Analysis of Strain Law of Structural Layer of Semi-rigid Base Asphalt Pavement with Graded Crushed Rock

Feng Liu 1,2, a, *, Chuanhai Wu 1,2, Xinquan Xu 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. Based on the long-life test road project of Yunluo expressway in Guangdong province, the strain law of the semi-rigid asphalt pavement with graded crushed rock was analyzed and studied. Firstly, the ANSYS finite element analysis model was established according to the structure of Yunluo long-life test road, and the strain data of corresponding points were extracted according to the strain arrangement scheme of Yunluo test road. Secondly, FWD was used as the loading device, and the strain data of different points of the corresponding structure layer were obtained according to the test scheme of the long-life test road of Yunluo. Finally, through the analysis of the theory and the measured strain data, the strain law of the semi-rigid base asphalt pavement with graded gravel rock was obtained. To grasp the mechanical response law of this type of asphalt pavement structure, it would provide useful help for the design, construction and maintenance of the semi-rigid base asphalt pavement structure with the graded crushed rock.

Keywords: Road Engineering, Asphalt Pavement, Graded Crushed Rock, Cement Bound Granular, Layout and Test Plan.

1. Introduction

The Semi-rigid base asphalt pavement in China's highway construction occupied the dominant position due to its good stability, strong plate body, high load carrying capacity and the ability to take materials locally [1]. However, the asphalt pavement structure on the semi-rigid base layer also exposes early cracking, weak anti-scour capability and weak points sensitive to heavy-duty vehicle during use. This led to early damage to the pavement structure. The main reason for this early damage included construction problems, material problems, and design problems of asphalt pavement structures. The design problem is the source of the early disease. As we all know, the design of asphalt pavement was to control the mechanical parameters of different structural layers to meet the design requirements. However, for the actual asphalt pavement structure, whether the stress characteristics were consistent with the theoretical analysis results, there was a big doubt in a long period of time. The study of a full-scale test road with mechanical response sensors was developed abroad, such as the United States.
WAHSO (Western Association of States Offices) test road and AASHTO test roads [2-3]. The actual force characteristics of the asphalt pavement structure were slowly revealed. However, the asphalt pavement in foreign countries is more of a full-thickness structure, which was quite different from the force characteristics of the semi-rigid base asphalt pavement in China. Therefore, based on the long-life test road project of Guangdong Yunluo Expressway, this paper provided theoretical and practical analysis support for the design of this kind of pavement structure by analyzing the theoretical and measured strain of the semi-rigid base asphalt pavement with graded crushed rock.

2. Yunluo Expressway Overview
Guangdong Yunfu (Shuangfeng) to Luoding (Suibin) Expressway (referred to as Yunluo Expressway) project started from Shuangfeng Management District. In order to better study the strain law of the semi-rigid base asphalt pavement structure layer under the FWD load, the research team paved three test sections with a total length of about 3km at a certain place in Yunluo Expressway. The pavement structure forms were the RCC base asphalt pavement, the semi-rigid base asphalt pavement with non-graded crushed rock and the semi-rigid base asphalt pavement with the graded crushed rock [4]. In this paper, the strain law of asphalt pavement structure with the graded crushed rock would be studied. The structural form of this kind of pavement was shown in Fig. 1.

![Fig. 1 Schematic diagram of semi-rigid base asphalt pavement with the graded crushed rock.](image)

3. Finite Element Model of Asphalt Pavement Structure
A theoretical analysis model of the semi-rigid asphalt pavement with crushed rock was established by using ANSYS FEM software [5]. The structural and material parameters of the analysis model were shown in Fig. 1. The final ANSYS finite element model of the asphalt pavement was shown in Fig. 2. A total of 264,768 elements were divided. The model conformed to the assumption of continuity between structures layers. The boundary condition was to limit the total displacement of the bottom of the soil base, and the displacement of the normal direction of the soil base and each structural layer was limited. The grid division need to include the location of the measured strain sensor, the data was extracted according to the corresponding strain arrangement. The FWD pulse load was used, and when the load is maximum, the strain data of the corresponding point was extracted.
4. Monitoring Scheme for Strain Response of Asphalt Pavement Structure

4.1. Strain Sensor Deployment Scheme
In order to obtain the strain law of semi-rigid asphalt pavement with the graded crushed rock, the strain sensor design was needed first. According to the literature [6] and the corresponding mechanical response theory analysis conclusions, it was determined that the strain sensors of each structural layer were arranged in two directions along the cross section and along the driving direction. Two adjacent strain sensors in the same layer were arranged at a distance of 60cm. Fig. 3 show the sensor layout of the asphalt pavement structure layer. The blue "I" and "H" in the Fig. 3 were the location of the strain sensor and also the FWD load loading position. Fig. 4 was a map of the position of strain sensors arranged in different layers of the asphalt pavement structure.
Fig. 3 Layout plan of asphalt pavement structure sensor

(a) Sensor layout of the bottom of the lower subbase layer

(b) Sensor layout of the bottom of the lower base layer

(c) Sensor layout of the bottom of the lower layer

(d) Sensor layout of the bottom of the middle layer
4.2. Mechanical Response Test Scheme
The strain data output of each structure layer of asphalt pavement was loaded by FWD which was a pulse load. The position applied was the location of the upper layer strain sensor (Fig. 4a). The output data format was FWD + structure type + line number + column number + sensor number. Since the FWD load was a pulse load that changed with time, the strain detection signal of a single strain sensor was also a continuous signal containing noise that changes with time. The processing process of the strain signal waveform was as follows: the original strain waveform signal → 30 Hz filtering processing → smoothing processing → obtaining the true strain signal waveform.

5. Analysis of Theory and Measured Strain Law
Through theoretical and practical analysis, the results of theoretical strain analysis of the bottom central point of each structure in Table 1 were obtained, and the corresponding measured results in Fig. 6 to 10 were obtained. From Table 1 and the corresponding analysis results, we can see that the asphalt pavement structure had compressive strain at the center of the upper layer in both directions. Under the same load, the compressive strain in the driving direction was greater than the compressive strain in the cross-sectional direction. The strain at the bottom of the middle layer and the lower layer were both tensile strains. The bottom layer tensile strain of the middle layer was about 25-30 με larger than the bottom layer tensile strain of the lower layer. Therefore, the middle surface layer of the asphalt pavement structure was in the most unfavorable state of stress. Comparing the different layers of cement stabilized graded gravel, when the material was in different structural layers, the force characteristics were greatly different.
Table 1. Theoretical strain analysis results of the central node of each structural layer

| Layer position          | ANSYS Node NO. | X-the driving direction strain/με | BISAR Calculation results | Z- the cross-sectional direction strain /με |
|-------------------------|----------------|-----------------------------------|---------------------------|------------------------------------------|
| the upper layer         | 87746          | -56.29                            | -54.43                    | -48.33                                   |
| the middle layer        | 87486          | 57.26                             | 60.49                     | 72.88                                    |
| the lower layer         | 76884          | 30.24                             | 35.20                     | 34.56                                    |
| the lower base layer    | 34091          | 42.76                             | 42.12                     | 41.80                                    |
| the lower subbase layer | 7626           | 34.60                             | 31.32                     | 31.67                                    |

Fig. 6 The corresponding to the measured point strain curve of the upper layer

Fig. 7 The corresponding to the measured point strain curve of the middle layer

Fig. 8 The corresponding to the measured point strain curve of the lower layer
6. Conclusion

Based on the long-life test road of Yunluo Expressway in Guangdong Province, this paper analyzed the theoretical and measured strains of each structural layer of the semi-rigid base asphalt pavement with graded crushed rock. The mechanical response characteristics of the asphalt pavement structure under FWD load were obtained:

(1) The upper layer bottom of the asphalt pavement of the semi-rigid layer with graded crushed rock was subjected to compressive strain. The middle layer and the lower layer were subjected to tensile strain in both directions. The tensile strain in the cross-sectional direction was larger than the tensile strain in the driving direction. Comparing the tensile strains of the two layers, it can be seen that the tensile strain of the middle layer was larger than that of the lower layer.

(2) The tensile strain of the cement-stabilized grained semi-rigid material was greater than that of the grained semi-rigid material. But this did not mean that the semi-rigid material at the bottom of the base was in a safe state. This type of asphalt pavement need to be drained with graded crushed rock layer.

(3) According to the analysis of the measured strain data, the ANSYS finite element model established in this paper was reasonable. It could be used for the mechanical analysis of asphalt pavement design, but the mechanical analysis of the design of the asphalt pavement structure should be combined with the layer function.

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).

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