

# Mechanical Response Analysis of Long-life Asphalt Pavement Structure of Yunluo High-speed on the Semi-rigid Base

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**Abstract.** In order to grasp the rule of the strain change of the semi-rigid asphalt pavement structure under the FWD load and provide a reliable theoretical and practical basis for the design of the pavement structure, based on the test section of Guangdong Yunluo expressway, taking FWD as the loading tool, by using the finite element analysis software ANSYS, the internal variation rules of each pavement structural layer were obtained. Based on the results of the theoretical analysis, the measured strain sensor was set up in the corresponding layer of the pavement structure, and the strain test plan was determined. Based on the analysis of the strain data obtained from several structural layers and field monitoring, the rationality of the type pavement structure and the strain test scheme were verified, so as to provide useful help for the design and the maintenance of the pavement structure.

**Key words:** road engineering; long-life asphalt pavements; dynamic response; measured strain system

## 1. Introduction

The asphalt concrete pavement structure had been widely used in the highway because of its good integrity, smoothness, convenient construction method and the convenience of later maintenance (Li et.al, 2013). The structure type of the asphalt pavement had asphalt pavement structure on flexible base and asphalt pavement structure of semi-rigid base. Different countries and regions, due to the differences in natural resources and economic conditions, would adopt different types of the pavement structure. Due to the lack of high-quality asphalt resources and a wealth of inorganic binder resources, so the asphalt concrete pavement structure type on semi-rigid base was more used by China (Rui et.al, 2015). Although the corresponding analysis and design can be done in accordance with the appropriate procedures. However, through theoretical analysis, it can be seen that the asphalt layer of this kind of pavement structure was in the state of compressive stress, so it was easy to meet the design requirements. But the strain of the asphalt layer was not always in compression state. If the design didn't check the



strain indicators, it would bring uncertainty to this type of pavement structure design, also brought the emergence of asphalt pavement diseases. But how was the actual strain state of the type of asphalt pavement layers? Although the related research have been done both at home and abroad, but because of the diversity of materials and structures, the actual strain state of the asphalt pavement structure on the semi-rigid base was different to different countries and regions. Therefore, based on the Yunluo high-speed test section in Guangdong Province (Wang et.al, 2016), this paper would study the mechanical properties of the long-life asphalt concrete pavement on the semi-rigid base layer based on the measured strain system, so as to provide useful help for a long-life semi-rigid pavement structure design and maintenance.

Table 1 was the pavement structure and material parameters of the Yunluo expressway test section.

**Table 1.** Pavement Parameters of Long-Life Test Road in Yunluo Expressway

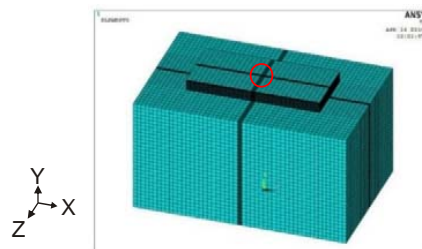
Structure Name	Material name	Thickness/cm	Elastic Modulus/MPa	Poisson's ratio
Surface layer	AC-16	5	1200	0.25
	AC-25	8	1000	
Base	19cm CSM*	19	1600	
	19cm CSM	19	1600	
	19cm CSM	19	1400	
	19cm CSM	19	1400	
Soil base	--	--	45	0.35

\*The cement stabilized macadam referred to as CSM.

## 2. the strain law Analysis of asphalt pavement structure

### 2.1. Establishment of Three Dimensional Finite Element Model for Asphalt Pavement

In ANSYS, the soil base and the various structural layers were established by using block command. But the size of the soil base model was larger than the size of each structure layer in the horizontal direction. The soil base size was  $16\text{m} \times 9\text{m} \times 10.5\text{m}$  (where,  $x \times y \times z$ ,  $x$  was the driving direction;  $y$  was the depth direction;  $z$  was the cross-section direction.). In addition to the soil base, the plane size of each structural layer was  $10\text{m} \times 4.5\text{m}$  ( $x \times z$ , the depth of the different structural layers was shown in Table 1). In the dynamic load analysis, when the thickness of the soil base was more than 12m, the measured results were similar to the simulation results, which can meet the calculation requirements (Wang, 2015). In order to ensure the continuous contact state between each layer and soil layer, the GLUE command was used to connect the soil base and the structural layers before dividing the grid. The SOLID45 element was used to divide the mesh of the soil base model and each structure layer. And its finite element model was established. The corresponding boundary conditions were set so that each side of the soil base restricts its displacement in the normal direction. The normal displacement of the side faces of other structural layers was not limited. The bottom of the soil base limited its total displacement (Liu, 2015). Fig. 2 was the finite element model of the asphalt pavement after meshing.

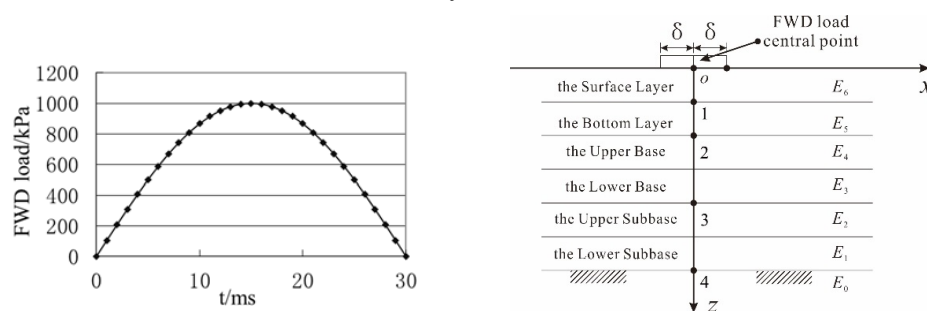


**Figure 1.** Asphalt pavement finite element model of Yunluo experimental road

### 2.2. Application of FWD Load and Strain Data Extraction

In order to obtain the mechanical response of the asphalt pavement structure, so as to evaluate the mechanical properties of the asphalt pavement structure, it was necessary to impose some load on the existing asphalt pavement structure. In the mechanics analysis of road structures, it was possible to simulate the actual vehicle load by using half-wave sine load, double-circle vertical load, Fourier series, random load model and multi-degree of freedom model (Yang, 2008; Wang, 2015). The FWD load form of the nondestructive testing of road structures was the impact load. Based on the Fourier series transformation, the general impact load can be expressed as the linear combination of a number of half-sine wave load. Therefore, the dynamic load of the vehicle can be expressed as a half-sine wave load, as shown in Fig. 2, which is the reason for the use of the FWD device.

According to Fig. 3, the strain data were extracted. The extraction rules were as follows: in Fig. 3, the driving direction strain and the cross-section direction strain at 1 to 4 points were extracted. They were located at the bottom of the surface layer, the bottom of the bottom layer, the bottom of the lower base layer and the bottom of the lower sub-base layer.



**Figure 2.** FWD pulse load time history curve **Figure 3.** Schematic diagram of the strain data location

### 2.3. The strain analysis results of each structural layer

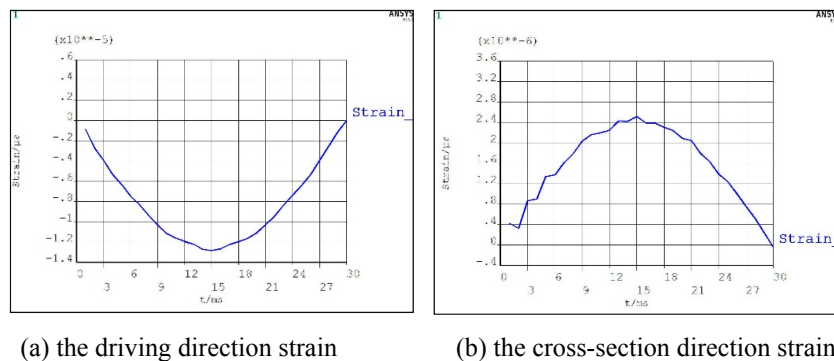
According to the finite element model of the asphalt pavement structure, the results of the strain analysis at the center of each structure layer were obtained as shown in Table 2 (the FWD sine wave was at the maximum value). And under the FWD load, Fig. 4 was the change trend graph of the driving direction strain and the cross-section direction strain with time. Due to space limitations, here only intercept the center node strain of the bottom of the surface layer.

From table 2 and Fig. 4, the driving direction strain of the surface layer was the compressive strain for the asphalt concrete pavement structure on the semi-rigid base layer. And its strain in the cross-sectional direction was tensile strain, there were differences between the two. While the other three structural layers in both directions were for tensile strain, but the size was different. The strain size in the driving direction and the cross section direction were as follows: the bottom strain of the lower sub-base layer > the bottom strain of the bottom layer > the bottom strain of the lower base layer. Therefore, when the monitoring scheme of the asphalt pavement structure strain was developed, it was necessary to consider the orientation of the strain sensor and the difference of the strain value of each structural layer.

**Table 2.** The theoretical strain analysis results of the center node of each structure layer bottom

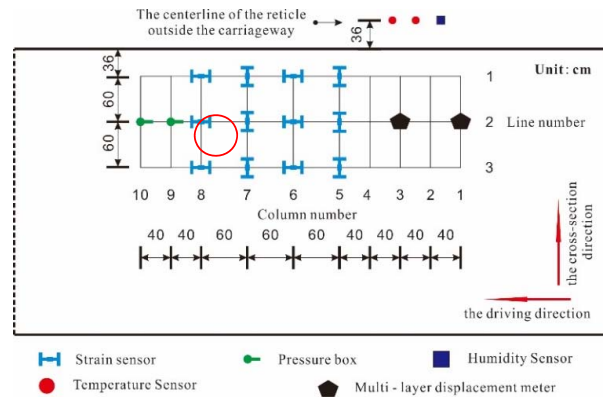
Structure layer name	ANSYS node NO.	X-the driving direction strain/ $\mu\epsilon$		Z- the cross section direction strain / $\mu\epsilon$
		ANSYS Calculation results	BISAR*Calculation results	
the bottom of the surface layer	78406	-12.83	-12.38	2.52
the bottom of the bottom layer	72222	29.89	34.79	38.3
the bottom of the lower base layer	28486	17.08	25.96	16.42
the bottom of the lower sub-base layer	7626	38.58	36.29	35.59

\* The corresponding mechanical properties were analyzed by BISAR3.0 software.

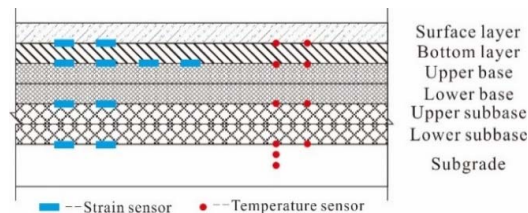
**Figure 4.** The change curve of the center node strain of the surface layer bottom with time

### 3. Pavement STRUCTURE strain test program

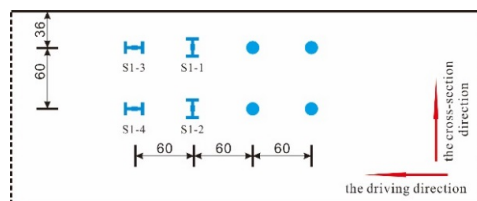
Based on the previous theoretical analysis of the Yunluo test road structure and the actual situation of the pavement structure, the sensor layout of the Yunluo test road was shown in Fig. 5 and Fig. 6. Fig. 7 was the schematic diagram of the layout point position of the Yunluo test section strain sensor. The pavement structure was equipped with the resistance strain sensor, which was produced by the American Construction Technology Laboratory (CTL) and temperature sensors and humidity sensors, etc. As from the Fig. 5 and Fig. 6, according to the results of theoretical analysis, there were a different number of strain sensor on the bottom of the surface layer, the bottom of the bottom layer, the bottom of the lower base layer and the bottom of the lower sub-base layer, and takes into consideration the location problem of strain sensor. Due to the construction process, the strain sensor was easy to damage, so each structural layer were arranged more than a number of strain sensors. The corresponding test procedure was as follows: the load was applied at the intersection point of the transverse and vertical lines in Fig. 5(a) by using FWD test equipment (as in the red circle). The strain data of each structural layer in Fig. 6 were collected by strain data acquisition instrument. In Fig. 6 ("I" and "H") a numbered strain sensor had a strain output data. The output data format was encoded as FWD + 1 + horizontal line number + column line number + sensor number. For example: FWD127S1-1 indicated that the load was FWD, 1 was the pavement structure type, 2 was the second line, 7 was the 7th column, and S1-1 was the strain sensor at the bottom of the surface layer.



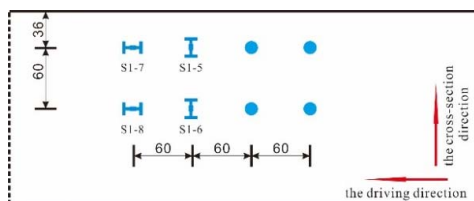
(a) Sensor placement and FWD loading mark plan



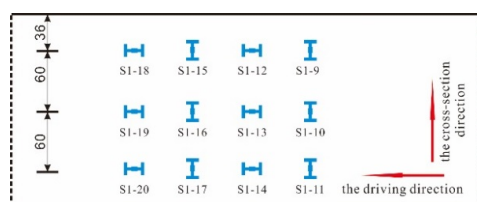
(b) Sensor layout elevation

**Figure 5.** The schematic diagram of the layout point position of the Yunluo test section strain sensor

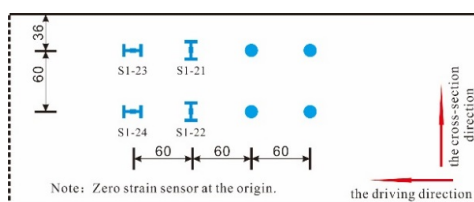
(a) Strain gauge layout of the lower sub-base



(b) Strain gauge layout of the lower base



(c) Strain gauge layout of the bottom layer



(d) Strain gauge layout of the surface layer

**Figure 6.** Strain sensor layout plan of the pavement structure layer

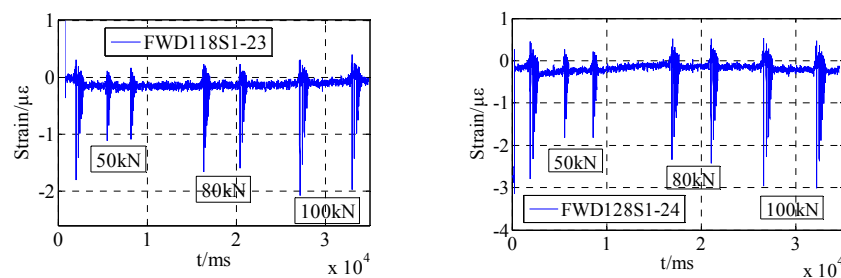


**Figure 7.** Schematic diagram of sensor arrangement and FWD loading mark in the pavement structure

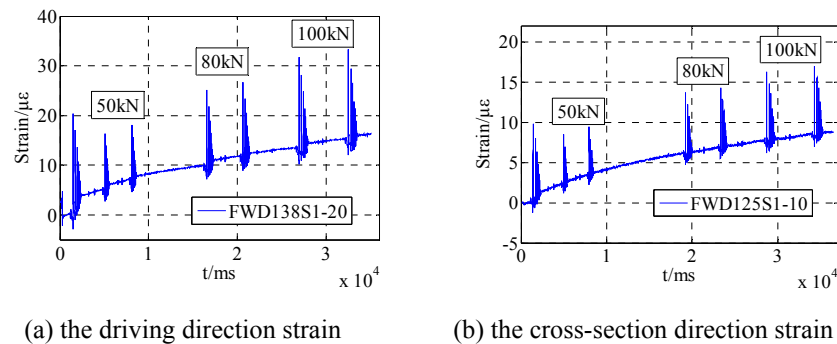
#### 4. Measured Strain Data Analysis

Fig. 8 to Fig. 11 showed the strain of the corresponding structural layers obtained from different FWD loading points and different structural horizons. As from the graph, the 50kN, 80kN and 100kN were used to load at each FWD test point, 2 times for each load level. The first pulse in each strain test diagram was caused by the inertia of the FWD device, and the six other pulse was the output response of each structural layer under the corresponding FWD load.

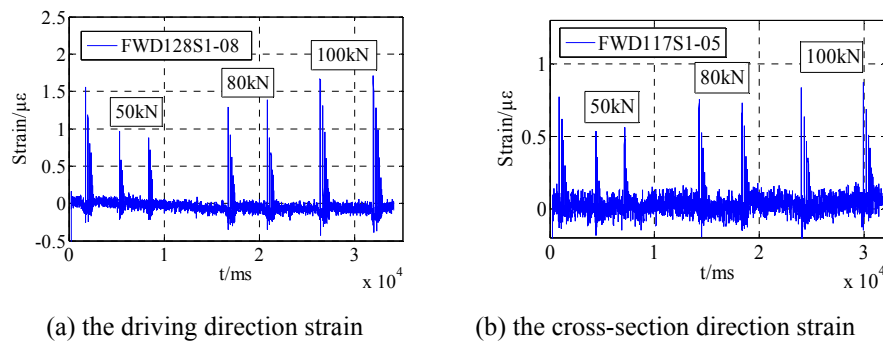
It can be seen from Fig. 8 that the two test points (FWD118 and FWD128) of the FWD were shown as compressive strain in the driving direction, which was consistent with the theoretical analysis. However, due to the damage of the transverse strain sensor in the surface layer structure, the test results were not collected. From Fig. 9 to Fig. 11, the strain sensors in each direction of the other structural layers were output tensile strain. Under the same load, the strain data collected by the strain sensor can meet the following rules: the bottom strain of the lower sub-base layer > the bottom strain of the bottom layer > the bottom strain of the lower base layer. At the same time, the strain of the driving direction was larger than that of the cross-section on the bottom of the lower sub-base layer. These results were consistent with the theoretical analysis results. Therefore, it was necessary to consider the tensile strain at the bottom of the asphalt layer structure in the design of the two layer asphalt pavement structure. For semi-rigid base, from the analysis results, the lower sub-base layer was relatively weak, and the strain values of the two directions were larger than those of other semi-rigid base layer. So when making this type of asphalt structure design, only the driving strain of the lower sub-base layer need be considered. It can be seen from the chart that there were some differences between the measured data and the theoretical analysis. The reason was because the actual material parameters and structure parameters of the asphalt pavement and the theoretical analysis parameters were different. At the same time, the construction process of the variability was also greater. The structure of the asphalt pavement can't be kept absolutely uniform.



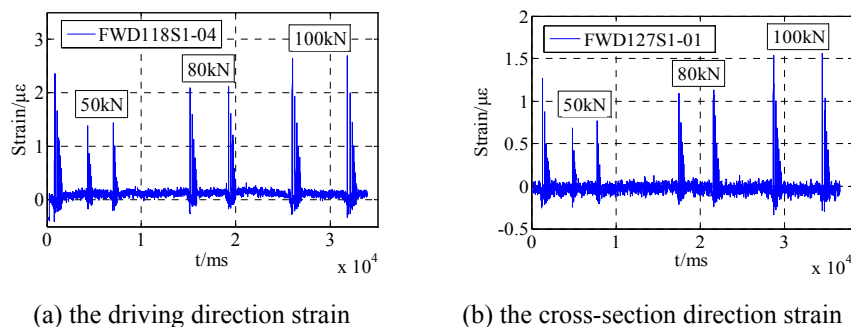
**Figure 8.** The driving direction strain curve of the corresponding measuring point on the bottom of the surface layer



**Figure 9.** The driving direction strain curve of the corresponding measuring point on the bottom of the bottom layer



**Figure 10.** The driving direction strain curve of the corresponding measuring point on the bottom of the lower base layer



**Figure 11.** The driving direction strain curve of the corresponding measuring point on the bottom of the lower sub-base layer

## 5. conclusion

The three-dimensional finite element model of the pavement structure of Yunluo test section was established by ANSYS finite element analysis software. The strain distribution law of the asphalt concrete pavement structure with two layer asphalt layer + four layer semi-rigid base was analyzed. Theoretical analysis confirmed that the strain of the asphalt pavement structure layer along the driving direction was compressive strain, while the driving direction strain and the cross-section direction strain of the other monitoring structure were tensile strain. In contrast, the driving bottom strain of the lower sub-base layer was the largest. According to the law, the corresponding test plan of the pavement



structure was established. Based on this test, the strain data of different structural layers and different orientations were obtained. It had been proved by practice that the measured results were in agreement with the theoretical analysis results. Therefore, in view of the structural design of the asphalt pavement on the semi-rigid base, the structural design was reliable through theoretical analysis. At the same time, it provided the basis for the back-analysis of the pavement structure parameters.

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### References

- [1] LI Zhihua, XIAO Qingyi. (2013). Design of long-life semi-rigid base asphalt pavement, China Building Materials Industry Press, Beijing.
- [2] RUI Yongqin. (2015). Study on structural optimization and rutting resistance of asphalt pavement with semi-rigid base, Northeastern University press, Liaoning.
- [3] WANG Jiachen, LI Hao, and WU Chuanhai. (2016). "Research on Dynamic Response Measurement System of Long - life Asphalt Pavement in Damp Heat and Heavy Duty Area". Chinese and Foreign Highway, 33(3), 83-87.
- [4] WANG Hao, LI Maoyun. (2016). "Comparative Study of Asphalt Pavement Responses under FWD and Moving Vehicular Loading". Journal of Transportation Engineering, 142(12), 53-57.
- [5] LIU Feng. (2015). Studies on Analysis of Airfield Pavement and Its Application into Structural Back-calculation. Wuhan University of Technology, Wuhan.
- [6] YANG Enhui, QIU Yanjun, JIANG Xin. (2008). "Theoretical study on inert point of deflection basin based on finite element analysis". Journal of Chongqing Jiaotong University (Natural Science Edition), 27(2), 232-235.
- [7] WANG Dong. (2015). "Prediction of Asphalt Pavement Temperature Profile During FWD Testing: Simplified Analytical Solution with Model Validation Based on LTPP Data". Journal of Transportation Engineering, 139(1), 106-113.