Study on Strain Test Law of the Semi-rigid base Asphalt Pavement

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Abstract. In order to grasp the similarities and differences in the experimental strain law of different types of semi-rigid base asphalt pavement, based on the Yunluo highway durability test pavement, the strain monitoring system, temperature monitoring system and humidity monitoring system of the full-scale pavement were constructed, and corresponding test plans were formulated. Through the test scheme, the strain response laws of different structural layers of two asphalt pavements were obtained. Through the comparative analysis with the relevant theoretical analysis results, the rationality and credibility of the strain layout scheme and test scheme of the Yunluo durability test pavement were confirmed. Through the analysis of the measured strain data, it was verified that the graded crushed rock layer did have a decentralized effect on the load. At the same time, it was also confirmed that when the same pavement material was in different structural layers, its mechanical response under load was different.

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

Different from the research on the actual mechanical response of AASHTO, WASHO (Western Association of State Highway Officials) and other experimental roads developed by foreign developed countries for full-thick asphalt pavement structure[1-3], because China is subject to construction funds and high-quality asphalt resources in the early stage of expressway construction, the semi-rigid base asphalt pavement represented by cement stabilized graded gravel has developed rapidly and occupied a dominant position in China's highway construction[4]. Therefore, the practical experience of the fully flexible asphalt pavement structure based on the sensing system cannot be fully applied to the mechanical response analysis and design of the semi-rigid base asphalt pavement structure. In order to reveal the early damage mechanism of the semi-rigid base asphalt pavement and the factors affecting its mechanical behavior, the Highway Research Institute of the Ministry of Transport has built a full-scale test site in Beijing, and arranged corresponding sensors to study different pavements[5]. Hu Peng[6] carried out research on the response and damage of asphalt pavement under dynamic load. Based on the durability test road project of Yunluo Expressway in Guangdong Province, this paper will greatly enrich
the theory and practical experience of semi-rigid base asphalt pavement structure by studying the measured strain law of each type of semi-rigid base asphalt pavement.

1. Overview of Yunluo Expressway Test Section
Yunluo Expressway started in Luoding, Guangdong Province, and the research team paved three test sections with a total length of about 3km[7]. Among them, two types of semi-rigid base asphalt roads of 2km are paved, as shown in Figure 1. The base layer and the lower base layer of the structure 1 are composed of cement stabilized graded gravel, and only the strength of the material is different, and the structure is called a reinforced semi-rigid base asphalt pavement. Considering the dispersion of the flexible material to the stress, the lower base layer of the structure 3 is paved with graded gravel, which is called a flip-chip semi-rigid base asphalt pavement.

Fig. 1 Schematic diagram of two types of semi-rigid base asphalt pavement

2. Strain Sensor Layout and Test Plan

2.1. Strain Sensor Layout
Structural layer strain test was carried out on the Yunluo expressway test section (Fig. 2 is the CTL strain sensor site layout diagram), temperature field test, humidity field test and various structural layer pressure tests. However, due to space limitations, this article can only analyzed the strain field law of two rigid base asphalt pavement structure.

Fig. 2 Field installation of the US Building Technology Laboratory (CTL) resistance strain sensor

Figure 3 shows a schematic diagram of two structural sensor arrangements. In the floor plan, the blue "I" and "H" are the locations of the strain sensors. According to the literature[8], two strain sensors adjacent to the same structural layer are arranged at a pitch of 60 cm. Figure 4 is a layout view of the strain sensor corresponding to Figure 3 in each structural layer position. Among them, S1-1 represents...
the first sensor of structure 1, and S3-1 in parentheses represents the first sensor of structure three, and the others are the same.

![Diagram of sensor layout](image)

(a) Layout plan

(b) Elevation layout

**Fig. 3** Two kinds of sensor layout of semi-rigid base asphalt pavement structure

![Diagram of sensor layout](image)

(a) Lower base layer bottom sensor layout

(b) Lower base layer sensor layout
2.2. Mechanical Response Test Program

The mechanical response test of the Yunluo test section uses two loading modes: FWD (Fig. 5) and real vehicle load (Fig. 6). FWD is a pulse load. The real vehicle load is loaded along the line number 2 in the direction of the blue arrow in the plane layout diagram of Figure 3. However, due to space limitations, only the strain response law of asphalt pavement under FWD load is analyzed here. Loading test is using FWD at the blue "I" and "H" of the strain sensor layout scheme of Figure 3. After loading, use the Donghua DH3817F dynamic data acquisition instrument to collect the strain sensor signals of each structural layer and save them accordingly. The saved strain data format is as follows: FWD + load action position (structure type + line number + column number) + sensor number. FWD118S1-23 indicates that the FWD load acts at the intersection of line number 1 and column number 8 of structure 1 of Figure 3a, while S1-23 represents the strain sensor of the structure-upper layer bottom.
In engineering practice, it is often necessary to process a useful strain signal containing noise (Figure 7b). The signal processing flow is as follows: ① DH3817F dynamic data acquisition instrument collects raw data, and converts it into MATLAB data. ② The measured strain data is imported into MATLAB, the data is filtered (filtered and smoothed). ③ The strain measurement curve is zeroed at the baseline, and the data before the strain strain point is averaged. ④ The average value is zeroed, the signal curve is translated, and the true strain waveform signal is obtained. ⑤ The peak value of the relevant strain signal is extracted. Due to the complexity of signal processing, the research team developed the corresponding signal processing software[9]. Figure 7(b) shows the processed strain signal. It can be seen from the figure that FWD is loaded six times at each point, and seven peaks are obtained. The second peak to the sixth peak respectively corresponds to the FWD loads of 50 kN, 80 kN and 100 kN.

![Fig. 5 FWD test](image1)
![Fig. 6 Driving load test](image2)

![Fig. 7 Asphalt pavement FWD118S1-8 test point strain curve](image3)

3. Analysis of Actual Measurement Strain Law of Asphalt Pavement

Figure 8 to Figure 12 are the measured strain curves of the driving directions of the structural layers of the two semi-rigid base asphalt pavements. Among them, Fig. 9 is the measured strain curve of the cross-sectional direction and the driving direction of the three middle layers of the structure. The following is divided into two aspects: asphalt surface layer and (bottom) base.

3.1. Analysis of Strain Law of Asphalt Surface

From Figure 8, it can be seen that the upper layer bottom of two-layer asphalt pavement and three-layer asphalt pavement structure are under the compressive strain under load, which is beneficial to the stress of the structure. It can be seen from Fig. 10 that the underlying layers of the two structures are subjected to tensile strain, which is in good agreement with the theoretical analysis results of the elastic layered system of asphalt pavement. This indicates that there is the possibility of fatigue cracking at the bottom of the asphalt layer, and it is unreasonable to use the asphalt layer bottom stress to control the cracking to design the asphalt pavement. Under the same 80kN load, the tensile strain of structure three (about 20με) is about 12με than that of structure one (about 8με), which means that the risk of structural three-
fatigue cracking is larger than that of structure one. It can be seen from the strain measurement curves in the two directions of the middle layer of the structure of Fig. 9 that the middle layer of the structure is subjected to tensile strain in both directions, and the tensile strain in the driving direction is larger than that in the cross-sectional direction. Therefore, this kind of structure has a higher proportion of fatigue lateral cracks in the middle layer than in the longitudinal direction. At the same time, comparing the tensile strain in the driving direction of the middle layer (Fig. 9a) and the lower layer (Fig. 10 right), the tensile strain of the lower layer is smaller than that of the middle layer, and the middle layer of the structure 3 is less favorable.

**Fig. 8** Strain curve of the corresponding measuring point at the bottom of the upper layer

(a) Driving direction strain  
(b) Cross-sectional direction strain

**Fig. 9** Strain curve of the measuring point corresponding to the driving direction of the middle layer in structure 3

**Fig. 10** The driving direction of the lower layer corresponds to the strain curve of the measuring point
3.2. Analysis of Measured Strain Law of Lower (Bottom) Base Layer

By analyzing the measured strain curves of the base layer and the lower base layer of the two structures, both structural layers are subjected to tensile strain, and the tensile strains tend to increase with the increase of the load. However, in the same layer, the same semi-rigid material under the same level of FWD load (100kN), the tensile strain at the bottom of the lower base layer containing the graded gravel structure 3 is about 5με compared with the structure one (Figure 11). According to Figure 12, the tensile strain of the bottom base of the structure 3 is smaller than that of the structure 1. This shows that graded gravel layer has dispersing effect on load, and the existence of graded gravel layer is beneficial to the stress of soil foundation. However, under the same load, the strain of the sub-base under the structure is larger than that under the sub-base. It shows that the dangerous layers of fatigue cracking are different between them.

Fig. 11 Strain curve of the corresponding measuring point in the driving direction of the base layer

Fig. 12 Strain curve of the corresponding measuring point at the bottom of the lower base layer

4. Conclusion

Through the analysis of the measured strain data of each structural layer of the durability test road of Yunluo Expressway in Guangdong Province, the measured strain law of two types of semi-rigid base asphalt pavement structures is obtained. Research indicates: ① It is feasible to use the strain sensor embedded in the full-scale pavement to measure the mechanical response of the pavement and then guide the structural design of the asphalt pavement. ② To two types of asphalt pavement structure, the upper layer is subjected to compressive strain, and the structure is relatively safe. However, the two layers may have different levels of fatigue cracking. The structure 1 is located in the lower layer, while the structure 3 is located in the middle layer. ③ Semi-rigid materials with the same mechanical properties show different mechanical behaviors when applied to different structural layers, and there are some differences in mechanical properties. ④ The measured results show that the graded gravel layer has a certain dispersing effect on the load, and it is a more favorable conclusion for the overall force of the structure.
Due to the differences of climate, geological conditions and traffic volume in actual projects, the two types of semi-rigid base asphalt pavement based on this research can not represent the mechanical response law of all semi-rigid base asphalt pavement. At the same time, because of construction and other reasons, the survival rate of strain sensor can not reach 100%, which leads to the failure of some strain sensor output. All these have brought obstacles to the improvement of the design method of semi-rigid base asphalt pavement. However, with the development of science and technology, the field measurement sensor technology will surely enter the field of pavement design more and more, and will gradually reveal the dynamic response characteristics of the real pavement once considered as "black box".

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