the soil foundation at the center of the two-wheel gap was the largest.

2. The maximum tensile stress and tensile strain of the subbase layer bottom of the two structures

### Table 4. Comparison results of stress and strain laws of two kinds of asphalt pavement structures

| Structure type | Layer position | Pull/compression stress information | Pull/compression strain information |
|----------------|----------------|-------------------------------------|------------------------------------|
|                |                | Direction | Position                     | Numeric-al value /MPa | Direction | Position | Numeric-al value /με |
| Structure1     | Asphalt Lower Layer | x         | Single circle center, (0.1331, 0), Point 6 | -0.2048 | x         | Single circle center, (0.1598, 0), Point 7 | 4.58 |
|                |                | y         | Single circle center, (0.1598, 0), Point 7 | -0.1980 | y         |                                      | 6.76 |
|                | Semi-rigid base | x         | two-wheel gap center, (0.0), Point 1 | 0.0377 | x         | two-wheel gap center, (0.0), Point 1 | 6.30 |
|                |                | y         |                                      | 0.0459 | y         |                                      | 7.95 |
|                | Subbase        | x         |                                      | 0.0727 | x         |                                      | 16.15 |
|                |                | y         |                                      | 0.0751 | y         |                                      | 16.96 |
|                | Top of roadbed | --        | --                                   | --      | --        | --                                   | -52.35 |
| Structure2     | Asphalt Lower Layer | x         | Single circle center, (0.1598, 0), Point 7 | -0.2833 | x         | Point 30 | 0.7285 |
|                |                | y         |                                      | -0.2859 | y         | Point 15 | -7.359 |
|                | RCC Base       | x         | two-wheel gap center, (0.0)          | -0.1468 | x         | Point 1  | -11.37 |
|                |                | y         |                                      | -0.1362 | y         | Point 30 | 0.7267 |
|                | Subbase        | x         | (0.0799, 0), Point 4                | 0.2090  | x         | (0.0799, 0), Point 4                | 6.70  |
|                |                | y         | two-wheel gap center, (0.0), Point 1 | 0.2676  | y         | two-wheel gap center, (0.0), Point 1 | 9.50  |
|                |                | y         |                                      | 0.2073  | x         |                                      | 6.61  |
|                |                | y         |                                      | 0.2676  | y         |                                      | 9.50  |
|                |                | y         |                                      | 0.0739  | x         |                                      | 16.51 |
|                |                | y         |                                      | 0.0765  | y         |                                      | 17.37 |
|                | Top of roadbed | --        | --                                   | --      | --        | two-wheel gap center, (0.0)          | -55.20 |
Were in two-wheel gap center along the driving direction. (3) The maximum tensile stress and tensile stress of the subbase layer bottom of the two structures were in two-wheel gap center along the driving direction. (4) The stress of the bottom layer of the asphalt pavement under two asphalt pavement structures was compressive stress.

5. Function Analysis of Asphalt Pavement Structure Layer

Through the analysis of the most unfavorable points above, the point coordinates of different structures that play a key role in the structure life were obtained, which provided a certain basis for the initial design of asphalt pavement. However, this point was an isolated point. Through the analysis of the most unfavorable points, it was impossible to accurately understand the distribution of mechanical responses in each structural layer. It was also impossible to determine whether the mechanical response value was the maximum value of the corresponding structure layer. Therefore, it was necessary to study the distribution law of the mechanical response of each structural layer with the depth of the pavement structure for different asphalt pavement structures. That is to say, the corresponding layer function analysis was carried out to clarify the functional positioning of different structural layers against rutting or anti-fatigue. Figures 3 to 5 were related analysis results.

![Fig. 3](image1)

(a) Structure One  
(b) Structure Two

Fig. 3 Analysis of Shear Stress Variation of Two Asphalt Pavement Structures with Pavement Depth

![Fig. 4](image2)

(a) Structure One  
(b) Structure Two

Fig. 4 Analysis of Horizontal Stress Variation of Two Asphalt Pavement Structures with Pavement Depth
Due to space limitations, here, the importance of the layer function was analyzed only by the variation of structural shear stress with pavement layer depth in Fig. 3. The proportion of shear deformation of other structural layers was negligible compared with the asphalt surface layer. Therefore, the study only analyzed the shear stress of the asphalt structure of the two structures, and the final calculation data was extracted to the full thickness of the asphalt layer. It can be seen from the figure that the shear stress of the two structures in the continuous state between the structural layers increased with the increase of the depth of the pavement structure. After the maximum value was reached, the parabola law was gradually reduced. The maximum shear stress in the asphalt layer was not all located at the bottom of the layer. And the results of shear stress calculation at different points were different. The horizon coordinates of reaching the maximum value were also different. For example, the shear stress of the structure No. 7 point reached the maximum shear stress of 197.4 kPa at a depth of 0.08 m from the road surface. The shear stress at the 5th point reached the maximum shear stress of 191.5 kPa at a depth of 0.06 m from the road surface.

Therefore, in the design of different types of asphalt pavement structures, only the stress at the bottom of the asphalt structure couldn’t be determined to achieve the purpose of controlling the road life. It was not enough to control the strain at the bottom of the layer only by the composition of the asphalt surface layer. The corresponding layer function analysis should be carried out according to different structures in order to determine the maximum value of the maximum tensile strain and its coordinate position. Therefore, when designing the corresponding asphalt pavement structure, it was necessary to analyze the corresponding layer function area according to the preliminary asphalt pavement structure scheme, so as to match the performance of the selected pavement material and realize the integrated design of material and structure.
6. Conclusion
Taking the two types of asphalt pavement structure in the durability test section of Yunluo Expressway in Guangdong Province as an example, by using the BISAR3.0 elastic layered system mechanics analysis software, the mechanical response law of double-circular load analysis of two different structural types of asphalt pavement was applied. The most unfavorable point in many calculation points was found. And the analysis of the layer function of asphalt structure was carried out at this point, and the functional positioning of different structural layers was clarified. Thereby a theoretical basis for the material design of each structural layer was provided. The research of this paper proves that it was not accurate to check the design of asphalt pavement by the bottom position of each structure, and it was advisable to use the method of the most unfavorable point + layer function analysis to design asphalt pavement.

Acknowledgments
The authors appreciate the support of the science and technology project of Guangdong Provincial Communications Department (Project number: Science and technology -2012-02-011).

References
[1] YAO Zhukang. (2016). Structure design of asphalt pavement, People's Transportation Publishing Co., Ltd., Beijing.
[2] XIU Shan, WANG Taotao, FAN Yanxugao. (2013). “Research on China’s high-grade highway design index of asphalt pavement with granular base”. Sciences in Cold and Arid Regions, 5(4), 498-502.
[3] Paulo Pereira, Jorge Pais. (2013). “Main flexible pavement and mix design methods in Europe and challenges for the development of an European method”. Journal of Traffic and Transportation Engineering (English Edition), 4(4), 316-5346.
[4] LIU Feng. (2016). “Post-treatment of measured strain data of asphalt pavement structure”. Highway, 62(5), 59-63.
[5] LIU Feng. (2015). “Studies on Analysis of Airfield Pavement and Its Application into Structural Back-calculation”. Wuhan University of Technology, Wuhan.
[6] DONG Zhejiao, TAN Yiqiu. (2015). Study on dynamic response of asphalt pavement, Science Press, Beijing.