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Evaluating the Longitudinal and the Transverse Horizontal Strains at the Bottom of Hot Mix Asphalt

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Abstract— Horizontal strain at the bottom of asphalt concrete due to repeated traffic loads is the most critical parameter in characterizing fatigue performance of flexible pavement. The study of horizontal strain is thus very important to understand the strain behavior, predict the fatigue life and implement in design and analysis. A total of twelve Horizontal Asphalt Strain Gages (HASGs), six gages oriented in longitudinal direction and the other six sensors oriented in transverse direction are installed at the bottom of the asphalt concrete to measure the horizontal strains in both the longitudinal and the transverse directions for real time traffics. This study investigates these strains using data from the installed sensors. The strains responses for eighteen-wheel vehicles for a couple of days passing between 4:00 pm to 6:00 pm are considered for the study. Results show that the longitudinal strain has both compressive and tensile components and the transverse strain is totally tensile when the wheel is on the sensor's path and compressive if the wheel totally deviates from the sensor's path. It is also measured that the transverse strain is 1.18 times of the longitudinal strain.

Index Terms— Flexible pavement, Asphalt concrete, Longitudinal horizontal strain, Transverse horizontal strain, Field Instrumentation, T-test, ANOVA test.

1 Introduction

PAVEMENT materials are compacted vertically during construction. Only vertical downward pressure is applied with vibration. Moreover, compactor rolls over the pavement in longitudinal direction, not in lateral direction. Therefore, material properties in longitudinal direction and in transverse direction are not same. In addition, traffics run in longitudinal direction. Therefore, horizontal strain at the bottom of the asphalt concrete is not same in both longitudinal and transverse directions considering the anisotropic compaction and traffic movement.

Numerous studies were conducted in the past to evaluate the cross-anisotropy of pavement material [1], [2], [3]. However, the study of material in longitudinal and transverse directions is rarely found. Garcia and Thompson [4] studied the longitudinal and the transverse strain of asphalt concrete based on field instrumentation. The tire inflation pressure ranged 5 -11 kips and the speeds were 2, 6 and 10 miles per hour (mph). The researchers concluded that the transverse strain was 1.5 times of the longitudinal strain. However, the vehicle speeds used in that study are quite impossible in real highway. Therefore, no real traffic response is measured to this date. The authors of the present study are thus motivated to study these two strains behaviors for real traffic based on an instrumentation section.

2 Description of the Instrumentation Section

The horizontal strain data were collected from an instrumented pavement section on I-40 east bound driving lane at milepost 141 in New Mexico in the United States of America. The plan view of the instrumented section is shown in Fig. 1.

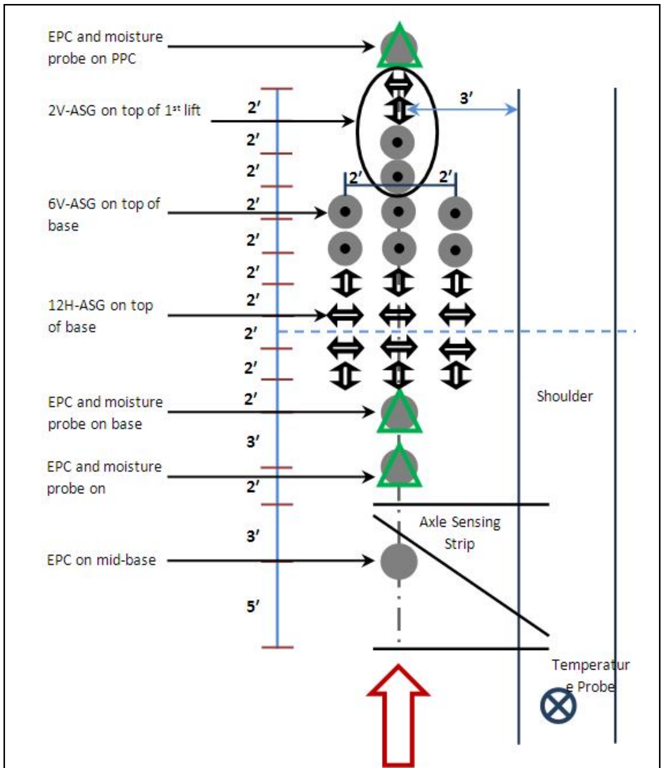

Fig. 1. The plan view of the instrumentation section. The arrow symbols are the horizontal asphalt strain gages. The group of the twelve gages are installed at the bottom of the asphalt concrete.

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The section has fourteen Horizontal Asphalt Strain Gages (HASGs), twelve are installed at the bottom of the asphalt concrete and the rest two are embedded at the top of the second lift of the Hot Mix Asphalt (HMA) (90 mm depth). It has also eight Vertical Asphalt Strain Gages (VASGs), four Earth Pressure Cells (EPCs), six temperature probes, three moisture probes, three axle sensing strips, a weigh-in-motion, a weather station and some roadside constructions.

The present study deals with the data of the twelve HASGs installed at the bottom of the asphalt concrete (300 mm depth). The black arrow symbols are the HASGs. Six gages are installed in longitudinal direction and the rest are installed in transverse direction.

The section has four layers. The top layer is a 300 mm (12") HMA followed by a 144 mm (5.75") thick crushed stone base course. There is a subbase layer, called Process Place and Compact (PPC) of 200 mm (8") thickness underlain by natural subgrade.

3 HORIZONTAL STRAIN GAGES INSTALLATION

Twelve HASGs were installed below the HMA, at 300 mm (12") depth and two were embedded on the top of 2nd lift of the HMA, at 90 mm (3.6") depth. Both types of gages are identical. The array of gages is centered in the outside wheel path with 0.6 m (2') offsets from center to capture the wheel wander of traffic.

One of the HASGs installed inside the I-40 pavement is shown in Fig. 2. It has two steel anchors (H shape) and a middle spring embedded inside a membrane. When the asphalt concrete bends due to the wheel load, the bottom of the asphalt concrete elongates and tensile strain forms due to the bending action. The middle spring is also elongated and the resulting strain is measured.

Fig. 2. Close view of the Horizontal Asphalt Strain Gage. The cable is inserted into aluminium conduit to protect it from larger aggregates.

The top of the base course was cleaned for installing the HASGs. The surveyor marked the positions of the sensors as shown in Fig. 3. Then, the sensors were laid out. The cable trench was prepared in the base layer. The cables were inserted into the aluminum conduit to protect it from larger aggregates. After the gages are placed in the positions, some sand-binder mix was placed to hold the gages in the prescribed positions. The sand binder mixture (1:2 ratio) was kept in the oven overnight at the temperature of 150 °C (300 °F) and mixed thoroughly.

Fig. 3. The positions of the gages marked by the surveyor. After installation, the positions of the sensors were again recorded.

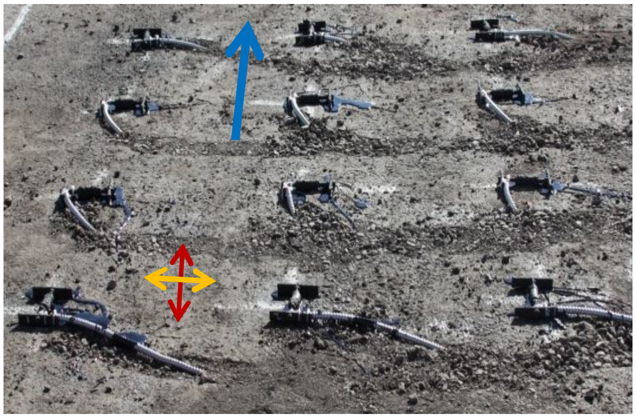

Fig. 4. The layout of the gages. The blue arrow represents the traffic direction, the red and the yellow colored arrows dictate the longitudinal and the transverse directions respectively. The three sensors in the first row (from bottom) are longitudinal sensors and measure the longitudinal strain. The second and third rows are transverse and the top row is again longitudinal sensors.

The cable trench was covered with the #4 sieved base materials. The covered cables with the sensors are shown in Fig. 4. Just before the paving over the gages, some mix was taken from the dumping of the construction truck and sieved with

#4 opening. The mix was placed over the gages and compacted carefully with tamping rod as shown in Fig. 5. The compacted area was approximately 300 mm diameter. Then, the truck dumped the mix over the sensors and rolled statically. While rolling over the gages the functionality of the sensors has been checked in the data acquisition system. No sensor was damaged during the construction.

Fig. 5. The gages covered with the #4 sieved asphalt mixtures just before paving over the sensors area. The mixture was hand compacted with tamping rod as best as possible without damaging the sensors.

The procedure described and followed in this study is the standard practice followed at the National Center for Asphalt Technology (NCAT) [5]. The experts from NCAT also helped us to install the sensors and recording the data.

While placing the asphalt concrete over the sensors much precaution was adopted that the wheels of the paving vehicle did not damage the sensors, shown in Fig. 6.

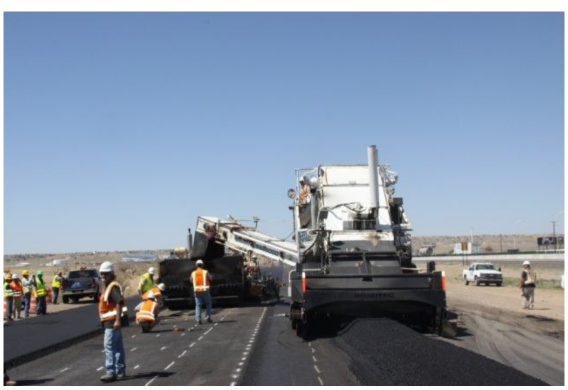

Fig. 6. Paving over the sensors. After the paving, the compaction was conducted without vibration. It was monitored that the wheels of the construction vehicles did not damage the sensors.

The other two sensors (HASGs) were installed at the top of 2nd lift (90.0 mm depth) in similar way. The only difference is that the cable was not inserted into aluminum conduit rather than some #4 sieved asphalt concrete mixtures were manually compacted over it.

4 Hot Mix Asphalt Mixture

Dense graded SuperPave (SP) mixture, type SP-III, was used in this project. New Mexico Department of Transportation (NMDOT) uses this mixture widely in NM. This mix contained 35% plant screened Reclaimed Asphalt Pavement (RAP) materials. Performance Grade (PG) binder, PG 70-22 was 4% by weight of mixture. The gradation of the SP mix aggregate is shown in Table 1.

TABLE 1
Gradation of the Aggregates

Sieve Size	% Passing
25 mm (1.0")	100
19.0 mm (0.75")	99
12.5 mm (0.5")	87
9.5 mm (0.375")	72
4.75 mm (No. 4)	42
2.375 mm (No. 8)	26
1.185 mm (No. 16)	20
0.67 mm (No. 30)	16
300 µm (No. 50)	11
150 µm (No. 100)	7.9
75 µm (No. 200)	5.0

5 Field Data

The field data was collected using a high speed data acquisition system and recorded in a computer. The data are processed with a data analysis software, DaDisp. The third row of the eighteen-wheel vehicle is considered for the present study. The vehicle passing between 4:00 pm to 6:00 pm for the period of December 03-December 08, 2012 are considered. The vehicles which pass through the centerline of the sensors (through the middle four sensors) are considered.

A typical snapshot of the longitudinal strain for an eighteen-wheel vehicle is shown in Fig. 7. The material is first compressed when the tire approaches to it. Soon after the compression the material is elongated when the wheel reaches on the top of the sensor.

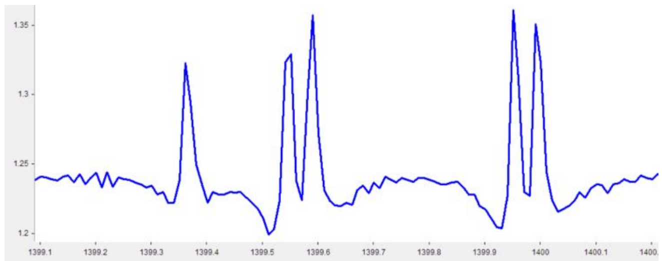

Fig. 7. Typical response for an eighteen-wheel vehicle. This is a snapshot of the response where no filtration is conducted. The vertical axis shows the output voltage and the horizontal axis shows the time of recording.

A screenshot of the transverse strain is shown in Fig. 8. When the wheel is on the top of the sensor the material is elongated. No compression occurs if the wheel follows the sensor's path.

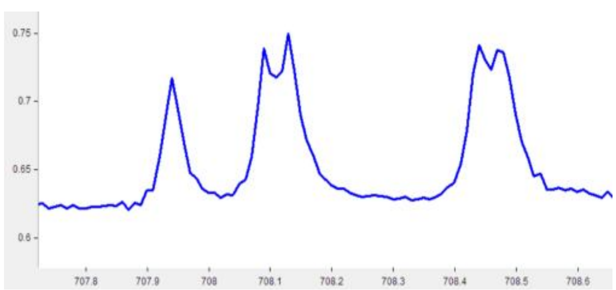

Fig. 8. The transverse strain at the bottom of the asphalt concrete. No compressive part exists. The vertical axis is the output voltage which is multiplied by the calibration factor to determine the strain response in microstrain.

If the wheel deviates from the centerline of the sensor's path the strain magnitude decreases sharply and reaches to compressive strain. Compressive strain develops if the wheel is totally outside the sensor's path as shown in Fig. 9. Five axles of the vehicle can be marked clearly. The amplitude of the compressive strain is usually less than the tensile strain.

Fig. 9. The snapshot of the transverse strain for a wheel outside the sensor's path for an eighteen-wheel vehicle.

The above discussion implies that when a wheel moves over the pavement successive compressive and tensile strains occur in longitudinal direction at the bottom of the asphalt concrete. In transverse direction, tensile strain forms along the wheel path and compressive strain outside the wheel path.

6 Results and Discussion

The responses for real highway traffic are used for determining the horizontal strain at the bottom of the asphalt concrete. The average speed of the vehicle ranges 70-75 mph. The longitudinal and the transverse strain data are plotted in Fig. 10. A total of 50 data of each are analyzed for this purpose.

The boxplots show the transverse strain is higher than the longitudinal strain with some overlaps. The minimum and the maximum values of the longitudinal strains are 32.9 and 55.99 µm/m respectively, with the average value of 44.5 µm/m and the standard deviation of 6.4 µm/m. The minimum and the maximum values of the transverse strains are 39.2 and 68.2 µm/m respectively, with the average value of 52.9 µm/m and the standard deviation of 8.2 µm/m. The upper and the lower whiskers of the boxplot represent the maximum and the minimum value respectively. The bold line in the box is the median level and the box contains the half of the total data.

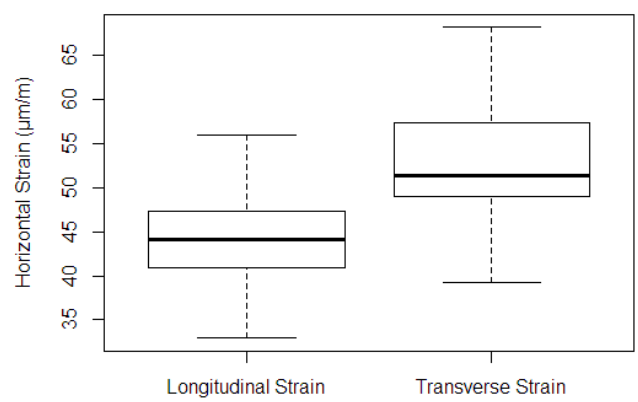

Fig. 10. Comparison of the longitudinal and the transverse horizontal strains at the bottom of asphalt concrete for an eighteen-wheel vehicle. The strain values are plotted in the vertical axis and expressed in microstrain (µm/m or µε). The bold lines in the figure represent the medians of the data.

Formal statistical t-tests are conducted on the data with the null hypothesis that the difference between the means (the averages of the longitudinal strain and the transverse strain) is zero and the alternative hypothesis is that the difference is not zero. Both the two sample and the Welch two sample t-tests produce p-value close to zero. Therefore, the null hypothesis is rejected. The difference between the means of the strain data is not equal to zero. The mean values of the longitudinal and the transverse strain range 40.81-48.15 µm/m and 48.56-57.3 µm/m respectively at 95% Confidence Interval (CI). There is no overlap between these two ranges. Therefore, the probability of the means be equal at 95% CI is extremely low.

One Way Analysis of Variance (ANOVA) test is also conducted to evaluate the means. The null hypothesis is that the means are equal and the alternative hypothesis is that the means are not equal. The ANOVA test shows insufficient evidence for the null hypothesis to be true. The produced p-value is 0.004 which is much lower than 0.05 (5% level and 95% CI). Therefore, the null hypothesis is rejected and the means are not equal at 95% CI.

However, ANOVA test has some assumptions such as the data are normally distributed and randomly sampled. The randomness can be ensured as the data is collected arbitrarily. The eighteen-wheel vehicle is chosen as the output for this vehicle is distinct and can be read easily. The normality assumption is checked by formal normality tests, like Shapiro-Wilk, Anderson-Darling, and Cramer von-Mises normality tests. The null hypothesis is that the data is normally distributed and the alternative hypothesis is that the data is not normally distributed. p-values of all the tests ranges 0.62-0.93 which are much higher than 0.05. Therefore, the alternative hypothesis is rejected in favor of null hypothesis. Hence, both the longitudinal and the transverse strains data are normally distributed.

The above discussion clarifies that the transverse strain is higher than the longitudinal strain. Based on this study, the average transverse strain is 1.18 times of the average longitudinal strain. The distribution of the longitudinal strain is more consistent than the transverse strain.

4 Conclusions

This paper deals with the characteristics of the longitudinal and the horizontal strains at the bottom of the asphalt concrete. Based on this study the following conclusions can be drawn:

- The transverse horizontal strain at the bottom of asphalt concrete is 1.18 times of the longitudinal strain.
- The longitudinal strain consists of a compression strain followed by tensile strain.
- The transverse horizontal strain is largely dependent on the wheel wander of the traffic. The strain is tensile if the wheel follows the sensor's path. Outside the sensor's path, the strain is compressive.

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