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Analysis of Measured Mechanical Response Law of Asphalt Pavement on Roller Compacted Concrete Base Based on Strain Sensor System

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Abstract. In order to grasp the measured mechanical response law of the asphalt pavement structure on the Roller Compacted Concrete (RCC) base, taking the asphalt pavement structure of the roller compacted concrete base in the durability test road of Yunluo expressway in Guangdong Province as an example, firstly, the strain sensor layout principle of the asphalt pavement structure was determined and the relevant test plan was formulated with FWD as the loading tool. Then, according to the test scheme, the measured strain response law of the asphalt pavement structure was obtained. At the same time, the theoretical analysis of the same structure was carried out by using ANSYS finite element analysis software. The results confirmed that the theoretical and practical analysis results were in good agreement. The mastery of the measured strain curve law would provide useful help for the design, construction and maintenance of this kind of asphalt pavement in the future.

Keywords: Road Engineering, Asphalt Pavement, Strain Sensor System, Roller Compacted Concrete, Mechanical Response Law, Layout and Test Plan.

1. Introduction
Asphalt pavement could be divided into semi-rigid base asphalt pavement, rigid base asphalt pavement and flexible base asphalt pavement according to the different types of base [1]. Because the United States and some developed countries had a relatively strong economic foundation and possess high-quality asphalt resources, the structure of the asphalt pavement with full flexibility has made great progress. At the same time, by using the sensor technology the mechanical response characteristics of the fully flexible asphalt pavement structure was obtained through the corresponding full-scale pavement test, and the design method of fully flexible asphalt pavement was gradually improved [2-3], such as the United States WAHSO (Western Association of States Offices) test road and AASHTO test road and so on [4-5]. Because of the lack of high-quality asphalt resources in the early stage of highway construction in China, the development of flexible pavement was relatively slow. However, due to the
abundant natural resources such as cement in our country, the semi-rigid base asphalt pavement and the RCC base asphalt pavement based on cement materials had been rapidly developed. However, since the early road surface was designed only by experience and simple mechanical analysis, the understanding of the force characteristics of the real road structure was insufficient, which often brings about the early damage of the road surface. Therefore, this paper would take Guangdong Yunluo expressway durability test road as project support to carry out the research on the mechanical response law of asphalt pavement on the RCC base.

2. Rolled Concrete Pavement Engineering Example
The asphalt pavement structure of RCC base was widely used in Guangdong Province and had formed a certain scale. In order to better grasp the mechanical response characteristics of the asphalt pavement structure, and in order to grasp the similarities and differences of the response patterns of various common types of asphalt pavement structures, the response characteristics of asphalt pavement based on sensor technology was developed on the durability test section of Guangdong Yunluo Expressway. The test road had a total length of 3km and was divided into three test sections, each of which was 1km long. It was a semi-rigid base asphalt pavement, a roller compacted concrete asphalt pavement and a semi-rigid base asphalt pavement with the graded crushed rock. However, due to space limitations, this paper would only take the RCC asphalt pavement as an example to analyze the theory and measured strain response law of the pavement structure. Fig. 1 show the structural form of the pavement.

3. Measured Strain System Composition Analysis
The research on the measured strain of the RCC asphalt pavement structure need to establish a strain detection hardware system. Then according to the proposed test scheme, the strain data were extracted and the corresponding mechanical response analysis was carried out.

3.1. Strain Sensor Deployment Scheme
Fig. 2 was the layout diagram of each sensor system for the asphalt pavement of the RCC base in Yunluo expressway durability test section. It could be seen from the figure that the measured mechanical monitoring system of the pavement structure consists of temperature data acquisition system, humidity data acquisition system, pressure data acquisition system and strain data acquisition system. Among them, according to the literature [6], the spacing of the strain sensors adjacent to the same structural layer was preferably 60cm. The strain sensor of each level was arranged in both the driving direction and the cross section of the pavement structure. The "I" type strain sensor was arranged along the driving direction, and the "H" type strain sensor was arranged along the cross section of the pavement structure. Fig. 4 was a detailed layout diagram of strain sensors for the pavement structure.
Fig. 2 Asphalt pavement structure sensor layout

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

(b) Sensor layout of the bottom of the lower base layer
3.2. Strain Response Test Plan

According to the strain sensor layout scheme mentioned above, the corresponding test plan was formulated. The strain data acquisition selected the DH-3817F dynamic data collector in Fig. 4 connected with the corresponding strain sensor terminal according to the channel requirements. Each strain sensor signal enters the computer system through the corresponding channel for subsequent analysis. In order to obtain the strain information of the corresponding structure layer, FWD was selected as the loading device for the test, and the loading positions were "I" and "H" in Figure 2. The format of the output strain data was FWD + structure type + line number + column number + sensor number. Fig. 5 show the FWD loading diagram in the actual engineering. Fig. 6 show the measured strain signal processing flow (the original strain waveform signal → 30 Hz filtering processing → smoothing processing → obtaining the true strain signal waveform). Among them, Fig. 6a was the original strain signal with noise, and Fig. 6b was the true strain detection signal after corresponding processing.
Fig. 4 Donghua DH3817F dynamic data acquisition instrument and its terminal block

Fig. 5 FWD test on the durability test road

Fig. 6 Road measured strain curve of the asphalt pavement structure at 118

(a) Original strain signal  
(b) Treated strain signal

4. Analysis of the Measured Strain Law

Table 1 was the strain calculation result of each structure layer of the asphalt pavement structure on RCC rigid base layer below the FWD load. Fig. 7 to Fig. 11 were the results of the measured system analysis corresponding to the theoretical analysis results. From the analysis, we could see that in theory, the upper surface layer was in the pull strain state, and the bottom layer was the pressure strain state. From the actual test results (partial strain sensor damage), the theory of the upper layer bottom and the measured results were in the pull strain state. However, there was a difference between the results of strain theory analysis and the measured results of the asphalt bottom layer. The reason may be due to the change of the position of the strain sensor or the difference between the parameters of the actual pavement structure and the calculation parameters.

Therefore, it was necessary to take into account the fatigue damage of such pavement design analysis. For the bottom of the RCC upper base layer and the cement bound granular, the measured strain law of the driving direction and the cross-sectional direction was consistent with the theoretical analysis results. They're all in a pull state. The pull strain of the RCC layer was larger than other layers. The rigid base where the RCC was located is more prone to fatigue damage.
**Table 1** Results of theoretical strain analysis of the bottom nodes of each structure

| Layer Name       | ANSYS Node Number | X- the Driving Direction Strain /µε | Z- the Cross-sectional Direction Strain /µε |
|------------------|-------------------|-------------------------------------|-------------------------------------------|
| the upper layer  | 78406             | 20.87                               | 34.86                                     |
| the lower layer  | 72222             | -14.61                              | -12.35                                    |
| the upper base layer | 65471           | 18.62                               | 17.86                                     |
| the lower base layer | 28486           | 18.69                               | 16.08                                     |
| the lower subbase layer | 7626            | 33.46                               | 27.53                                     |

**Fig. 7** Strain curve of the corresponding measuring point at the bottom of the upper layer

**Fig. 8** Strain curve of the corresponding measuring point at the bottom of the lower layer
5. Conclusion

Based on the Yunluo expressway durability test road in Guangdong Province, this paper uses the strain sensor system in the actual pavement structure to study the mechanical behavior of the roller compacted concrete pavement structure. The relative theory was in good agreement with the measured results. Mastering the strain response law of the pavement structure under the FWD load had great benefits for improving the design, construction and maintenance of the asphalt pavement structure. The relevant analysis results were as follows:

(1) It was feasible to apply the strain sensor to the mechanical analysis of the actual road structure.

(2) The measured results show that the detection points at the bottom of each structural layer were in the tensile strain state, but there were numerical differences.
(3) For the RCC asphalt pavement structures, the tensile strain of the RCC base is an order of magnitude larger than that of other bases and subbase. Therefore, the probability of fatigue cracking was higher than that of other layers, which was the main anti-fatigue layer in pavement structure.

(4) The tensile strain of the asphalt surface layer of this kind of asphalt pavement structure was larger than that of other types of asphalt pavement structures, such as the semi-rigid base asphalt pavement structures. The pull strain on the upper layer was larger than the pull strain on the bottom layer.

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