Field Performance Monitoring and Modeling of Instrumented Pavement on I-35 in McClain County

ANNUAL PROGRESS REPORT: FY 2009

(ODOT SPR ITEM # 2200)

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1. General

This combined laboratory and filed study is conducted to better understand the mechanisms that cause pavement failure under actual traffic loading and environmental conditions. A 1,000-ft. long experimental pavement section was constructed on I-35 in McClain County and instrumented in collaboration with the National Center for Asphalt Technology (NCAT) and Oklahoma Department of Transportation (ODOT) for field data collection. The field data collection is focused on pavement performance data (namely, distribution of stresses within the pavement structure, longitudinal and transverse strains at the bottom of asphalt layer, rutting, cracking, etc.), environmental data (namely, air temperature, variation of temperature within the pavement structure, solar radiation, etc.), and traffic data (namely, axle load, position, speed, etc.). From the field data, necessary correlations, namely rut transfer function and fatigue transfer function, will be developed. From the laboratory data, rutting and fatigue cracking susceptibility will be analyzed to address the behavior of HMA mixes used in the construction of the test section. From the data analyzed from both field and laboratory, a 'shift factor' will be also developed so that the rutting and fatigue behavior from laboratory data can be correlated with the field data. Activities performed in FY 2009 included rut and fatigue testing in laboratory, pavement performance data collection from the field, temperature probe re-installation, analysis of traffic data, and analysis of mechanical and environmental data. An overview of these activities is given in the following.

2. Overview of Work Done

2.1 APA Rut Testing on Laboratory Compacted Specimens

A total of 116 samples were prepared from S-4 mixes in the Superpave Gyratory Compactor (SGC) following the AASHTO T 312 test method. Samples (Diameter = 150-mm; Height = 75-mm) were compacted covering a wide range of air voids (2±1%, 4±1%, 6±1%, 8±1%, 10±1%) and tested in the APA at three different temperatures (40°C, 50°C, and 64°C), in accordance with the OHD L-43 test method. Both manual and automated APA rut measurements were collected and analyzed.

2.1.1 Manual APA Rut Measurements

The manual rut measurements for 40°C, 50°C, and 64°C were plotted to examine variation in rut depth with air voids. An outlier approach was employed to discard data with significant deviation from the average. The approach explained in ODOT specification (OHD L-43) was used for this purpose. The critical value for student test (t-statistic) was taken to be 1.155. The samples showing aberrant rut values were discarded and only the remaining samples were used in revised plots. Subsequently, all these revised plots were presented in a single plot to analyze changes in rut depth with temperature (Figure 1). It is clear from this figure that depth of rut increases with increasing temperature, as expected. For example, specimens containing 7% air voids showed rut value of approximately 2.8, 4.1, and 6.3 mm at 40^{o}C, 50^{o}C, and 64^{o}C, respectively.

2.1.2 Automated APA Rut Measurements

Automated APA rut measurements data were also plotted for the same specimens selected after the outlier approach (Figure 2), as noted in the previous section. It is evident from Figure 2 that rut depth increases with an increase in temperature, which is similar to the previous observation. From Figures 1 and 2, it is also evident that automated rut measurements provided lower rut depth values as compared to manual rut measurements. One of the explanations could be that the APA does not record each specimen's rut depth independently but rather records the average rut of the two specimens in each APA mold.

2.2 Field Rut Measurements using Two Different Methods

Three field trips and distress surveys were conducted on December 03, 2008, January 08, 2009 and May 19, 2009 to address pavement distresses namely, rutting and fatigue cracking during FY 2009. The testing pattern was designed for a series of six stations, namely, Station # 144, 235, 319, 540, 738 and 900, located at approximately 100-ft. intervals along the outer wheelpath. Rut data was collected across the wheel paths at each station. During the distress survey on December 03, 2008 and January 08, 2009, rut measurements were taken using straight a edge/rut gage combination. On May 19, 2009, however, two different methods were used to measure rut. The first method used a straight edge/rut gage combination, while Face Dipstick® was used in the second method (Figure 3). After data collection, they were analyzed using the RoadFace 6.0 program and spreadsheets. Rut data obtained from Face Dipstick® was very reliable and consistent compared to the rut data obtained from the straight edge/rut gage combination. For example, rut data were collected at Station # 144 two times to address the repeatability of Face Dipstick® (see Table 1). From Table 1 we can see that the maximum rut depths found in two trials were very close and the location of maximum rut was also same from the starting point of data collection. To address the reliability of Face Dipstick®, data collected with 6-in moonfoot spacing and 12-in. moonfoot spacing were also compared at all the stations. Only one station's comparison (at Station # 144) is presented in Table 2. From Table 2, it is observed that the rut data obtained from different moonfoot spacing are very reliable. Also, Face Dipstick® can measure rut depths with an accuracy of 0.001 inch whereas the rut gage can measure with an accuracy of 0.1 inch. Again, with the straight edge/rut gage combination, the research team could measure rut at an interval of 12-in. whereas, with the Face Dipstick® project team measured rut depths at 12-in. and 6-in. intervals. A representative plot for the six stations (Figure 4) is presented here to compare the rut data obtained from Face Dipstick® and straight edge/rut gage combination.

To study the variation of rut data obtained from Face Dipstick® and straight edge/rut gage combination more closely, data was collected at Station # 540 by using the same start and end points for Face Dipstick® and straight edge/rut gage combination. A comparison of maximum rut depths obtained from these three methods is presented in Table 3. It is evident from Table 3 that rut depths measured with straight edge/rut gage combination are always lower than rut depths measured by Face Dipstick®. For example, at Station # 235, the maximum rut depth measured from Face Dipstick® (moonfoot spacing = 12-in.) was 0.471-in, whereas the maximum rut depth measured with straight edge/rut gage combination was 0.300-in (36.3% lower).

2.3 Field Crack Mapping

As noted earlier, crack mapping was also performed during the distress survey on the test section. For the Station # 144, 319, 540, 738 and 900, crack mapping was performed at 50-ft. both ways (north and south) of each station. To eliminate overlapping of mapping area, crack mapping was performed at 41 ft. north and 34 ft. south of Station # 235. No crack is observed so far at any station.

2.4 Temperature Probe Re-installation

There are five temperature probes installed at depths of 0.0-in., 2.0-in., 3.5-in., 7.0-in. and 10.0-in. (from the surface of the pavement) in the instrumented section for measuring pavement temperature. On September 8, 2008, however, two temperature probes namely, T1 (depth = 0-in.) and T2 (depth = 2.0-in.) started providing erroneous data. The temperature data obtained from these two probes dropped drastically from 25˚C to 13˚C, then to negative 26˚C (-26˚C) in a couple of hours. Whereas the temperature probes T3, T4 and T5 gave temperature data around 28˚C. This problem was reported to ODOT and it was decided to re-install all the temperature probes. Then, OU and ODOT teams jointly re-installed the new temperature probes on December 03, 2008.

Before installation, the new probes were tested for accuracy. The probes were tested at room temperature (18 ˚C to 20˚C) and at freezing temperature (0˚C to 2˚C). In addition, these probes were also tested using a Digital Volt Meter (DVM) following the instructions supplied by the Campbell Scientific, Inc. After installation, the OU team tested the temperature probes values using the data logger.

2.5 Analysis of Traffic Data

The traffic data is being collected by using the WIM (Weigh-In-Motion) system installed about 3/4 mile downstream from the instrumented site. These data include weight/axle, ESAL, speed, length, gross weight and classification of each vehicle according to the FHWA 13-class vehicle category scheme. The instrumented test section on I-35 was opened to traffic on May31, 2008. So far, data generated from May 31, 2008 to May 31, 2009 have been analyzed. In this study, the trucks with two or more axles (from Class 4 to Class 13) were analyzed, as recommended by the new Mechanistic-Empirical Pavement Design Guide (MEPDG, AASHTO 2004). To analyze the traffic data, a software, called Traffic Operations & Planning Software (TOPS v3.7.1) provided and installed by ODOT, was used. A summary of the results obtained so far is given below:

1. Traffic Volume: From May 31, 2008 to May 31, 2009, a total of 1,441,752 vehicles travelled on both lanes of the I-35 test section. Of these vehicles, 1,176,793 vehicles travelled on Lane 1 (slow-lane, which is the instrumented section) and 264,959 on Lane 2 (fast-lane). Thus, approximately 81.6% vehicles travel on the slow-lane. Also, the WIM data show that the traffic volume is mainly composed of Class 9 vehicles, as shown in Figure 5. About 60% of Class 9 vehicles travelled on Lane 1 and the remaining on Lane 2.
2. Traffic Weight: In terms of weight, a total weight of 58,900,670 kips were driven on the I-35 section, for the reporting period. Of these, 50,103,815 kips (82.4%) were on Lane 1, while the remaining (8,796,855 kips or 17.6%) on Lane 2. Analyses of vehicle weights showed that the trucks weighing between 0 and 20 kips, between 20 and 40 kips, between 40 and 60 kips, between 60 and 80 kips and over 80 kips constitute 25%, 29%, 20%, 24% and 2%, respectively, of overall Class 9 vehicles.
3. Traffic ESAL: During May 31, 2008 and May 31, 2009, a total of 899,687 ESALS were driven on the I-35 experimental section. About 84% of these ESALS travelled on Lane 1 and the remaining travelled on Lane 2. These percentages are comparable to the distribution of the overall traffic volume reported under Item 1 above.
4. Class Distribution: On Lane 1, it was found that around 60% of the vehicles were of Class 9, compared with only 45% for Lane 2.

2.6 Analysis of Dynamic and Environmental Data

The dynamic and environmental data collected through the data acquisition system were analyzed to determine the influence of heavy vehicles on the deterioration of the pavement. Three types of data including wheel wander, transverse and longitudinal strain and strain-temperature relationship are analyzed to obtain the behavior and response of the test section due to weather and traffic. The results are summarized in the following.

1. Wheel Wander: Wheel wander (μ) is the calculated distance between the center of the right wheel of a vehicle's axle and the inside of the edge stripe of the road. Wheel wander values are generated from the lateral positioning sensor and collected using the data acquisition system. During the reporting period, 3872 truck axle data belonging to 37 field trips were collected and analyzed to generate the wheel wander histogram shown in Figure 6. The average wheel wander

(μ) was found to be 15.5 inches with a standard deviation (σ) of 10.2 inches. Overall, the data is found to be normally distributed since more than 68% of the values are within 1 standard deviation of the mean (μ ± σ), more than 95% of the values are within two standard deviations (μ ± 2σ), and more than 99% lie within 3 standard deviations (μ ± 3σ).

2. Transverse and Longitudinal Strains: Two types of strain readings, namely, transverse and longitudinal were collected from 12 strain gauges Measured maximum transverse strains are plotted against the maximum longitudinal strains (for each axle) for comparison (Figure 7). From Figure 7, it is observed that the longitudinal strains at this site appear to be slightly larger than the lateral strains, so far. Because the data points are very scattered, both strains will be used in further correlation studies.
3. Strain-Temperature Relationships: Currently, the OU team is working on the development of strain-temperature relationships which will be used for developing fatigue and rut transfer functions. Strain-temperature relationships are critical for establishing transfer functions (Timm and Priest 2006). The strain/weight values (y-axis) (Figures 8 and 9) are calculated by selecting the maximum strain (longitudinal or transverse) for each axle and dividing by the axle weight and then taking the average for all the axles from a data collection trip. Each data collection trip typically includes 20 Class-9 trucks. The x-axis represents the average recorded temperature at the mid-depth of the asphalt layer (i.e., probe T3 at 3.5-in. depth) for each trip. Although there is scatter in Figures 8 and 9, the correlations seem reasonable and are likely to improve when results from additional trips are added.

2.7 Fatigue Test on Beam Specimens

A total of 1000-lbs of type S-3 mix were also obtained from Haskell Lemon for conducting laboratory testing. Similar mix was used during paving of bottom layer. Using the PMW linear kneading compactor, several slab specimens (15" x 6" x 3") were compacted. Further, these specimens were cut into two beams (15" x 2.5" x 2.0") by using saw-cutting machine available at the School of Petroleum Engineering, University of Oklahoma. These saw cut beams were then used to determine the bulk specific gravity (G_{mb}) and percent air voids in accordance with AASHTO T 166 and AASHTO T 269, respectively. These compacted beams were shipped to NCAT (Auburn University) for 4-point fatigue testing in accordance with AASHTO T 321 test method at two different temperatures (5°C and 20°C).

Also, field compacted beams extracted from the field after construction were tested by SemMaterials, a Tulsa-based company (now RoadScience, LLC). All specimens were tested by applying a sinusoidal loading (frequency = 10 Hz) at a constant strain of 400 microstrain. Table 4 shows a summary of results obtained from the selected four field compacted beam specimens tested at 5°C.

3. Plan for Fiscal Year 2009

Overall this project is on track. The FY2010 activities will include the following:

a) Fatigue testing on beam specimens covering a wide range of air voids.
b) Collection of various field data, namely traffic data, dynamic data, environmental data, and performance data, will continue.
c) With ODOT's assistance, field testing and distress survey will be conducted quarterly.
d) Analysis of data for developing 'Rut transfer function' and 'Fatigue transfer function'.
e) Field data will be analyzed and correlations among important parameters (e.g., ESAL vs. rut, ESAL vs. FWD modulus, temperature vs. strain, etc.) will be further pursued.
f) A meeting will be held with the ODOT personnel to discuss the overall progress.
g) Maintenance of the instrumentation such as temperature probes, axle sensors will be done, as needed.

Selected References

1. Monthly reports of the project "Field Performance Monitoring and Modeling of Instrumented Pavement on I-35 in McClain County" submitted to ODOT by the University of Oklahoma team from October 2007 to September 2008.
2. Oklahoma Department of Transportation (ODOT) (1999), "Standard Specifications for Highway Construction."
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5. Timm, D.H., and Priest, A.L. (2005). "Wheel Wander at the NCAT Test Track," Technical report No. 05-02, National Center for Asphalt Technology (NCAT), Auburn University.
6. Timm, D.H., and Priest, A.L. (2006). "Methodology and calibration of fatigue transfer functions for mechanistic-empirical flexible pavement design," Technical report No. 06-03, National Center for Asphalt Technology (NCAT), Auburn University.
7. Breidy, M., Muraleetharan, K.K., and Zaman, M. (2009). "Traffic report – Field performance monitoring and modeling of instrumented pavement on I-35 in McClain county," Technical Report, University of Oklahoma.

8. AASHTO (2004). Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. Final Report prepared for National Cooperative Highway Research Program (NCHRP), Transportation Research Board, National Research Council, Washington D.C.

Table 1: Rut Depth at Station no. 144 with Face Dipstick® (from RoadFace 6.0 software)

Trial No. (Moonfoot Spacing 6-in.)	Distance from starting point	Depth of Rut (in.)
Trial # 1	2.50	-0.268
	9.50	-0.382
Trial # 2	2.50	-0.269
	9.50	-0.390

Table 2: Comparison of Rut Depths with two different moonfoot spacing (at Station no. 144)

Moonfoot Spacing	Distance from starting point	Depth of Rut (in.)
6-in. (Trial # 2)	2.50	-0.269
	9.50	-0.390
12-in. (Trial # 2)	2.00	-0.262
	10.00	-0.382

Table 3: Comparison of Maximum Rut Depths

Station no.	Wheelpath	Rut depth from FD(spacing=12-in.) with RoadFace 6.0 program (in.)	Rut depth from FD (spacing=12-in.) with RoadFace 6.0 program (with 10-ft. SE) (in.)	Rut depth from rut gage and conventional SE (in.) (% difference)*
144	Outer	-0.262	-0.260	-0.10 (- 61.54%)
	Inner	-0.382	-0.375	-0.25 (-33.33%)
235	Outer	-0.295	-0.295	-0.05 (-83.05%)
	Inner	-0.451	-0.471	-0.30 (-36.31%)
319	Outer	-0.425	-0.425	-0.20 (-52.94%)
	Inner	-0.345	-0.334	-0.30 (-10.18%)
540	Outer	-0.368	-0.368	-0.20 (-45.65%)
	Inner	-0.250	-0.248	-0.20 (-19.35%)
540 (Special)	Outer	-0.435	-0.435	-0.20 (-54.02%)
	Inner	-0.358	-0.358	-0.20 (-44.13%)
738	Outer	-0.396	-0.396	-0.20 (-49.49%)
	Inner	-0.249	-0.249	-0.25 (0.40%)
900	Outer	-0.279	-0.279	-0.05 (-82.08%)
	Inner	-0.256	-0.256	-0.20 (-21.88%)

* Rut depth obtained from Face Dipstick® (spacing=12-in.) with RoadFace 6.0 program (with 10-ft. straight edge) was taken as reference

* FD= Face Dipstick ® and SE= Straight Edge

Table 4: Summary of Field Compacted Beam Specimens Tested for Fatigue

Temperature (^{o}C)	Specimen No.	Air Voids (%)	Initial Stiffness (ksi)	Final Stiffness (ksi)	Number of Cycles to Failure
5	540 R2	8.50	1,554.15	678.23	69,998
5	738 4	8.57	1,644.21	680.10	59,998
5	540 L1	9.19	1,579.40	578.21	34,998
5	540 R1	9.71	1,552.48	756.85	100,000

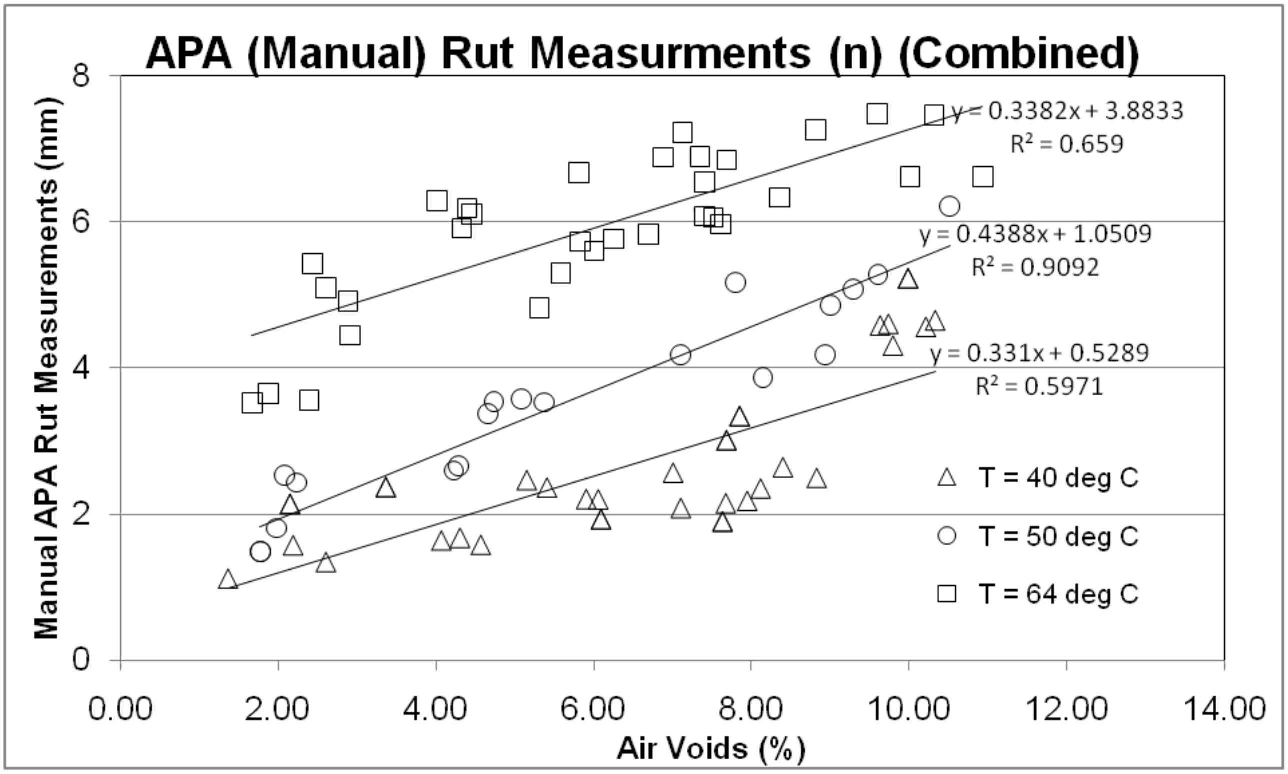


Figure 1: Combined APA (Manual) Rut measurements (at 40°C, 50°C and 64°C)

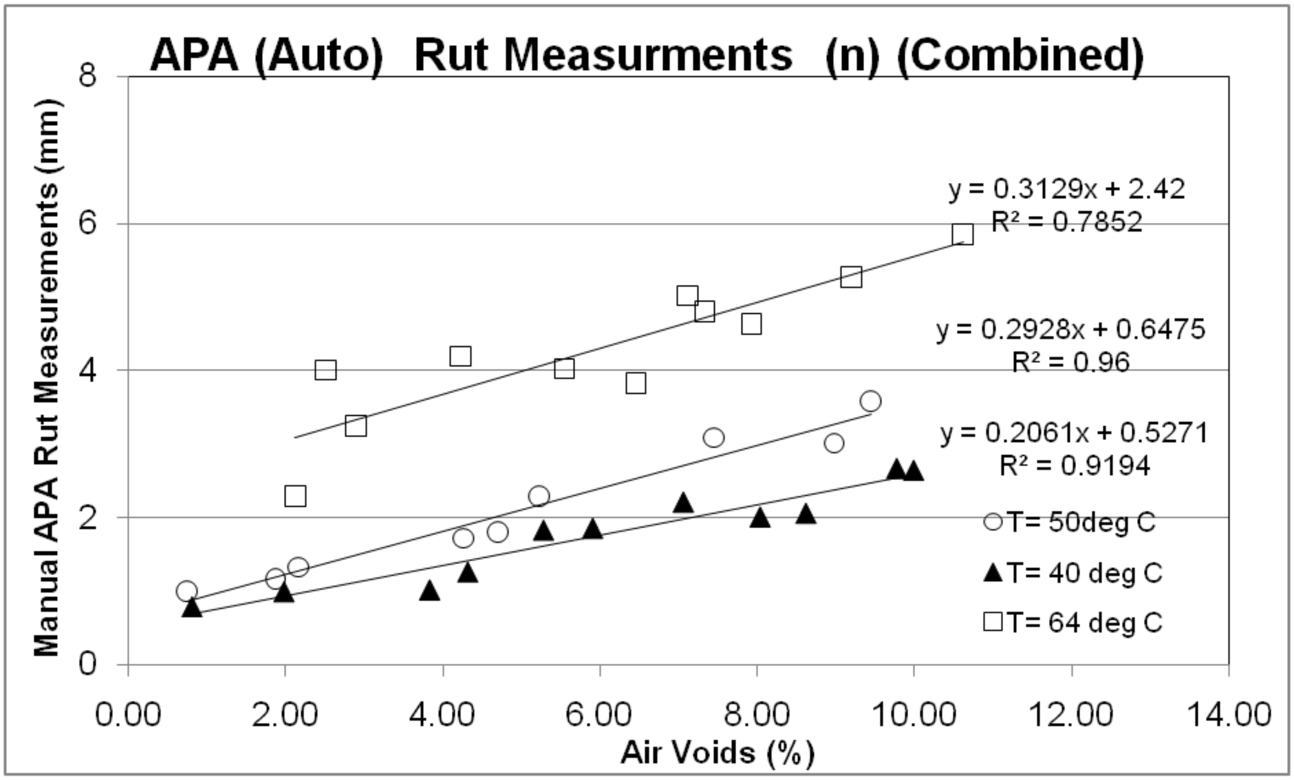


Figure 2: Combined APA (Automated) Rut measurements (at 40°C, 50°C and 64°C)

Figure 3: Rut Measurement with Face Dipstick®

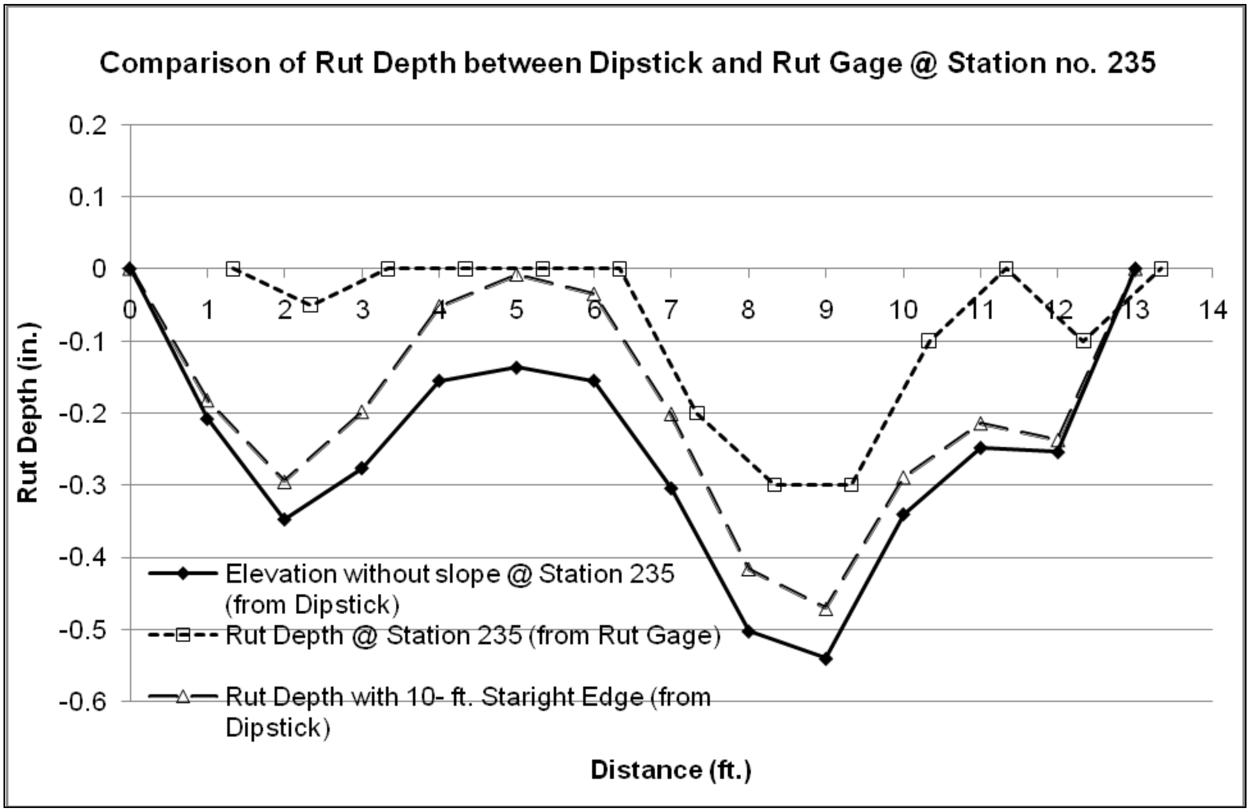
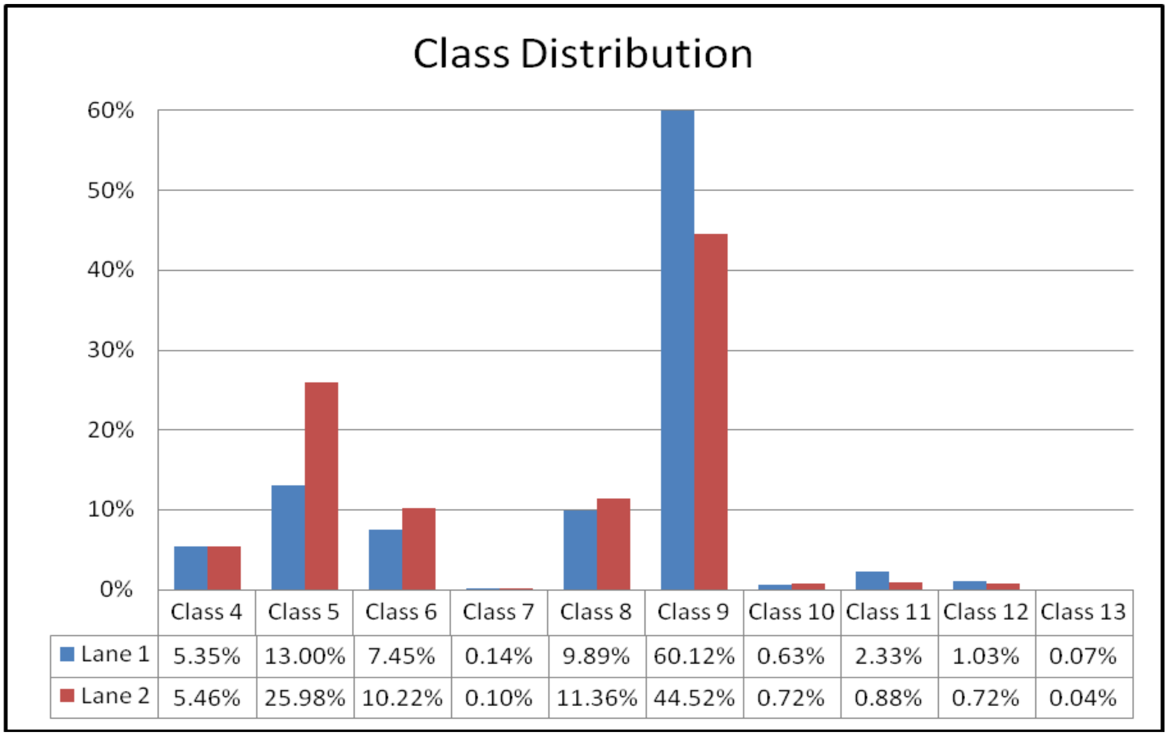


Figure 4: Comparison of rut depth between Face Dipstick® and rut gage at station no. 235



	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
🟦 Lane 1	5.35%	13.00%	7.45%	0.14%	9.89%	60.12%	0.63%	2.33%	1.03%	0.07%
🟥 Lane 2	5.46%	25.98%	10.22%	0.10%	11.36%	44.52%	0.72%	0.88%	0.72%	0.04%

Figure 5: Distribution of Traffic Volume according to FHWA Vehicle Classification System

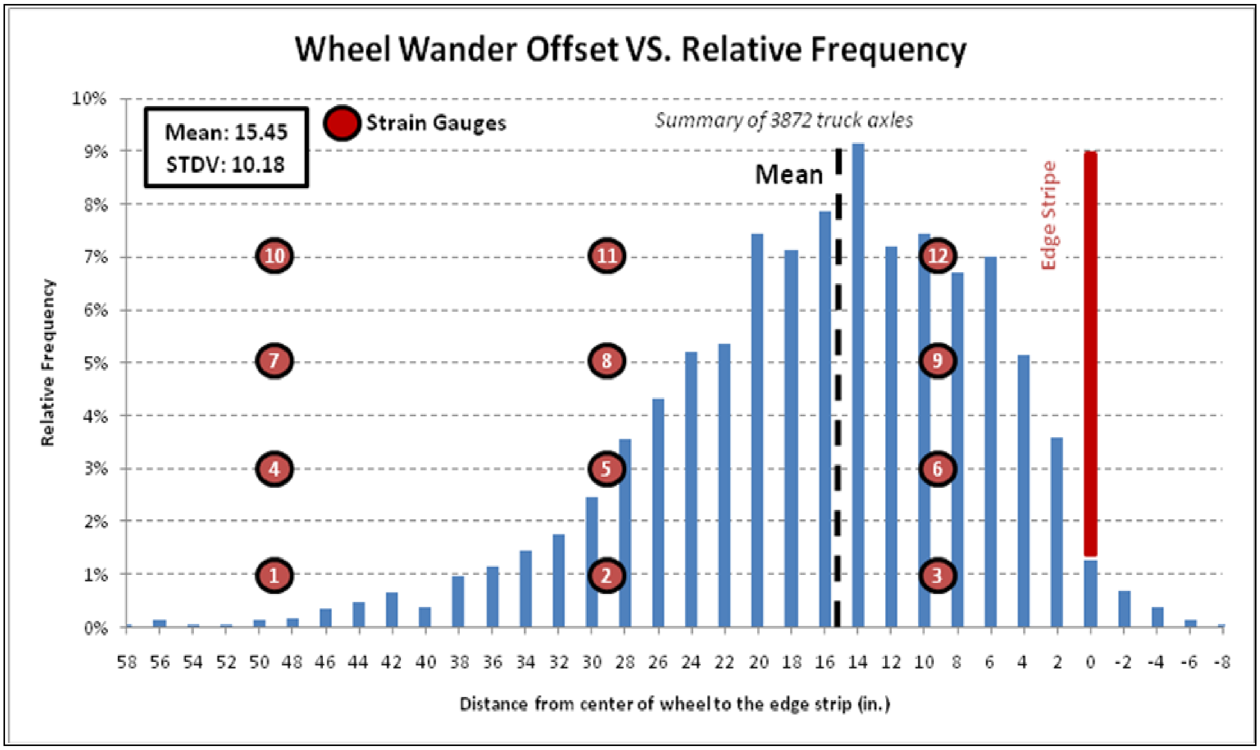


Figure 6: Statistical Summary of Wheel Wander Data

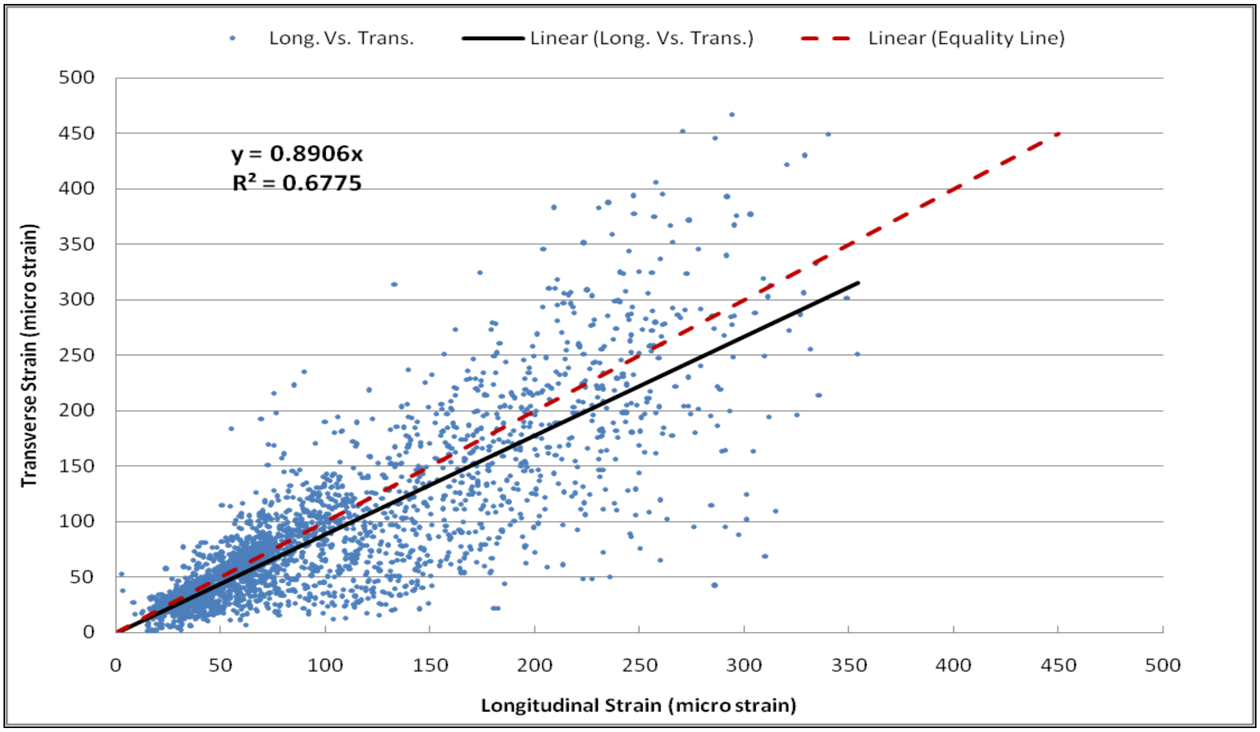


Figure 7: Transverse Strain vs. Longitudinal Strain

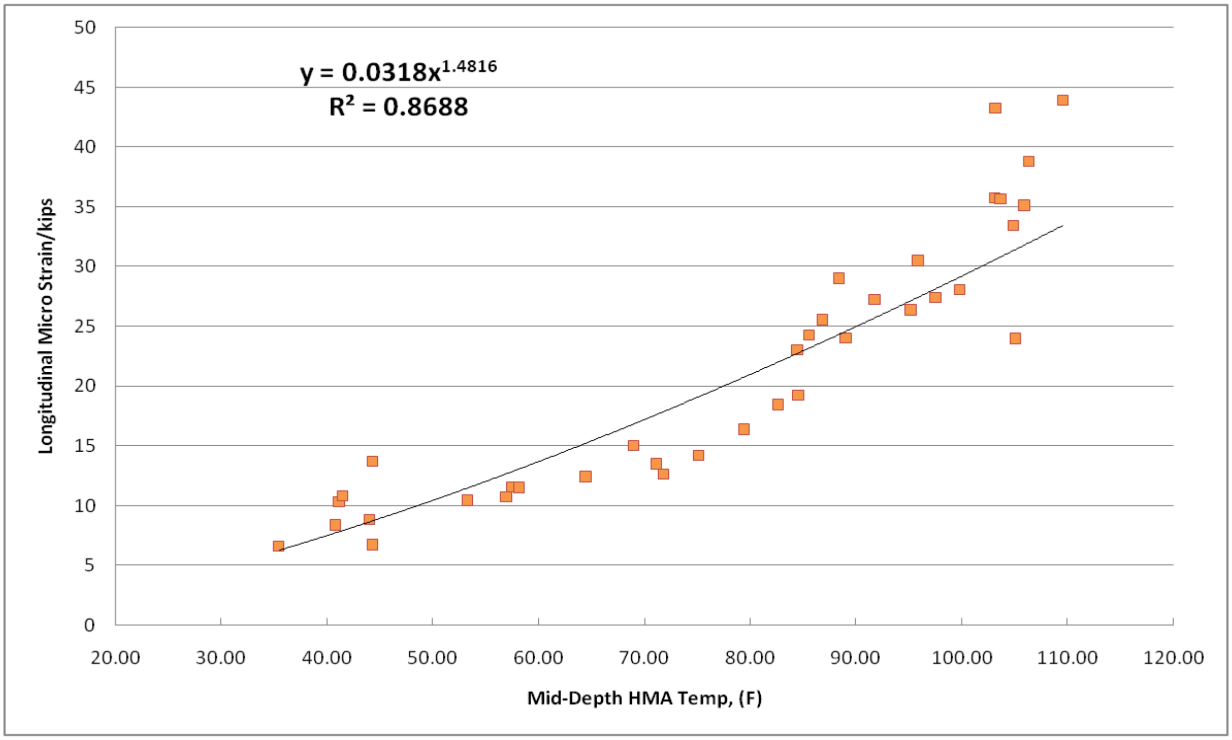


Figure 8: Strain- Temperature Relationship (Longitudinal Strain)

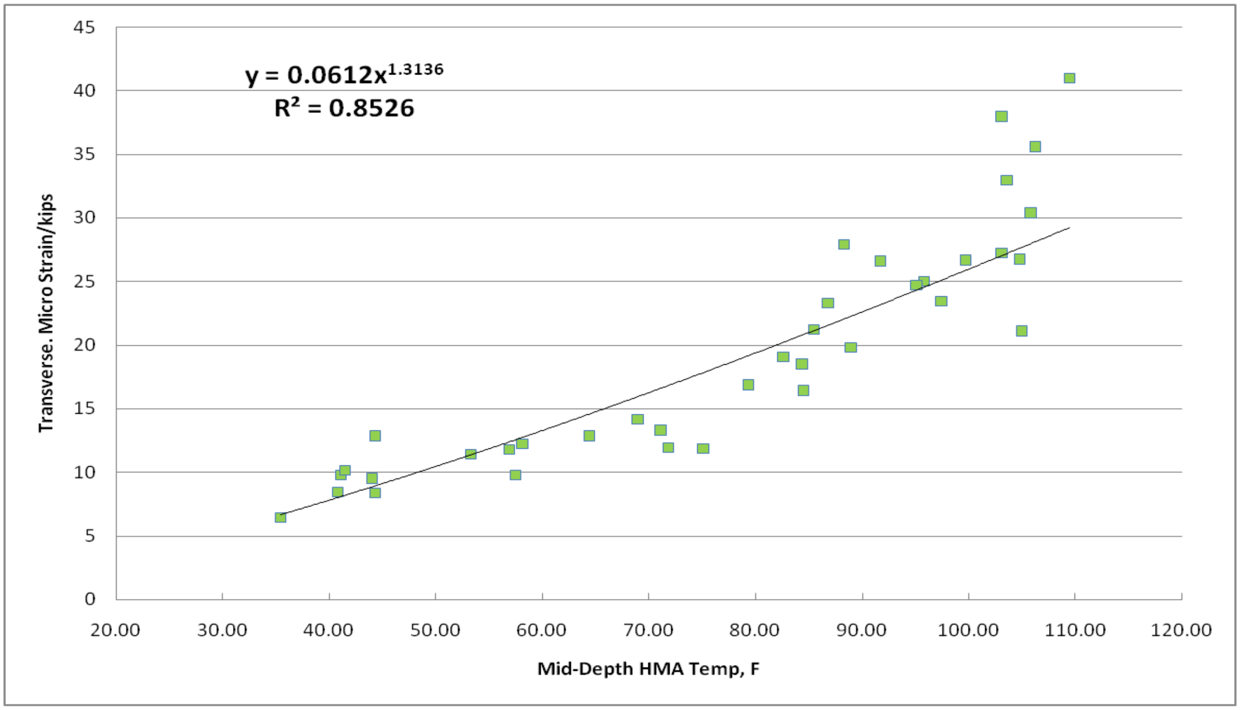


Figure 9: Strain- Temperature Relationship (Transverse Strain)