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TPF-5(291) FINAL REPORT:

EVALUATION OF TRANSVERSE JOINT OPENING WIDTH:

Prepared On Behalf Of	Date	Project Number
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1.0 BACKGROUND

The NCE team was awarded the Transportation Pooled Fund (TPF) Study 5(291) to investigate data from the Long-Term Pavement Performance (LTPP) Specific Pavement Study (SPS)-2 experiment for concrete pavement design factors, with the Washington State Department of Transportation as the Lead State. This pooled fund study included the investigation and proposal of a pavement preservation experiment utilizing existing test site conditions. Upon completion of the initial phase of the study, several SPS-2 Tech Days were conducted to broaden the pavement community's knowledge of the SPS-2 experiment and to garner input on analyses the community would find useful. The Pooled Fund Technical Advisory Committee (TAC) also provided recommendations for additional analyses.

As a result, five additional tasks were focused on SPS-2 test sections:

- Conducting a deterioration rate analysis
- Analyzing performance data
- Investigating sources of non-LTPP data
- Analyzing joint score and area of localized roughness (ALR) impacts on performance
- Updating previous SPS-2 analyses

Upon completion of these tasks, an additional 11 tasks were proposed. The purpose of this supplementary extension of TPF-5(291) was to conduct further analyses of existing data from the LTPP SPS-2 concrete pavement experiment. The focus of this set of tasks was to investigate the impact of non-experimental factors on pavement performance. The following tasks were completed:

- Identifying agency-specific trends
- Analyzing the impact of construction and materials issues
- Reviewing early SPS-2 failures
- Identifying lessons learned from state supplemental sections
- Analyzing the impacts of climate, traffic, and overall condition on deterioration rate
- Comparing SPS-8 and SPS-2 performance
- Assessing diurnal changes in roughness
- Evaluating service life
- Comparing mix-design performance
- Conducting Mechanistic Empirical Pavement Design Guide (MEPDG) sensitivity analysis of portland cement concrete/lean concrete base (PCC/LCB) bond
- Evaluating transverse joint opening width

The objective of this task was to determine whether there is a relationship between joint opening width and pavement performance (International Roughness Index (IRI), faulting, load transfer efficiency (LTE) with respect to SPS-2 design features. This report presents the results of the analysis.

2.0 INTRODUCTION

Joint movement is defined as the amount a joint expands and contracts due to changes in temperature. Due to the nature of rigid pavements, joints are cut at predetermined locations that can be reinforced with dowel bars to accommodate the expansion and contraction of the PCC material. These joints are then sealed to prevent the intrusion of water into the pavement structure, which is detrimental to the pavement's performance. Sealant selection is typically performed by estimating the amount of joint movement and calculating the percent expansion to which the sealant material will be subjected. Different sealants have different expansion properties, and a sealant that experiences too much expansion will pull away from the joints and allow water intrusion.

Previously collected field measurements of joint movement were obtained from SPS-2 sections that were part of the seasonal monitoring program (SMP). These measurements were compared to software-predicted joint movement using an American Concrete Pavement Association (ACPA) application (app), and then the app was used to calculate joint opening movement for the rest of the SPS-2 test sections (those not a part of the SMP). These joint movement estimates were compared between test sections located in different climates. In addition, the estimates were compared with the following values for all SPS-2 sites:

- IRI
- Faulting
- LTE
- Daily Temperature Changes

The latter comparison was conducted as a similar analysis to that presented in a Federal Highway Administration (FHWA) document, Evaluation of Joint and Crack Load Transfer Final Report.

Lastly, the joint movement measurements from three SMP SPS-2 sections were converted to joint opening widths and compared over time and with LTE values per joint.

3.0 ACPA JOINT AND SEALANT MOVEMENT ESTIMATOR APP

The ACPA provides web-based apps to help those working in the industry with different aspects of concrete pavements. One such app is the *Joint and Sealant Movement Estimator*, which estimates the maximum joint movement over the life of a typical concrete pavement joint using eight different inputs.

3.1 Comparison with SMP Sections

For this task, joint movement measurements from four SPS-2 sections were compared with the estimates from the ACPA app. The selected sections were part of the LTPP's SMP. These sections were visited monthly while the SMP was active to gather year-round data, including joint opening measurements.

Table 1 summarizes the general characteristics of each SMP SPS-2 section. The PCC joint sawing on 040215 was conducted using hand saws, likely resulting in variable sawcut depths. The Arizona SPS-2 construction report did not specify a target sawcut depth.

Table 1. Summary Characteristics of the Four SMP SPS-2 Sections.

Section Characteristic	040215	320204	370201	390204
Location	Arizona	Nevada	North Carolina	Ohio
PCC Thickness (in.)	11.0	11.8	9.2	11.1
PCC Modulus of Rupture (psi)	580	885	736	700*
Base Type	Aggregate Base	Aggregate Base	Aggregate Base	Aggregate Base
Lane Width (ft)	12	12	12	12
Sawcut depth (in.)	Not Recorded	4	2.5	3.7

psi = pounds per square inch
*estimated; was not directly measured

Joint gage measurements were conducted by drilling holes on both sides of a joint at 1-, 6-, and 11-foot offsets using a template. Snap rings were placed into these holes and calipers were inserted into both holes to measure the distance between the two. This measurement was reported as the joint gage distance; it should be noted this measurement does not reflect the joint width. Typically, two rounds of joint gage measurements were conducted at each visit (generally in the early morning and afternoon), but additional rounds of measurements may have been conducted if time allowed. The difference between two rounds of measurement represents the amount the joint moved (i.e., either opened or closed) in the time between the measurements.

Joint gage measurements were reported to the nearest 0.0004 inch (0.4 mil). Typically, only a single joint gage measurement was taken at each offset per joint during each round. However, there were times when multiple gage measurements were recorded at each offset per joint during each round. The average standard deviation of multiple joint gage measurements at the same offset of the same joint during the same round was 0.006 inch (6 mil); the median standard deviation was 0.002 inch (2 mil), and the 80th-percentile standard deviation was 0.009 inch (9 mil).

Table 2 summarizes the average maximum joint movement for each section compared to the predicted joint movement from the ACPA tool. The ACPA tool slightly underestimated joint movement for sections 320204 and 370201.

Table 2. Average Maximum Joint Movement Over Life of Joint, per SMP SPS-2 Sections, Compared to Predicted Joint Movement from ACPA Tool.

ID	Maximum Joint Movement (in.)			Predicted Joint Movement (in.)
	Outside Pavement Edge	Mid-lane	Inside Pavement Edge	
040215	0.353	0.368	0.501	0.097
320204	0.162	0.160	0.212	0.119
370201	0.137	0.154	0.135	0.072
390204	0.052	0.045	0.039	0.124

Table 3 summarizes the maximum joint movement for each SPS-2 SMP section, broken down per joint location. The ACPA tool drastically underestimated the joint movement for 040215 and overestimated the joint movement for 390204.

Table 3. Maximum Joint Movement Over Life of Joint, per Joint per Section.

ID	Joint Location (ft)	Maximum Joint Movement (in.)		
		Mid-lane	Outside Pavement Edge	Inside Pavement Edge
040215	426	0.4299	0.2547	0.7193
040215	443	0.3075	0.3803	0.8724
040215	456	0.4469	0.4811	0.5024
040215	472	0.3150	0.6697	0.4724
040215	489	0.6315	0.4594	0.4685
040215	502	0.3346	0.3252	0.4677
320204	-16	0.0772	0.2665	0.2130
320204	10	0.1531	0.1433	0.0862
320204	26	0.0953	0.2087	0.1343
320204	39	0.2803	0.1110	0.3055
320204	56	0.2327	0.1091	0.3874
320204	69	0.1315	0.1236	0.1457
370201	430	0.1602	0.1488	0.1850
370201	443	0.1268	0.1701	0.1295
370201	459	0.1083	0.1189	0.1020
370201	472	0.1528	0.2055	0.1051
370201	489	0.1453	0.1394	0.1657
370201	518	0.1264	0.1406	0.1240
390204	10	0.0350	0.0315	0.0362
390204	23	0.0343	0.0433	0.0303
390204	39	0.0705	0.0685	0.0594
390204	52	0.0370	0.0480	0.0390
390204	69	0.0984	0.0441	0.0295
390204	82	0.0394	0.0358	0.0390

3.2 Estimated Joint Movement for all SPS-2 Sections

Although the ACPA tool was not strongly predictive within the limited SMP sample size, it was deemed reasonable to run the app for all SPS-2 sections to investigate whether potential trends could be identified. Table A.1 in Appendix A summarizes the inputs used for each of the SPS-2 sections.

While entering data into the ACPA tool, it was noticed that the app limited the range of possible values for three of the input fields:

- Total cementitious material – Total cementitious material inputs were restricted to values between 400 and 700 pounds per cubic yard.

- Coefficient of thermal expansion (CTE) – CTE inputs were restricted to values between 4 and 8 * 10^{-6} per degree Fahrenheit.
- Joint spacing – Joint spacing inputs were restricted to values between 3 and 20 feet.

Measured values fell outside the limits of the APCA tool in 104 instances for the total cementitious material, 2 instances for the CTE, and 1 instance for the joint spacing. In those cases, either the maximum or minimum value was used in the app.

The LTPP database contained values for nearly all the input fields for the SPS-2 sections, with exception of the CTE values. CTE was not part of the original SPS-2 experimental design; therefore, CTE testing was not performed on a significant number of the SPS-2 sections. In these cases, an average CTE value was calculated for the SPS-2 project and assigned to the sections in that project that did not have CTE testing results.

Kansas, Nevada, and Washington's SPS-2 projects did not have a single CTE test result. A 2012 FHWA report (*User's Guide: Estimation of Key PCC, Base, Subgrade, and Pavement Engineering Properties from Routine Tests and Physical Characteristics*) presents a summary of estimated CTE values based on the PCC's coarse aggregate type. For Kansas and Washington, a CTE value of 4.33 * 10^{-6} per degree Fahrenheit was selected, based on having dolomite and basalt coarse aggregate, respectively. For Nevada, a CTE value of 4.7 * 10^{-6} per degree Fahrenheit was selected, based on having a granite coarse aggregate. The assumed CTE values in Appendix A are highlighted in orange. Table B.1 in Appendix B presents the predicted joint movement for each SPS-2 section.

The app-estimated joint movement values were then separated into different climate-related groupings.

Figure 1 illustrates the distribution of the app-estimated joint movement values separated for dry and wet climates. The graphs show the joint movement values in the dry climates roughly followed a normal distribution centered at 0.11 inches and ranging from 0.08 to 0.13 inches. The joint movement values for the wet climates showed a much larger spread, with about half of the values between 0.06 and 0.13 inches, though one value was 0.161 inches[1].

[1] Section 200259 had 27-ft transverse joint spacing, whereas all other SPS-2 sections had 15-ft joint spacing.

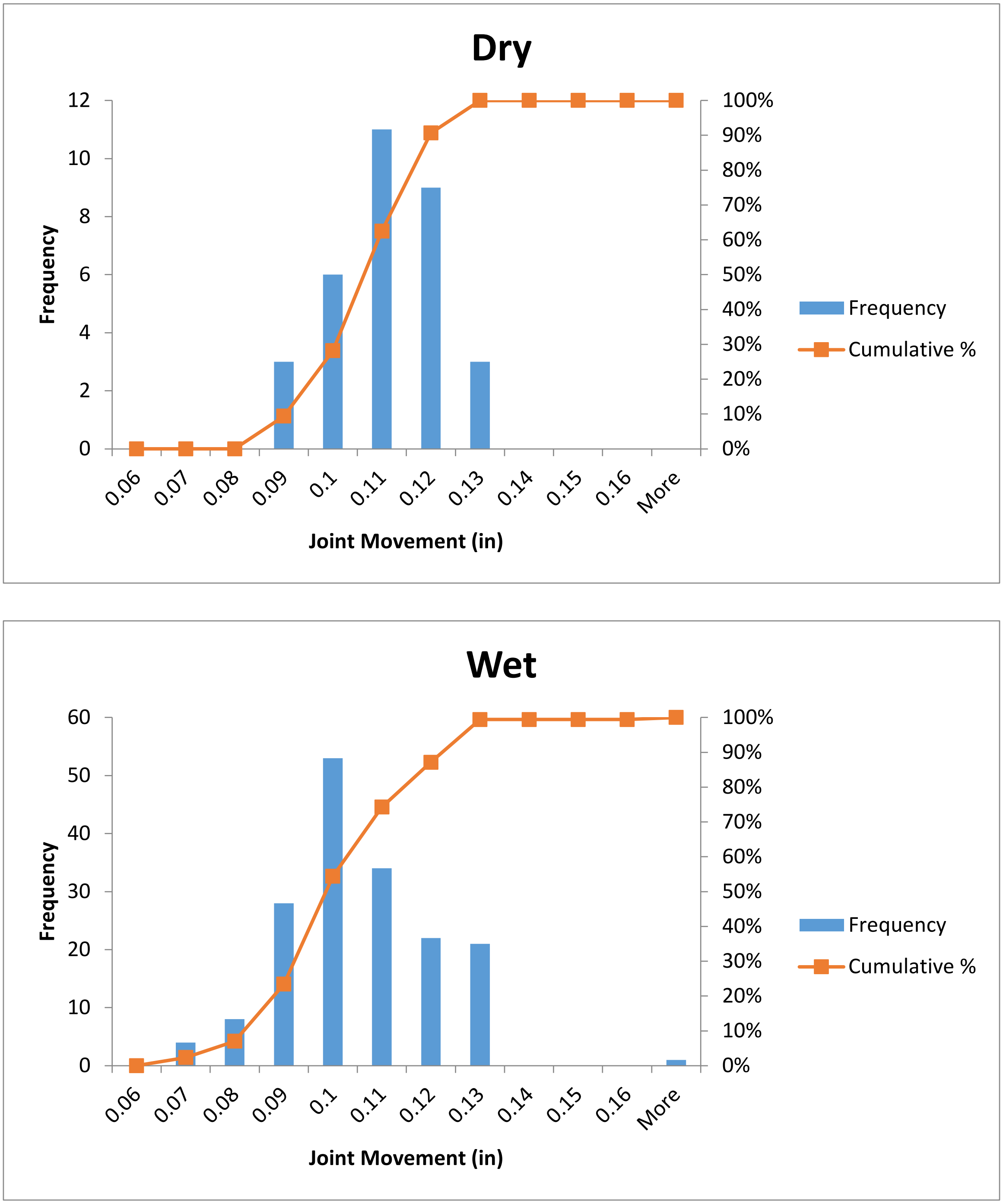


Figure 1. Distribution of Estimated Joint Movement Values for all SPS-2 Sections for Dry (top) and Wet (bottom) Climates.

Figure 2 illustrates the distribution of the ACPA-estimated joint movement values separated for freeze and no-freeze climates. The graphs show that 90% of the joint movement values in the freeze climates were between 0.08 and 0.13 and ranged from 0.07 to 0.161 inches. The joint movement values in no-freeze climates were lower compared to the freeze climates. For no-freeze climates, about 70% the values were between 0.08 and 0.11 inches and ranged from 0.07 to 0.161 inches. There was no difference in estimated joint movement values between sections within freeze or within no-freeze climates.

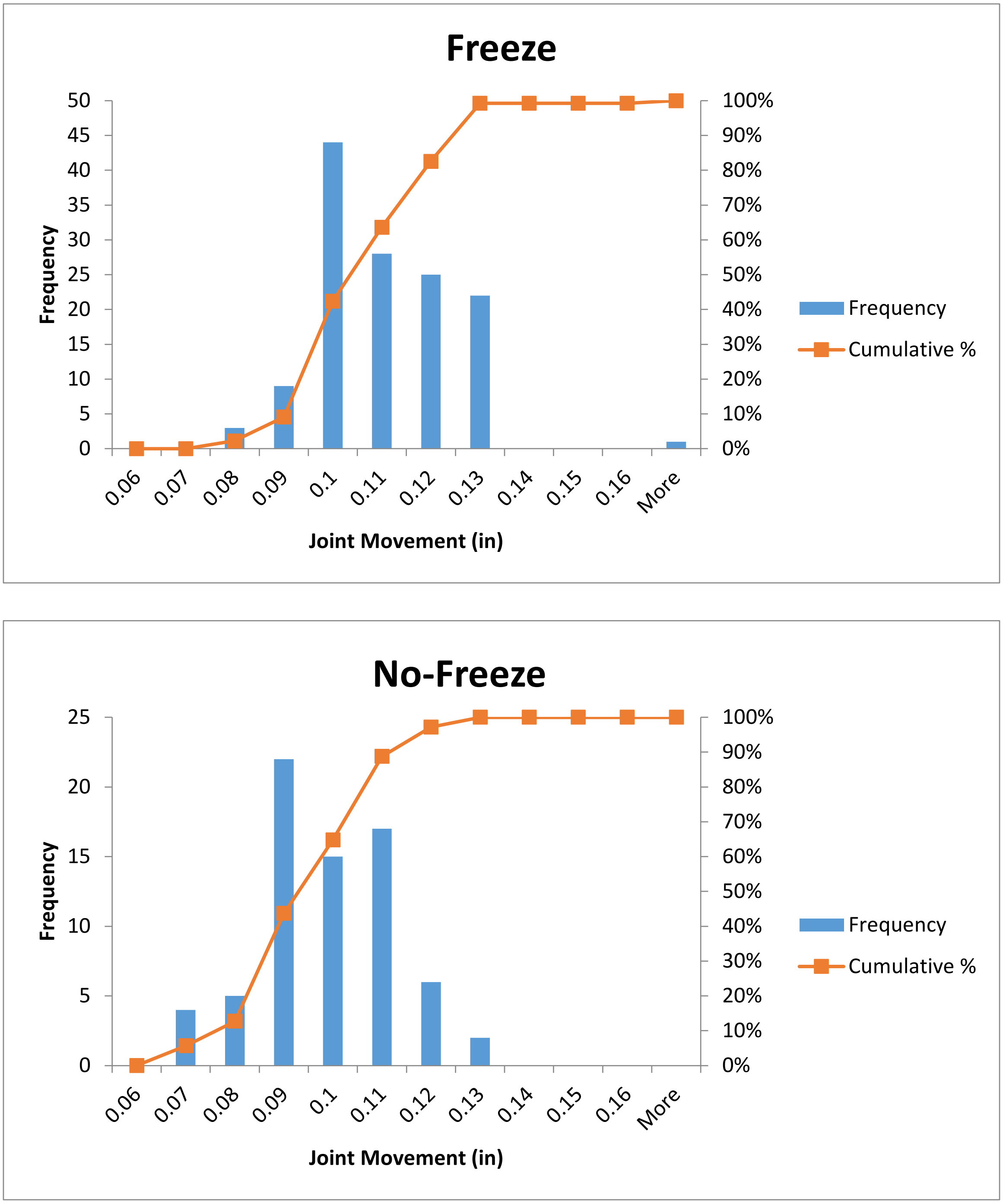


Figure 2. Distribution of Estimated Joint Movement Values for all SPS-2 Sections for Freeze (top) and No-Freeze (bottom) Climates.

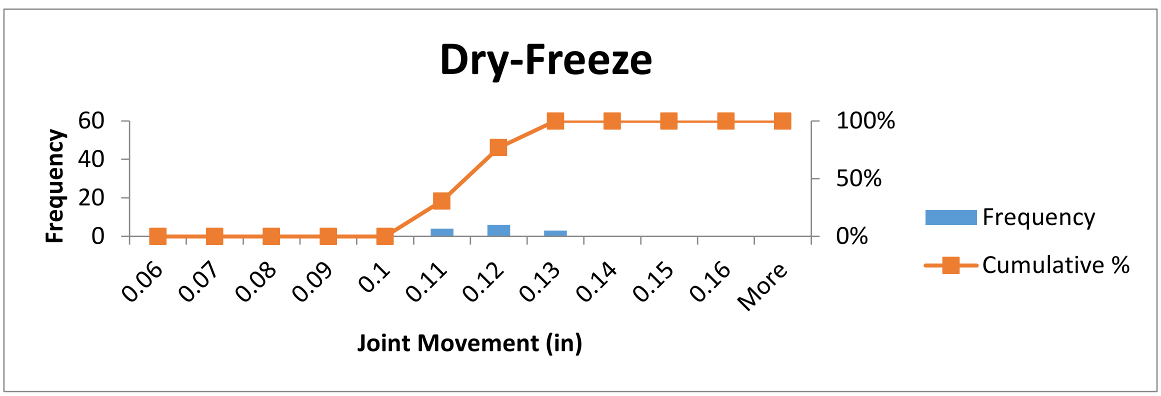
Next, the data were separated for each of the four LTPP climatic regions: dry-freeze, dry-no-freeze, wet-freeze, and wet-no-freeze. Table 4 shows the number of SPS-2 sections within each climate region.

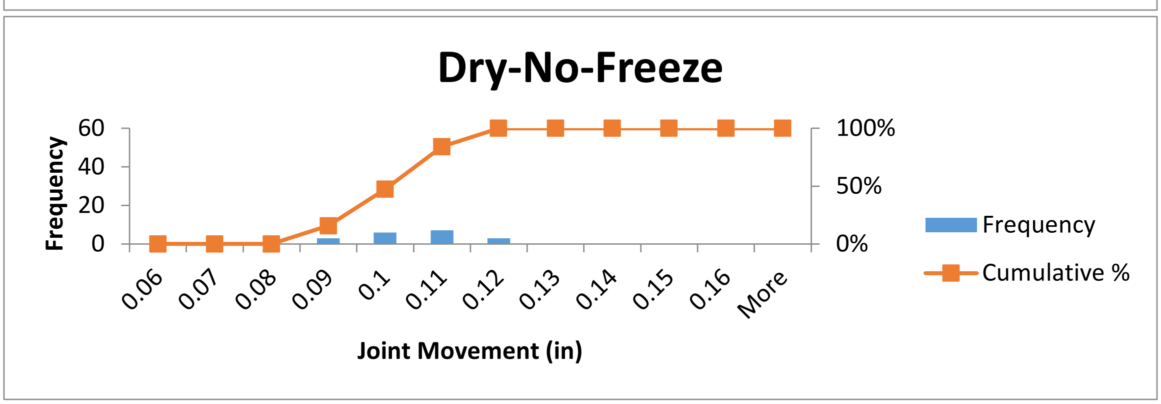
Table 4. Distribution of SPS-2 Sections Within theFfour LTPP Climatic Regions.

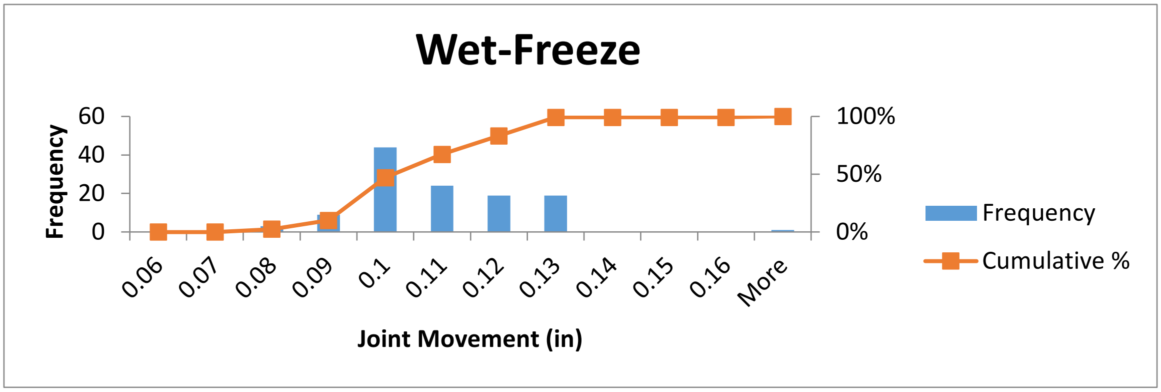
LTPP Climatic Region	Number of LTPP Sections
Dry-Freeze	13
Dry-No-Freeze	21
Wet-Freeze	121
Wet-No-Freeze	52

As shown in Table 4, most of the LTPP sections were in the wet-freeze region, followed by the wet-no-freeze region. Figure 3 illustrates the distribution of the ACPA-estimated joint movement values within each region.

The results show that a majority of the joint opening values for sections in the wet-freeze environments were between 0.08 and 0.13 inches. The wet-no-freeze climate had the widest range of joint movement values, from 0.06 to 0.13 inches, though the most common values were between 0.08 and 0.11 inches. The predicted joint openings in sections in the dry-no-freeze climate were roughly normally distributed between 0.08 and 0.12 inches. The few sections in the dry-freeze climate, about 30% of the values between 0.10 and 0.11 inches, 45% between 0.11 and 0.12 inches, and the remaining 25% between 0.12 and 0.13 inches.







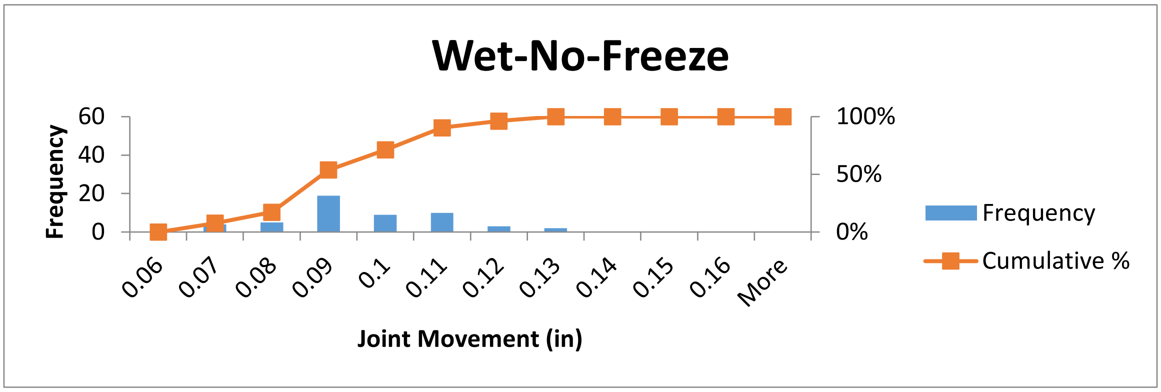


Figure 3. Distribution of Estimated Joint Movement Values for all SPS-2 Sections Based on the Four LTPP Climatic Regions: Dry-Freeze (top), Dry-No-Freeze (2nd from top), Wet-Freeze (2nd from bottom), and Wet-No-Freeze (bottom).

4.0 COMPARISONS OF MEASURED JOINT MOVEMENT WITH SPS-2 SMP PERFORMANCE

The measured joint movement values were compared to the pavement performance of the four SMP SPS-2 sections. The three pavement performance measurements evaluated were LTE, faulting, and pavement roughness quantified using IRI values from the high-speed profile unit. Figure 4 compares the average daily approach and leave LTE values to the average daily joint movement for the four SPS-2 SMP sections. The results show that there was no correlation between average daily LTE values and the joint movement on the same day. Furthermore, the limited data show that some of the lowest LTE values occurred when the joint exhibited relatively little movement.

Figure 4. Comparison of Daily Average LTE for Approach (top) and Leave (bottom) Side of Joints Compared to the Average Daily Joint Movement on the SPS-2 SMP Sections.

Figure 5 compares the average daily pavement roughness, quantified with IRI values, to the average daily joint movement for the four SPS-2 SMP sections. The results show there was little correlation between pavement roughness and daily joint movement for three of the four sections. For Section 320204, the pavement roughness increased as the daily joint movement values increased. However, five datapoints were too few to establish a trend.

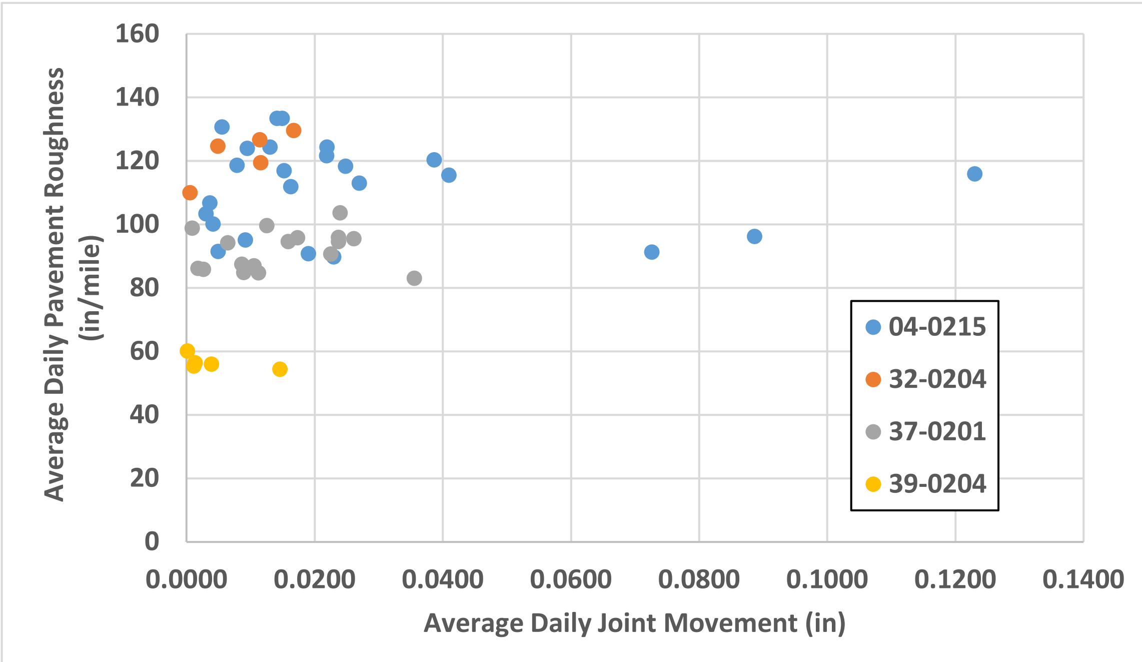
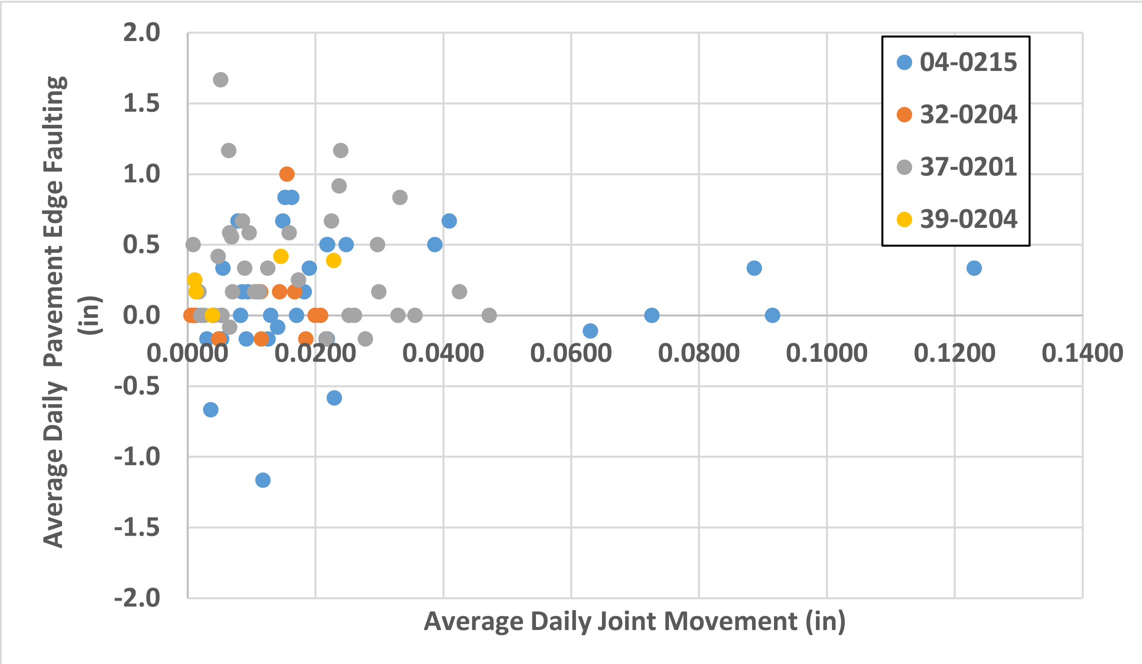


Figure 5. Average Daily Pavement Roughness Values Compared to the Average Daily Joint Movement on the SPS-2 SMP Sections.

Figure 6 compares the average daily faulting values to the average daily joint movement for the four SPS-2 SMP sections. The results show the faulting measurements did not correlate with the daily joint movement values. Figure 7 compares the average daily *change* in faulting to the daily joint movement. The results show that for most of the time, there was no change in the daily faulting measurements. The non-zero changes in daily faulting measurements could be partially attributed to slab curling from temperature changes.



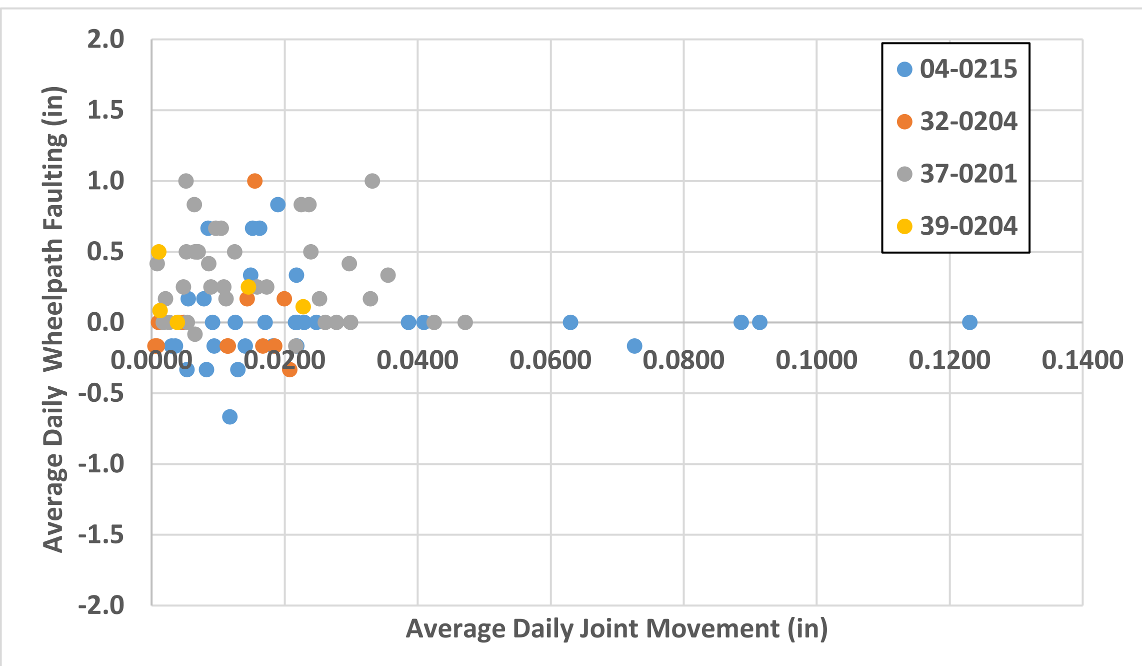
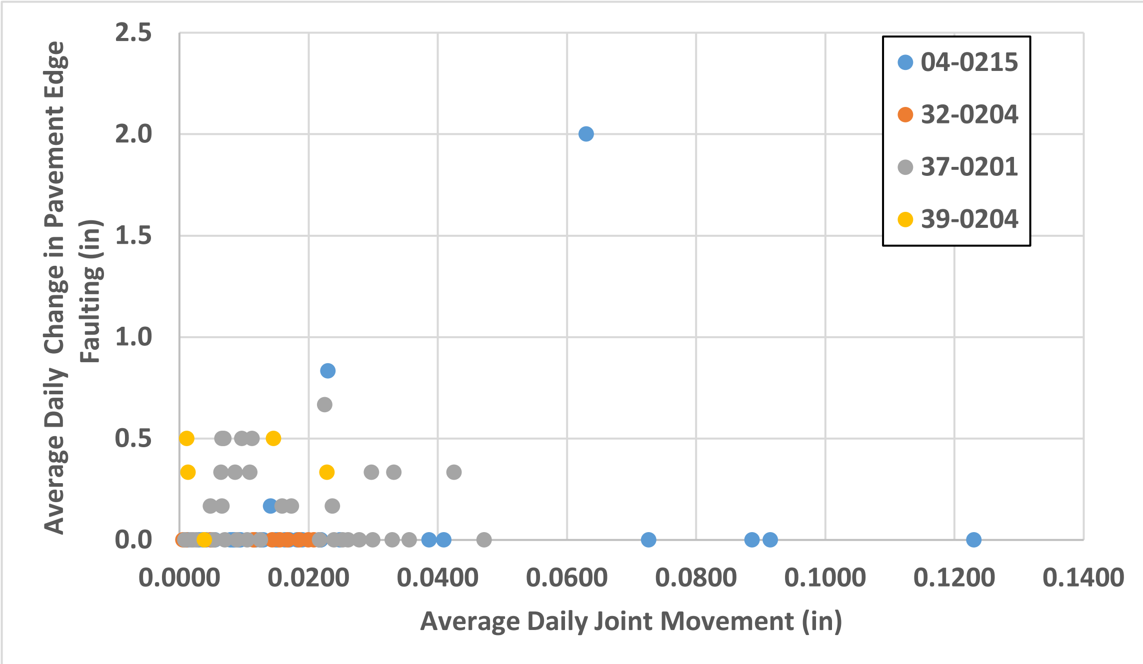


Figure 6. Comparison of Average Daily Pavement Edge (top) and Wheel-Path (bottom) Faulting Measurements Compared to Average Daily Joint Movement for SPS-2 SMP Sections.



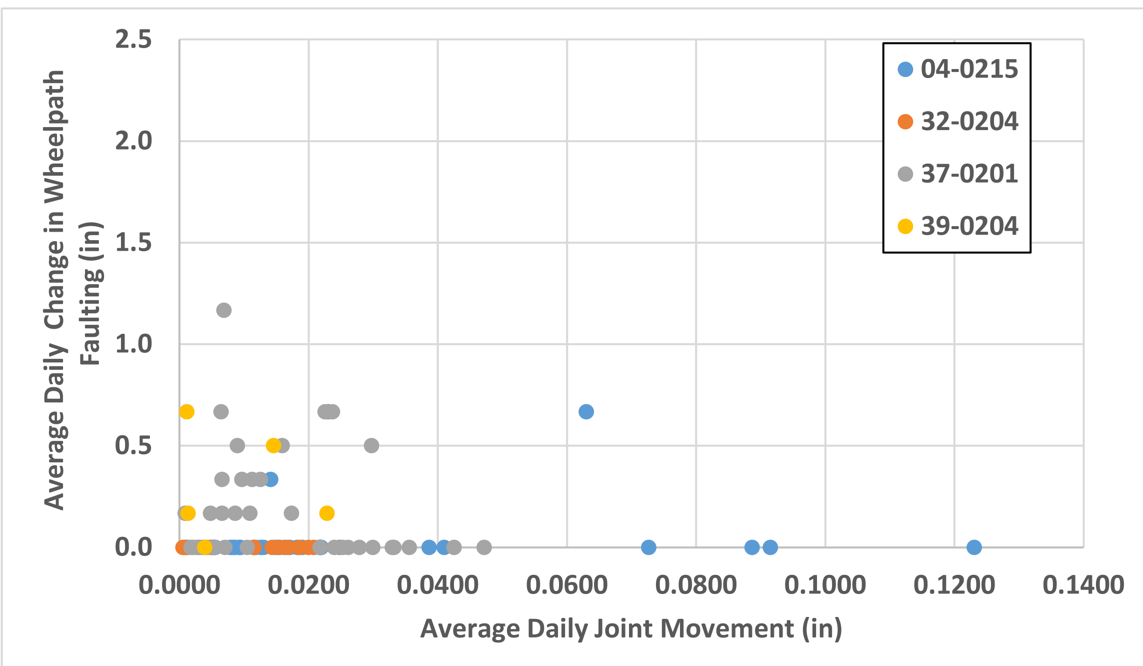


Figure 7. Comparison of Average Daily Change in Pavement Edge (top) and Wheel-Path (bottom) Faulting Measurements Compared to Average Daily Joint Movement for SPS-2 SMP Sections.

5.0 COMPARISONS OF MEASURED JOINT MOVEMENT WITH PCC TEMPERATURE FOR SPS-2 SMP SECTIONS

A 2003 report authored for the FHWA titled *Evaluation of Joint and Crack Load Transfer Final Report* was reviewed as part of the scope. The original report presented a comparison of PCC joint movement to changes in PCC temperature during testing for 15 different test sections. The results showed strong correlations between changes in joint opening and changes in PCC temperature for eight of the sections, weak correlations for four sections, and poor correlations for three sections. All sections showed that the joints narrowed as PCC temperature increased during testing.

The measured joint movements from the four SPS-2 SMP sections were compared to the change in mid-depth temperature of the PCC during joint movement testing. Joint gage measurements were collected at two different times during each site visit and the difference represents the average joint movement for that day. Holes were drilled into the PCC and filled with oil and temperature probes to measure the PCC's mid-depth temperature; the temperatures were usually measured both before and after joint gage measurements were collected. The temperatures were usually taken over a 5-to-8-hour period but varied for each visit. The difference between the two temperature measurements represents the daily PCC temperature change. The temperature gradient of the PCC was not considered in this analysis.

Figure 8 compares the average daily joint movement to the daily change in PCC temperature during joint movement testing for Section 040215. The results show that, in general, the joints narrowed with increases in PCC temperature. However, some datapoints showed the joints opening as the PCC temperature increased. Linear regression shows there was little correlation between the PCC temperature change and joint movement for Section 040215.

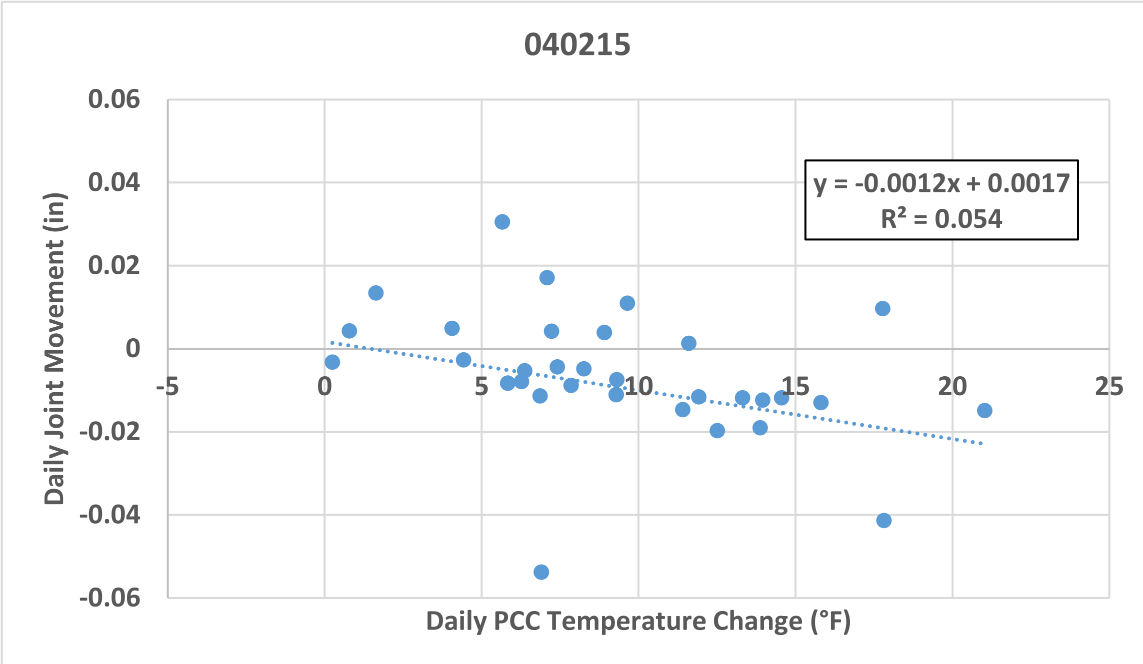


Figure 8. Comparison of Average Daily Joint Movement to Average Daily Change in PCC Temperature for 040215.

Figure 9 compares the average daily joint movement to the daily change in PCC temperature for Section 320204. The results show that the joints either closed slightly or remained relatively unchanged with increases in PCC temperature during testing. The linear regression shows there was little correlation between the joint movement values and the PCC temperature change.

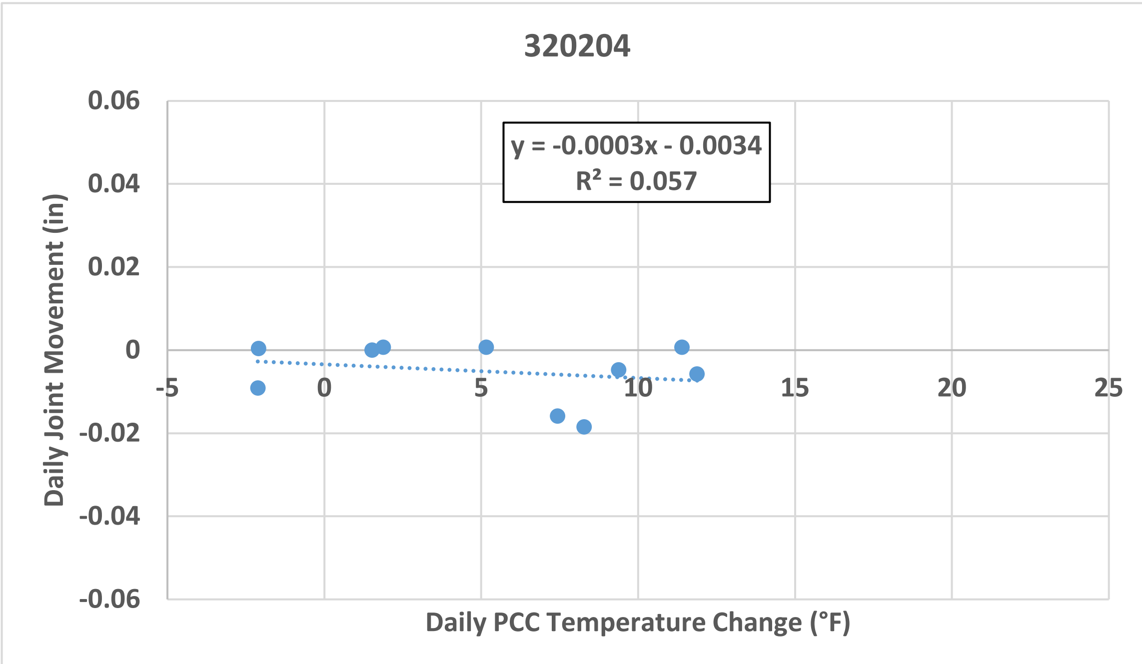


Figure 9. Comparison of Average Daily Joint Movement to Average Daily Change in PCC Temperature for 320204.

Figure 10 compares the average daily joint movement to the daily change in PCC temperature for Section 370201. The results show that, in general, the joints appeared to narrow with increases in PCC temperature during testing. As with Section 040215, the joints opened with increases in PCC temperature during testing on some days. The linear regression shows there was no correlation between joint movement and daily PCC temperature change during testing.

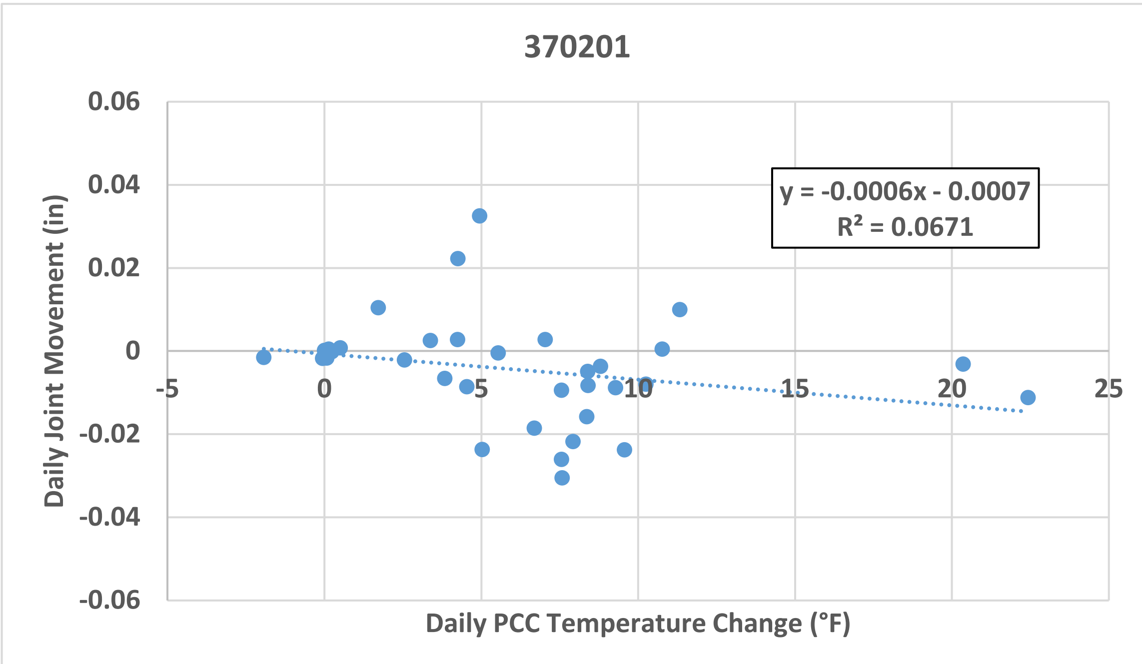


Figure 10. Comparison of Average Daily Joint Movement to Average Daily Change in PCC Temperature for 370201.

Figure 11 compares the average daily joint movement to the daily change in PCC temperature for Section 390204. The results show that the joints closed with increases in PCC temperature during testing. The linear regression shows that there was a weak correlation between the joint movement values and the change in PCC temperature. The joints moved about 0.0017 inch (17 mils) per degree Fahrenheit change in PCC temperature, when exceeding 3.5 degrees Fahrenheit.

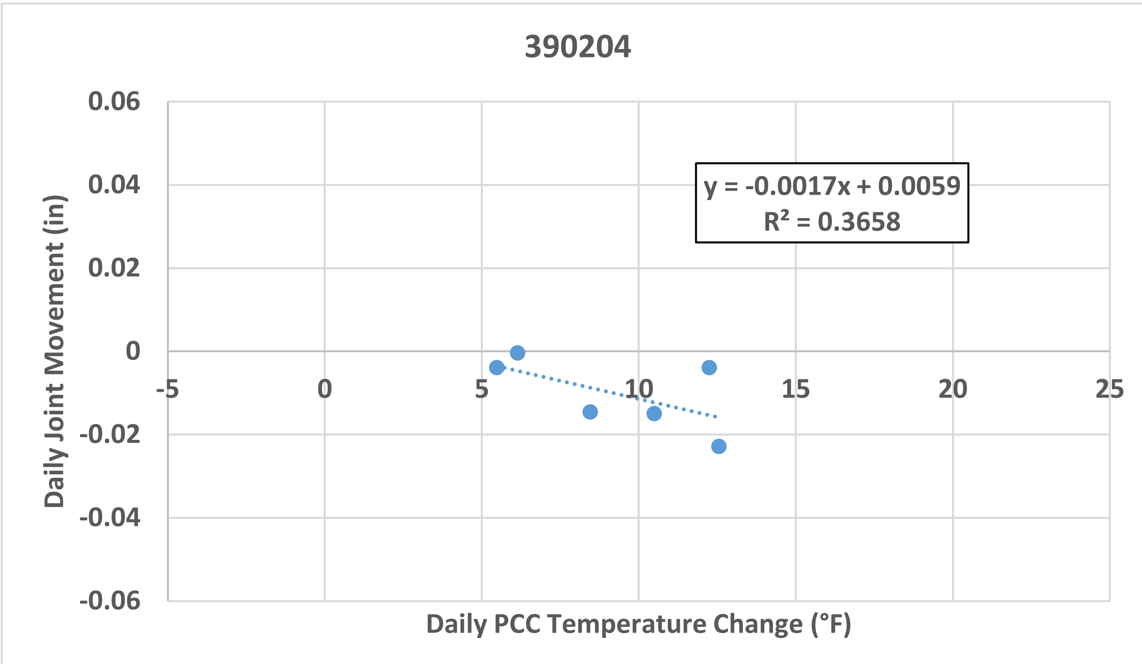


Figure 11. Comparison of Average Daily Joint Movement to Average Daily Change in PCC Temperature for 390204.

6.0 COMPARISONS OF PREDICTED JOINT MOVEMENT WITH SPS-2 PERFORMANCE

The predicted joint movement values from the ACPA app were compared with the pavement performance of all SPS-2 sections to determine if a relationship exists. The three pavement performance measures evaluated were LTE, faulting, and pavement roughness (IRI) values.

6.1 Load Transfer Efficiency

LTE values were determined from falling weight deflectometer (FWD) data collected on the SPS-2 sections. Infopave® contains the already-calculated LTE values in a separate table from the raw FWD deflection data. The average of all LTE values for the approach and leave side of the joints were averaged for each section and compared with the predicted joint movement for that section. Figure 12 compares the predicted joint movement values to the average LTE values from the approach and leave side of the joints at each SPS-2 section. The results show there was no correlation between joint movement values and the average LTE values at joints.

Since the joint movement values represent a change in the joint width during the life of the pavement, it was thought that using a change in pavement performance values could provide a better correlation with the joint movement. Figure 13 compares the average lifetime change in LTE for the approach and leave side of the joints to the estimated joint movement. The results still do not show that there was a correlation between lifetime changes in LTE and the estimated joint movement values.

6.2 Joint Faulting

Joint faulting values were measured using the Georgia Faultmeter. Figure 14 compares the predicted joint movement values to the average faulting measurements from the pavement edge and wheel-path at each SPS-2 section. Most of the SPS-2 sections had very little faulting, with less than 1 mm of faulting at the pavement edge. The results show that there was no correlation between average faulting values and the estimated joint movement values. The same held true for the wheel-path rutting measurements, where the range of average faulting measurements was also very small.

As with LTE values, the lifetime changes in faulting for each SPS-2 section was determined and compared with the joint movement values. Figure 15 compares the lifetime faulting change to the joint movement values. The results show that there was no correlation between lifetime changes in faulting and the estimated joint movement values.

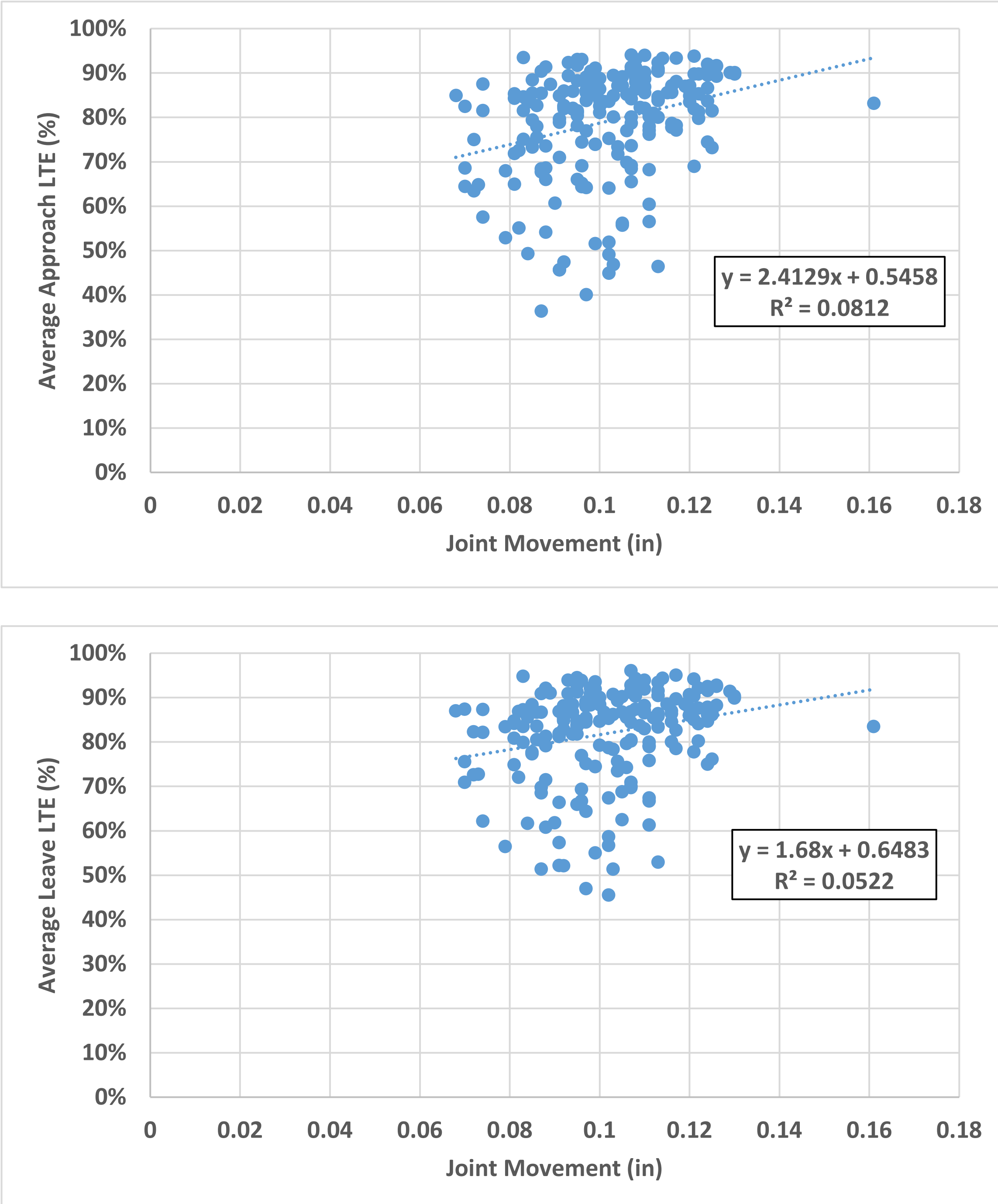
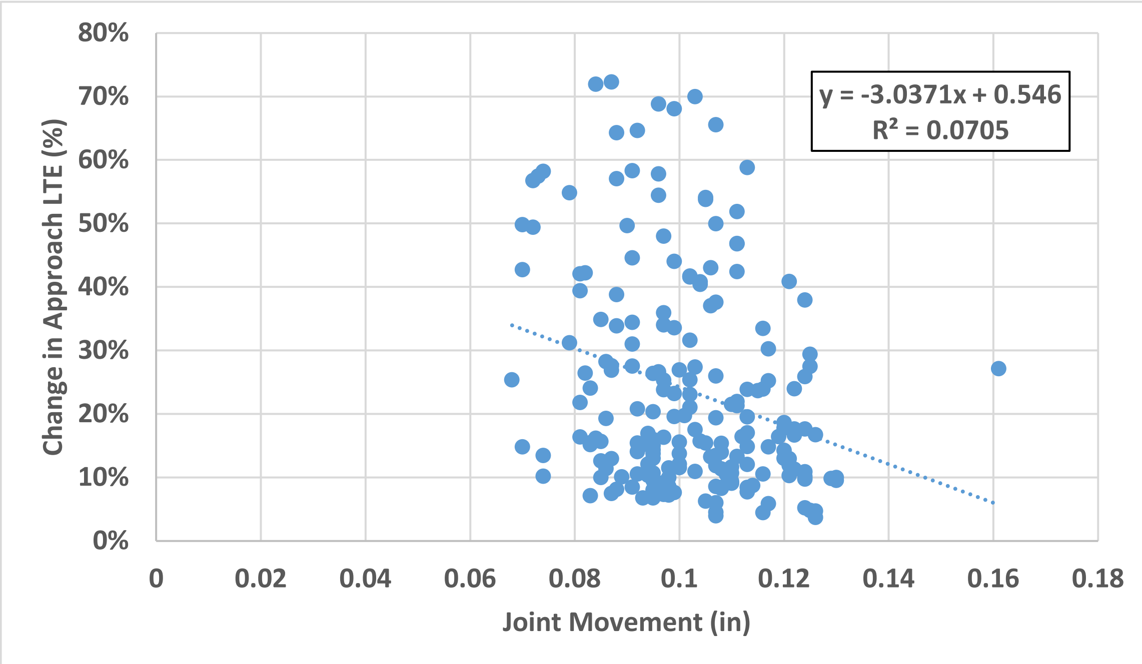


Figure 12. Comparison of Average Load Transfer Efficiency on Approach (top) and Leave (bottom) Side of Joints to Predicted Joint Movement for all SPS-2 Sections.



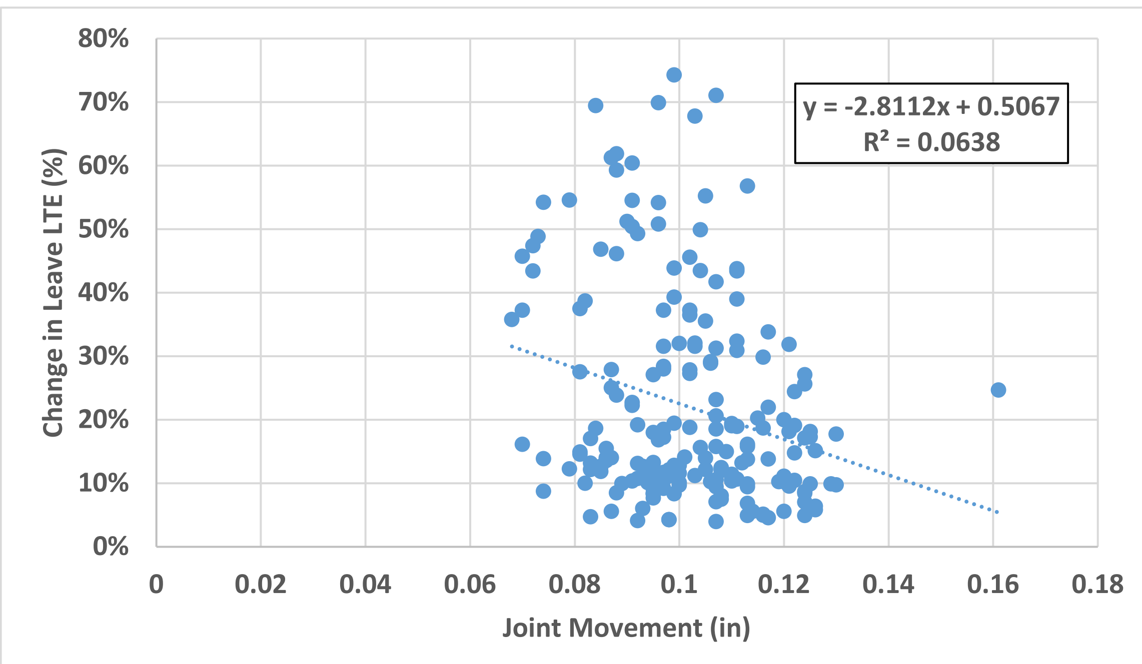
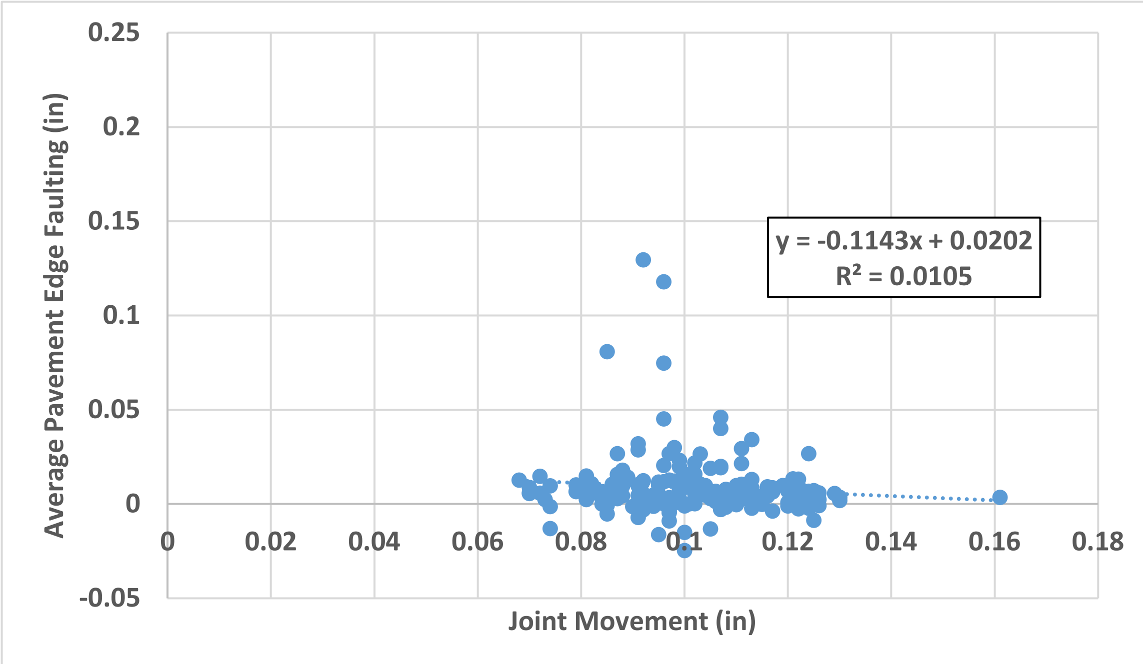


Figure 13. Comparison of Lifetime Change in Load Transfer Efficiency on Approach (top) and Leave (bottom) Side of Joints to Predicted Joint Movement for all SPS-2 Sections.



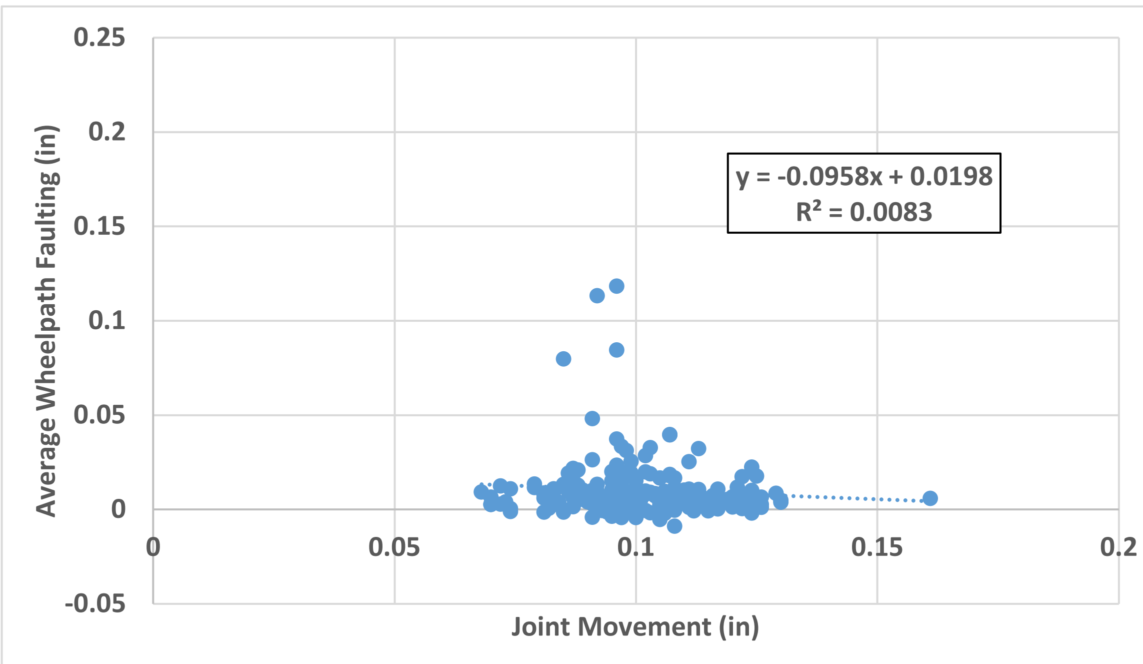


Figure 14. Comparison of Average Faulting Measurements at Pavement Edge (top) and Outer Wheel-Path (bottom) to Predicted Joint Movement for all SPS-2 Sections.

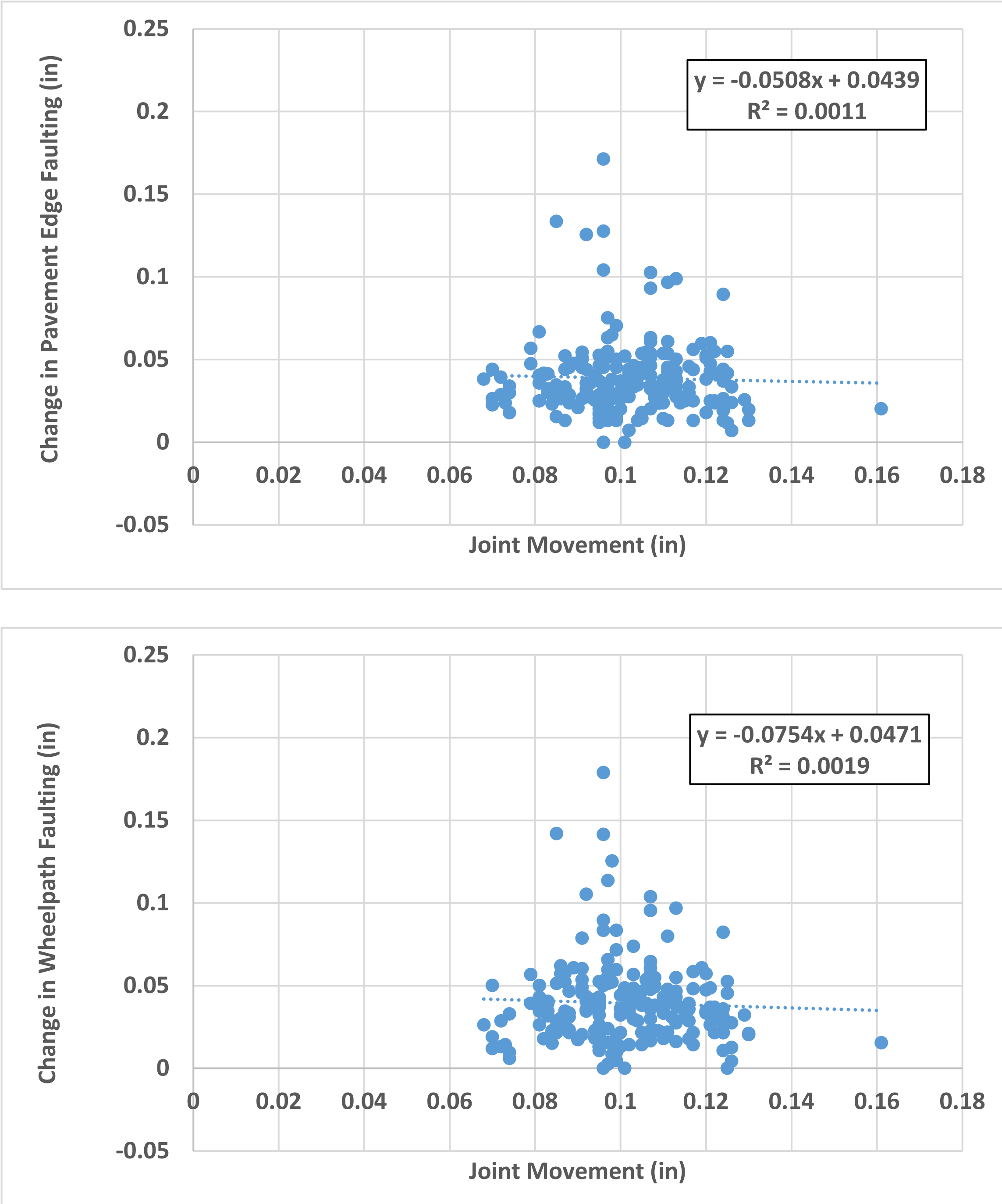
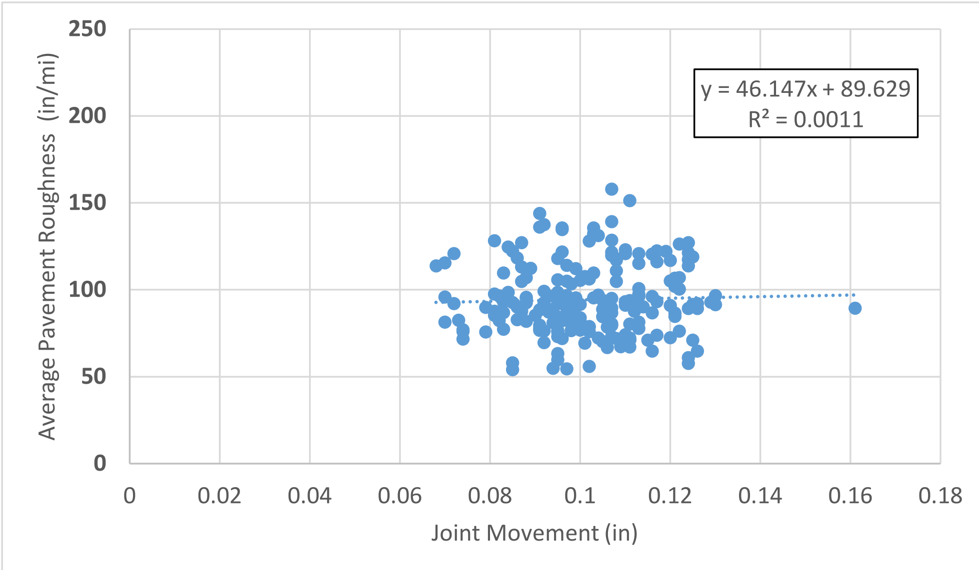


Figure 15. Comparison of Lifetime Change in Faulting Measurements at Pavement Edge (top) and Outer Wheel-Path (bottom) to Predicted Joint Movement for all SPS-2 Sections.

6.3 Pavement Roughness

Pavement roughness was the last of the three pavement performance measures evaluated. The high-speed profile unit data were analyzed to calculate IRI values for each data-collection run. The IRI values are provided on Infopave®. Figure 16 compares the average pavement roughness values to the predicted joint movement values. The average SPS-2 IRI values were generally centered around 100 inches/mile, seemingly regardless of the joint movement values. The results of the linear regression show there was no correlation between the joint movement and average pavement roughness values at the SPS-2 sections. As with the previous two pavement performance measures, the lifetime change in pavement roughness was compared with the joint movement values (Figure 16). The results show that there was no correlation between lifetime change in pavement roughness and estimated joint movement values.



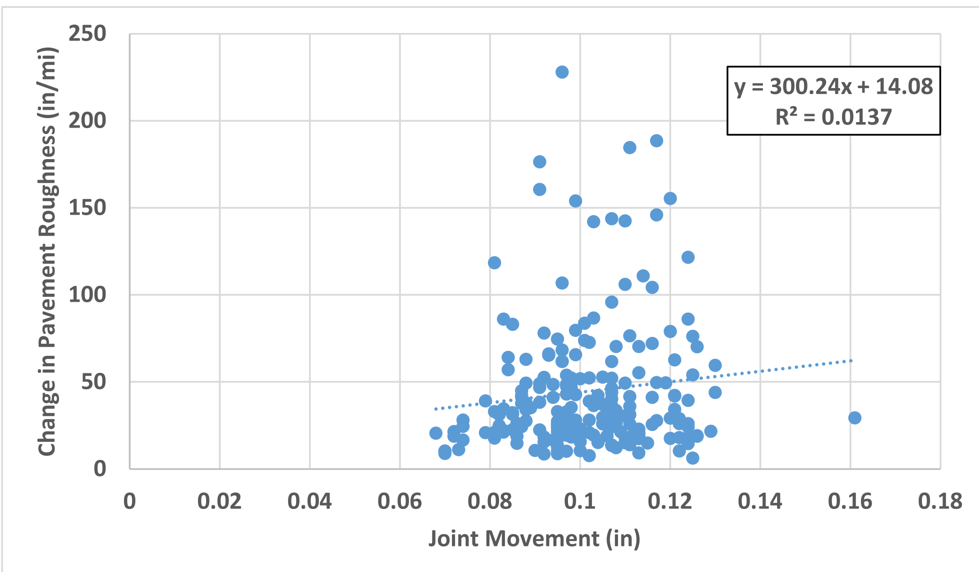


Figure 16. Comparison of Average Pavement Roughness (top) and Lifetime Change in Pavement Roughness (bottom) to Predicted Joint Movement for all SPS-2 Sections.

7.0 JOINT WIDTHS

The joint width represents the physical width of the joint. This differs from the joint opening movement (which represents a relative change in the joint width) and the joint gage measurement (which provides a relative change in the joint openings over time) but are not a measurement of the joint width itself. During FWD data collection on SMP SPS-2 sections, joint widths for most joints were measured with calipers to the nearest millimeter. As mentioned in Section 2.0 of this report, joint gage measurements were also collected at these test sections. At three of the four SPS-2 SMP sections (Arizona, Nevada, and Ohio), the FWD and joint gage measurements were generally collected at the same time. The joint gage measurement can be compared to the joint width measurement to provide a baseline per joint. Thereby allowing for all joint gage measurements to be converted to joint widths. The North Carolina section did not conduct FWD testing on any of the same days as the joint gage measurements were collected, so no joint gage measurements could be converted into joint width measurements for this section.

For each of the three sections with complete data, the LTE and joint width values for each joint were compared to determine if joint width impacted the joint's LTE. The changes in joint widths over time were also compared at for three SMP sections (Arizona, Nevada, and Ohio).

7.1.1 ARIZONA SMP SITE

Figure 17 compares the LTE values to the joint widths for all joints at section 040215 over the entire monitoring period. The results show that overall, there was no correlation between LTE and joint widths. Appendix C shows the LTE values versus joint widths for each joint. The results again show that there was no correlation between LTE and joint widths. For 040215, The difference in deflection from the loaded slab and unloaded slab was also determined all locations with a difference in deflection of 1.5 mils or less were removed and the remaining locations are shown in Figure 18. Joints with a low difference in deflection are not providing enough movement to accurately characterize the load transfer properties. The results show that there was a weak correlation and indicated that load transfer decreased as the joint widths decreased.

Figure 19 and Figure 20 illustrate the joint widths for each joint measured at 040215. The joint number corresponds to the joint's location from start of the test section in feet. The results show that the joints did not all behave the same way; some joints opened over time while other joints narrowed. There were also joints with widths that remained relatively unchanged over time, whereas other nearby joints moved significantly. Appendix C also contains plots illustrating the joint widths per joint over time. The results show that the correlations were weak. Joint 456 showed a weak trend of closing over time, whereas joint 489 opened over time. The remaining four joints had little correlation over time, with two opening over time and the other two narrowing.

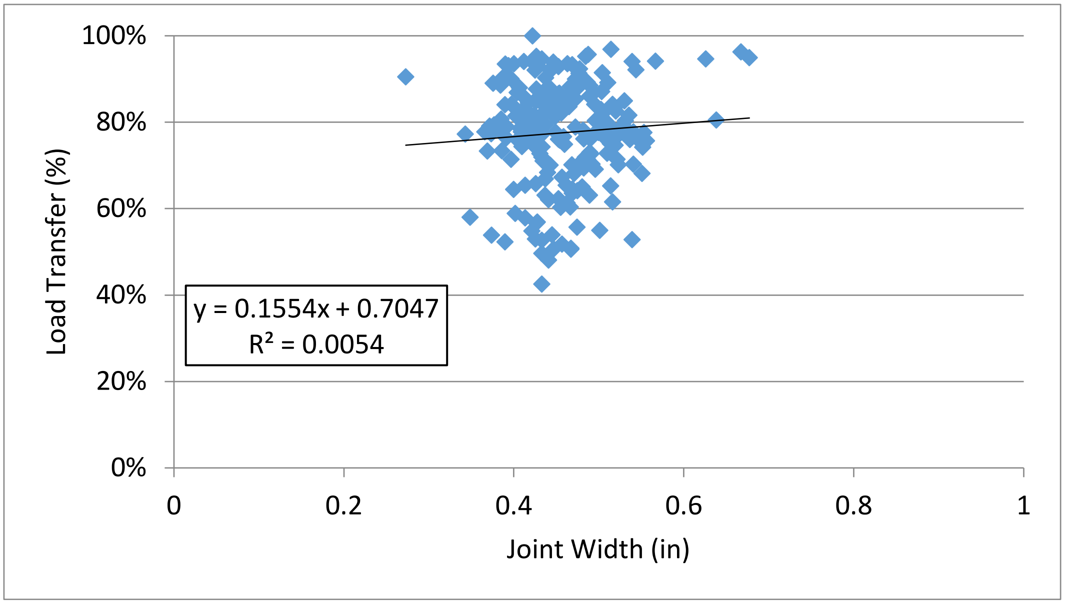


Figure 17. LTE Versus Joint Width for all Joints on 040215.

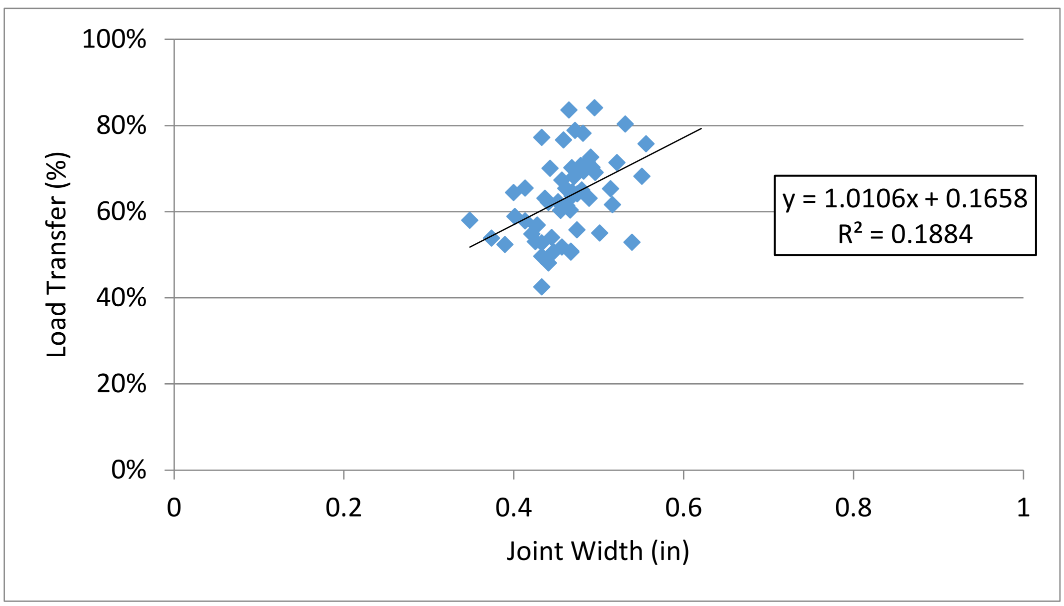


Figure 18. LTE Versus Joint Width for Joints with More than 1.5 mils Difference in Deflection on 040215.

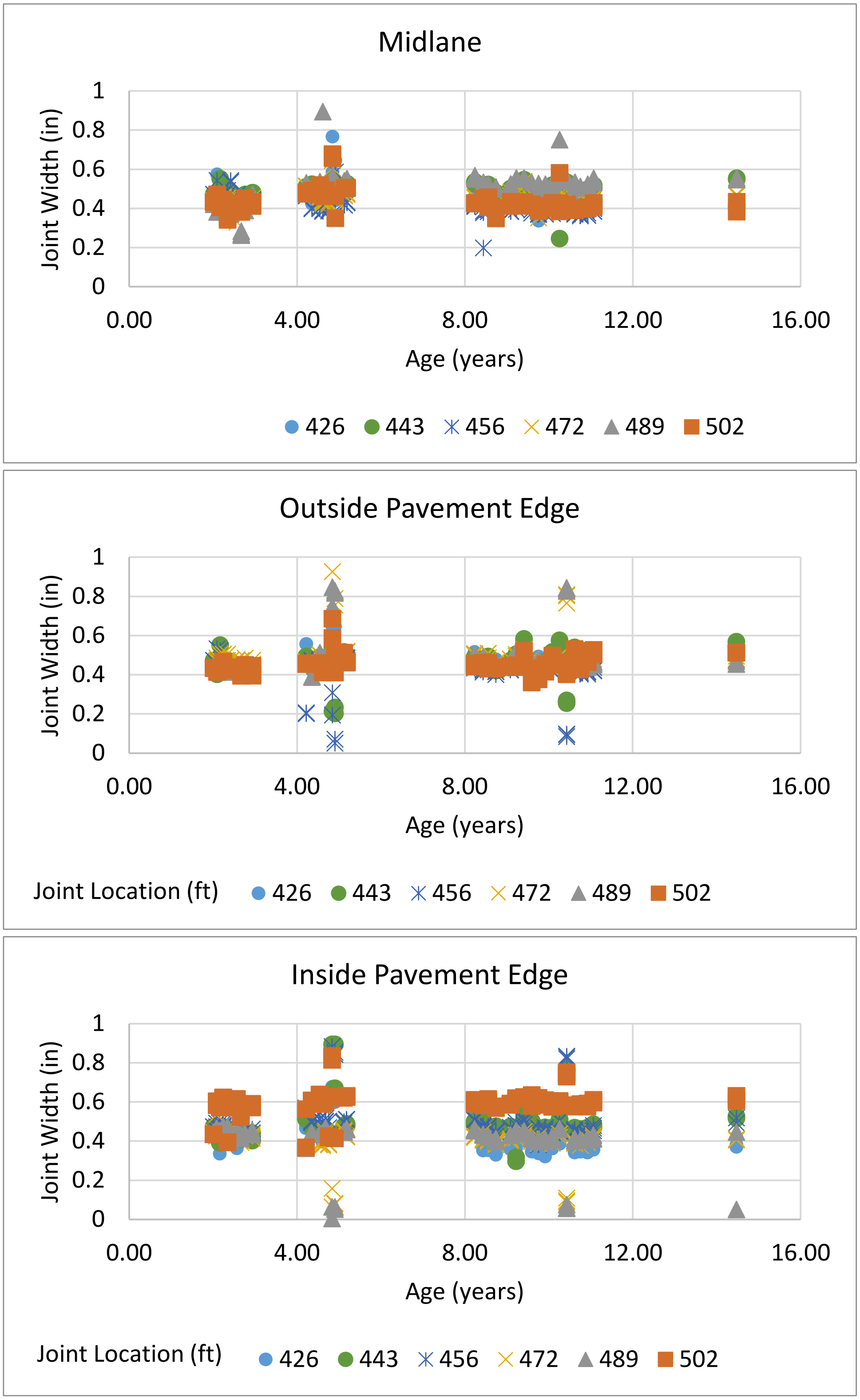


Figure 19. Joint Width Changes Over Time for All Six Joints Measured on 042015.

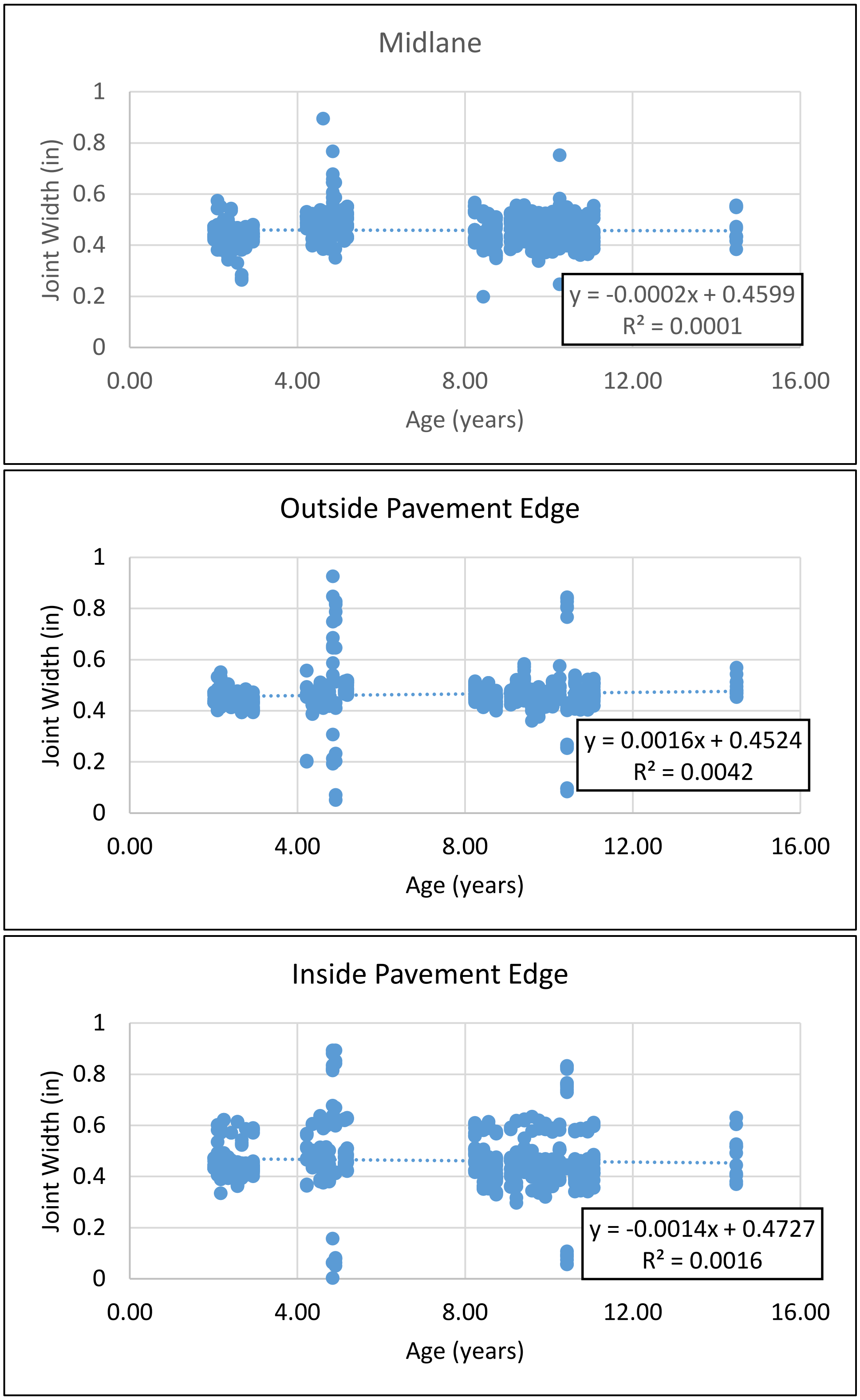


Figure 20. Linear Regression of Joint Width Against Time for All Six Joints Measured on 040215.

7.1.2 NEVADA SMP SITE

Figure 21 compares the LTE values to the joint widths for all joints at 320204 over the entire monitoring period. The results do not show a strong correlation. Appendix D shows the LTE values versus joint widths for each joint. The results again show that there was no correlation between LTE and joint widths. All locations with a difference in deflection 0.5 mils or less were removed and the remaining locations are shown in Figure 22. Again, there was no correlation between joint width and LTE.

Figure 23 and Figure 24 illustrate the joint opening widths for all joints over time. The results show that all six joints appeared to behave relatively uniformly. Appendix D also shows the joint widths for each joint over time. The results indicate that three of the joints (10, 26, and 69) had a moderate-to-strong correlation showing that the joints were closing over time. The other three joints had no correlation.

This section had several factors that may have influenced the results of this study. The joint widths at 320204 were all collected between October 1996 and September 1997 because the section went out of study quickly due to alkali-silica reactivity (ASR) distresses. ASR-related distresses are expansive in nature and would result in joint closure over time. During the short monitoring time of this section, the temperatures would have generally increased over time, and the joint widths would be expected to narrow. It is also possible that the materials-related distress was expansive, contributing to joint closure. Given the relatively short sampling window for the joint widths, it is possible that the observed trends at 320204 were a result of the small sample size and did not represent the long-term joint performance.

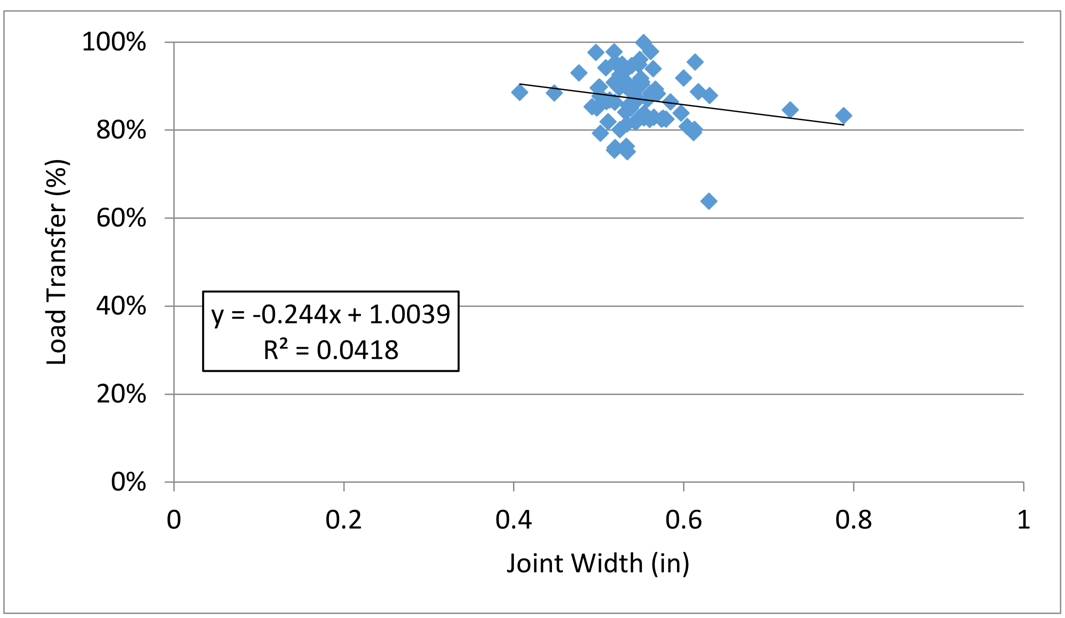


Figure 21. LTE Versus Joint Opening Width for All Joints on 320204.

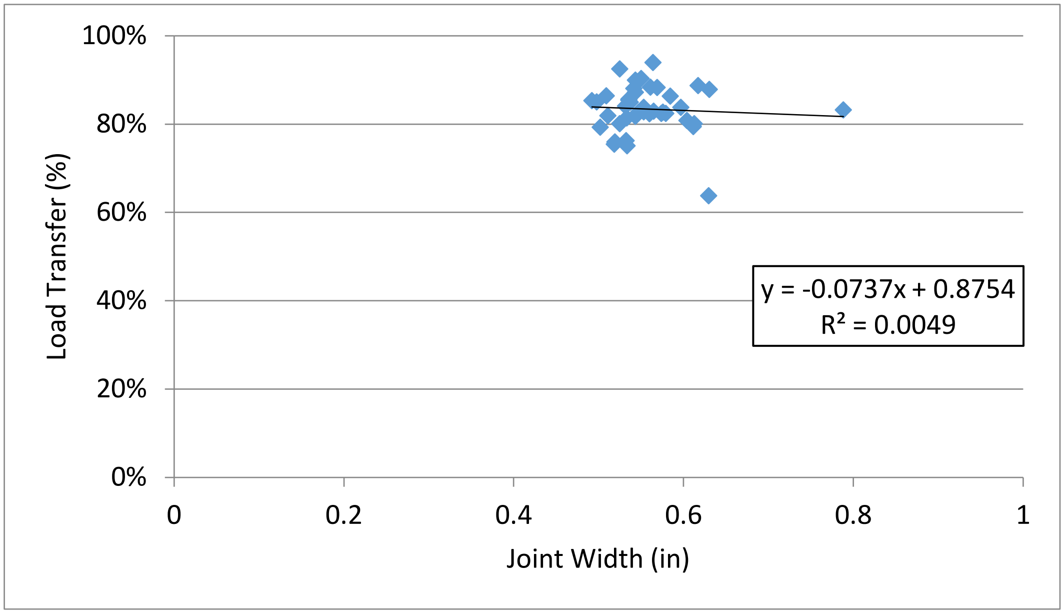


Figure 22. LTE Versus Joint Opening Width for Joints with More than 0.5 mil Difference in Deflection for 320204.

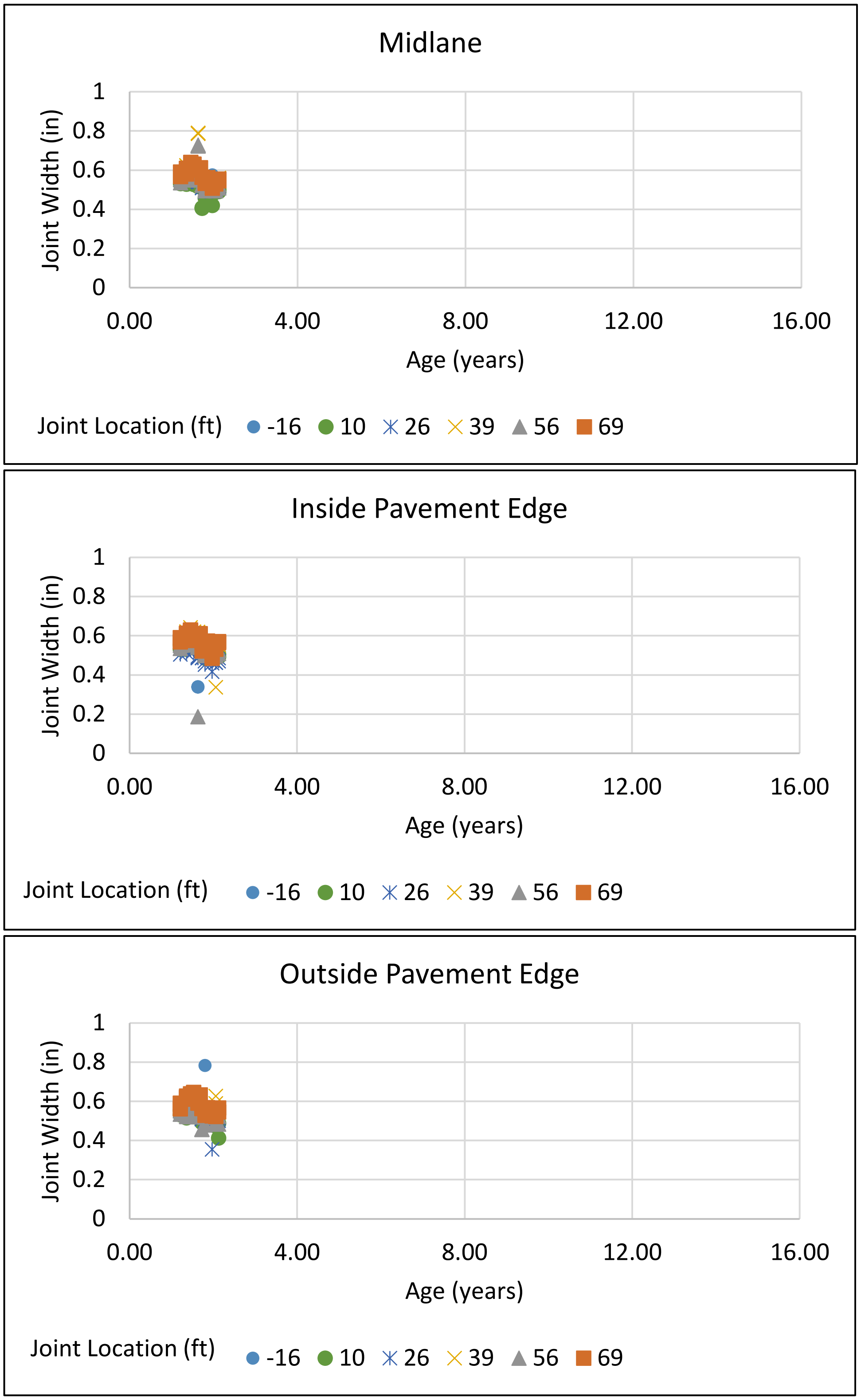


Figure 23. Summary of Joint Widths Over Time for Six Joints Measured on 320204.

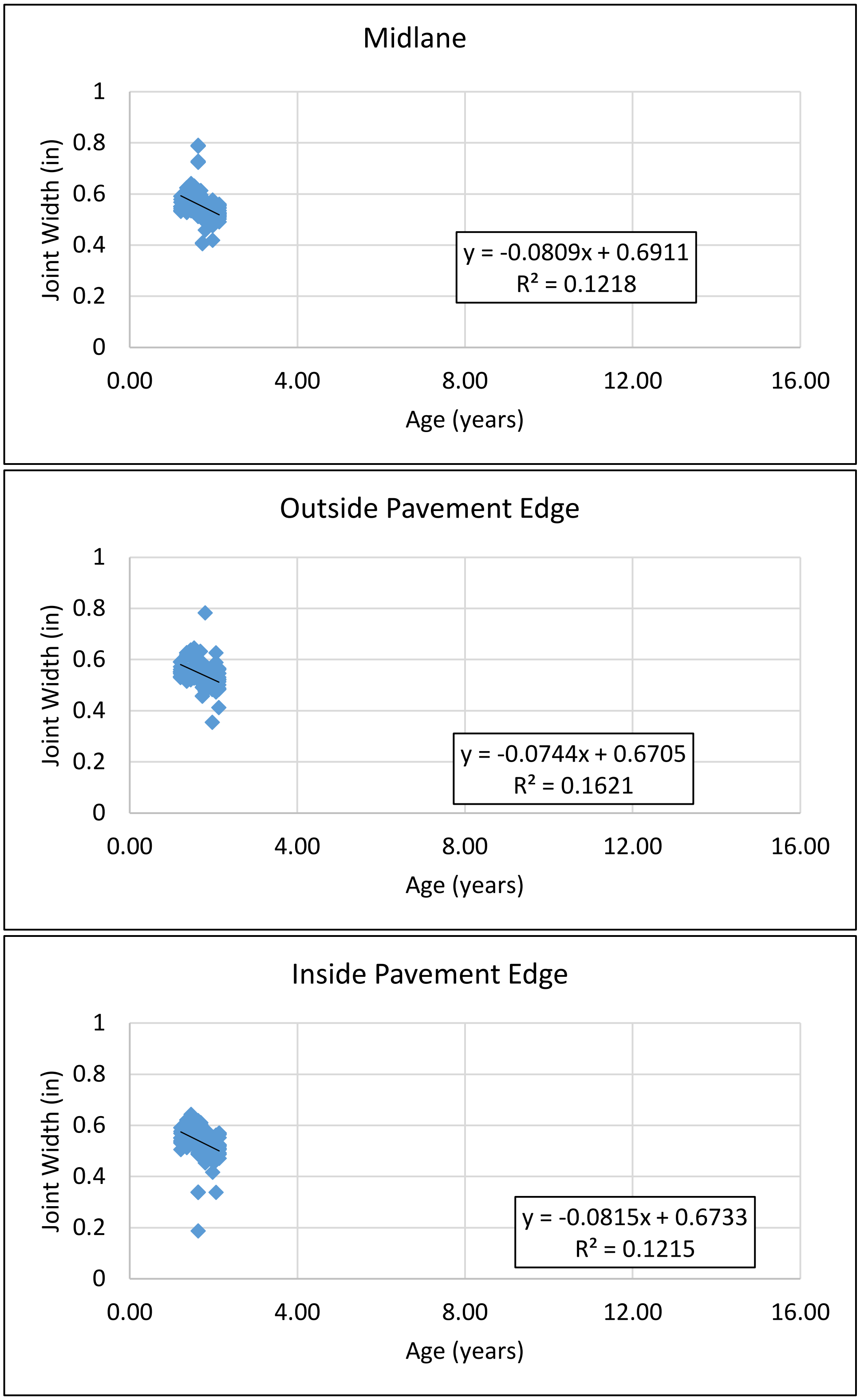


Figure 24. Linear Regression of Joint Width Against Time for Six Joints Measured on 320204.

7.1.3 OHIO SMP SITE

Figure 25 compares the LTE values to the joint widths for all joints at 390204 over the entire monitoring period. The results show strongly that there was no correlation. Appendix D shows the LTE values versus joint widths for each joint. These results indicate that there was a correlation showing that LTE values decreased as joint widths increased. These correlations were strong for two joints (39 and 69), moderately strong for one joint (23) and weak for the remaining three joints (10, 52, and 82). All locations with a difference in deflection of 0.5 mils or less were removed and the remaining locations are shown in Figure 26. The results show that there was no correlation between joint width and LTE.

Figure 27 and Figure 28 illustrate the joint widths for all joints at 390204. The results show that the joint widths remained stable during the monitoring period with very little joint movement observed. However, joint 52 appears to have widened whereas the adjacent joint (39) appears to have narrowed. This indicates that the despite all the joints having the same initial opening width based on the width of the saw cut, the sealant in joint 52 elongated more than the other five joints after construction. This extra elongation might be outside the range anticipated during sealant selection and may have failed earlier than the sealant in the other five joints.

Appendix D also shows the joint widths for each joint over time. The joint widths at section 390204 were all collected between May 1998 and May 1999.

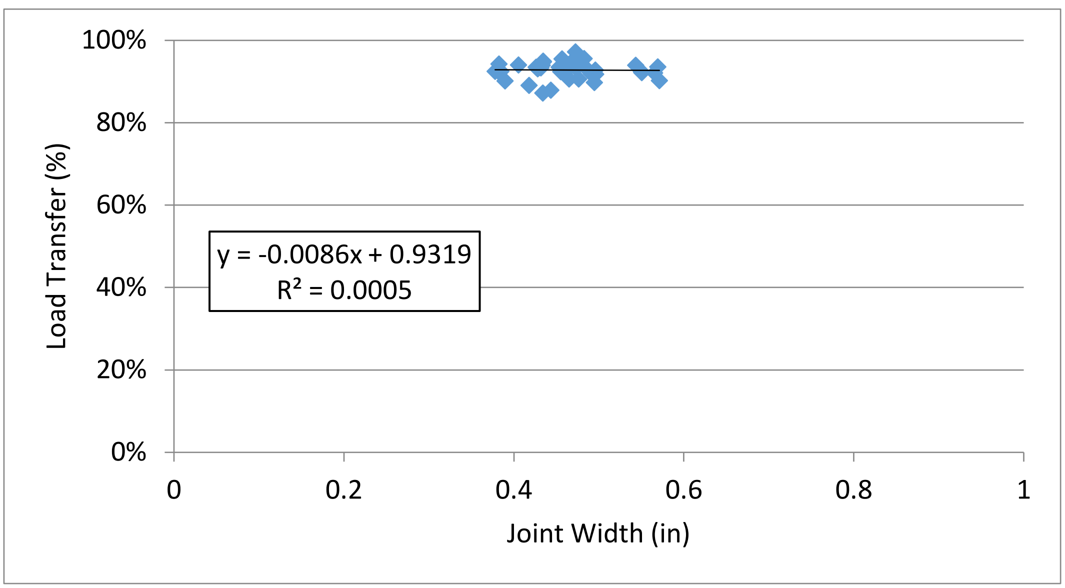


Figure 25. LTE Versus Joint Widths for All Joints on 390204.

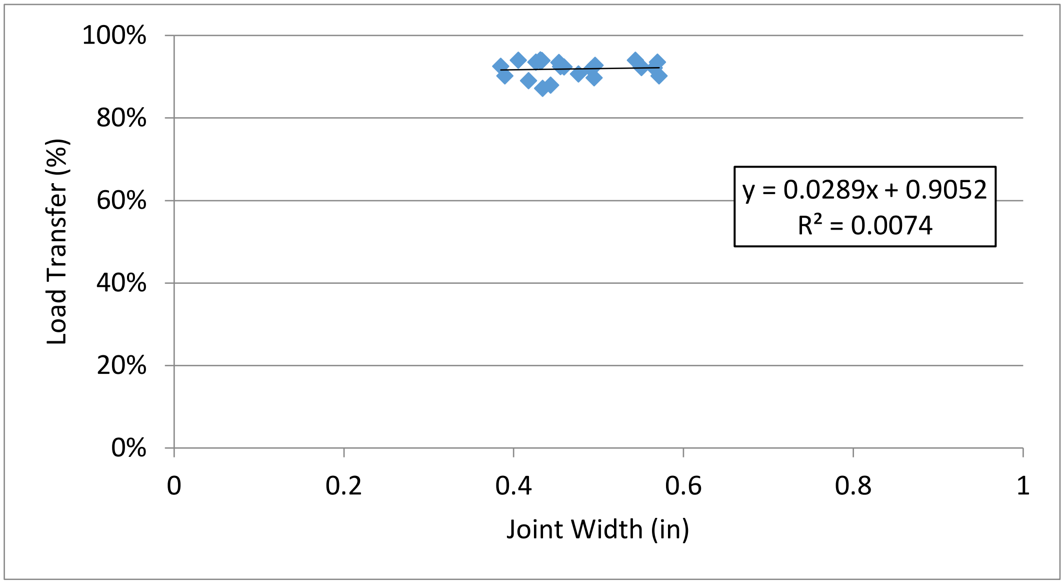


Figure 26. LTE Versus Joint Width for Joints with 0.5 mil Difference in Deflection for 390204.

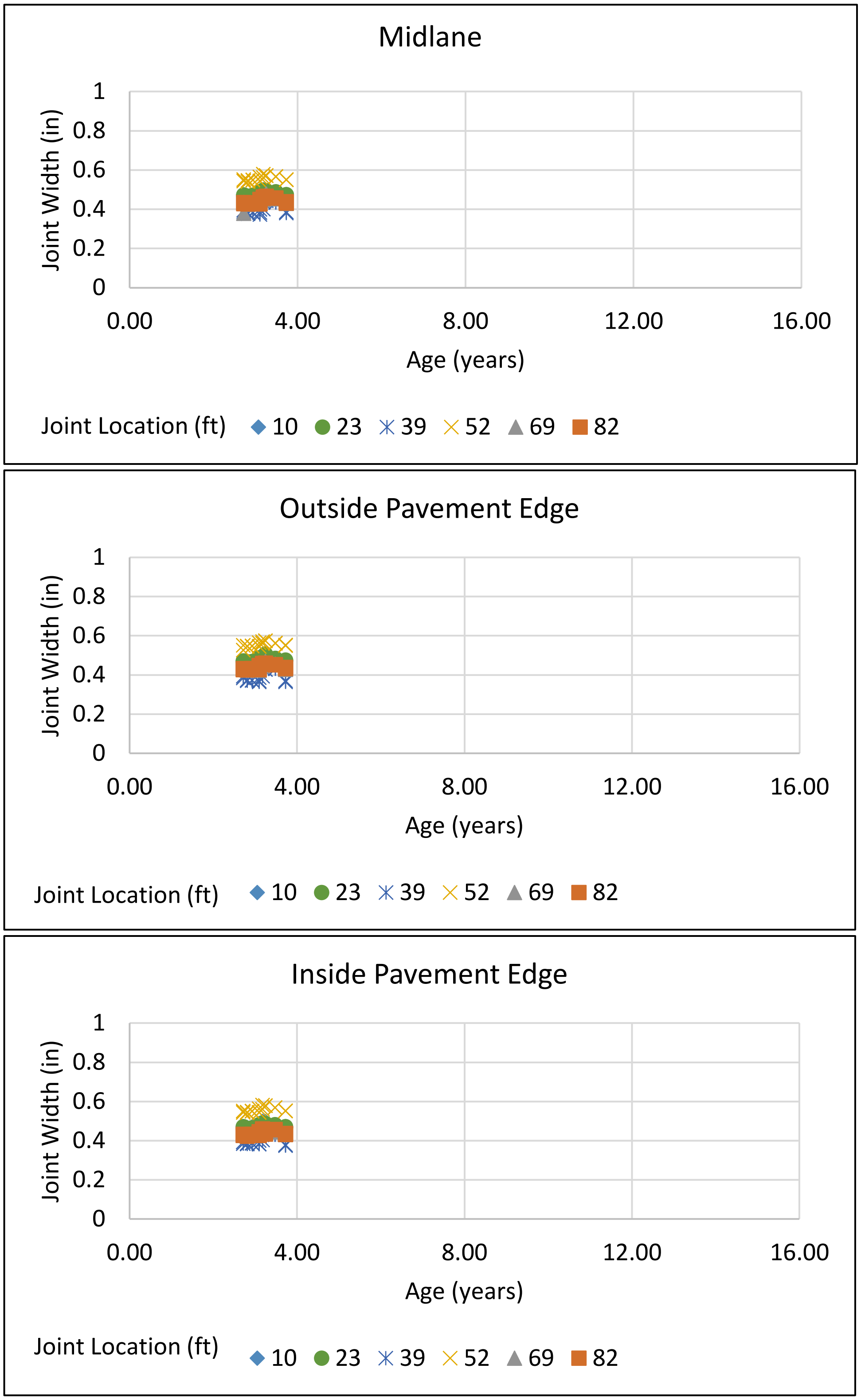


Figure 27. Comparison of Joint Widths Over Time for Six Joints Measured on 390204.

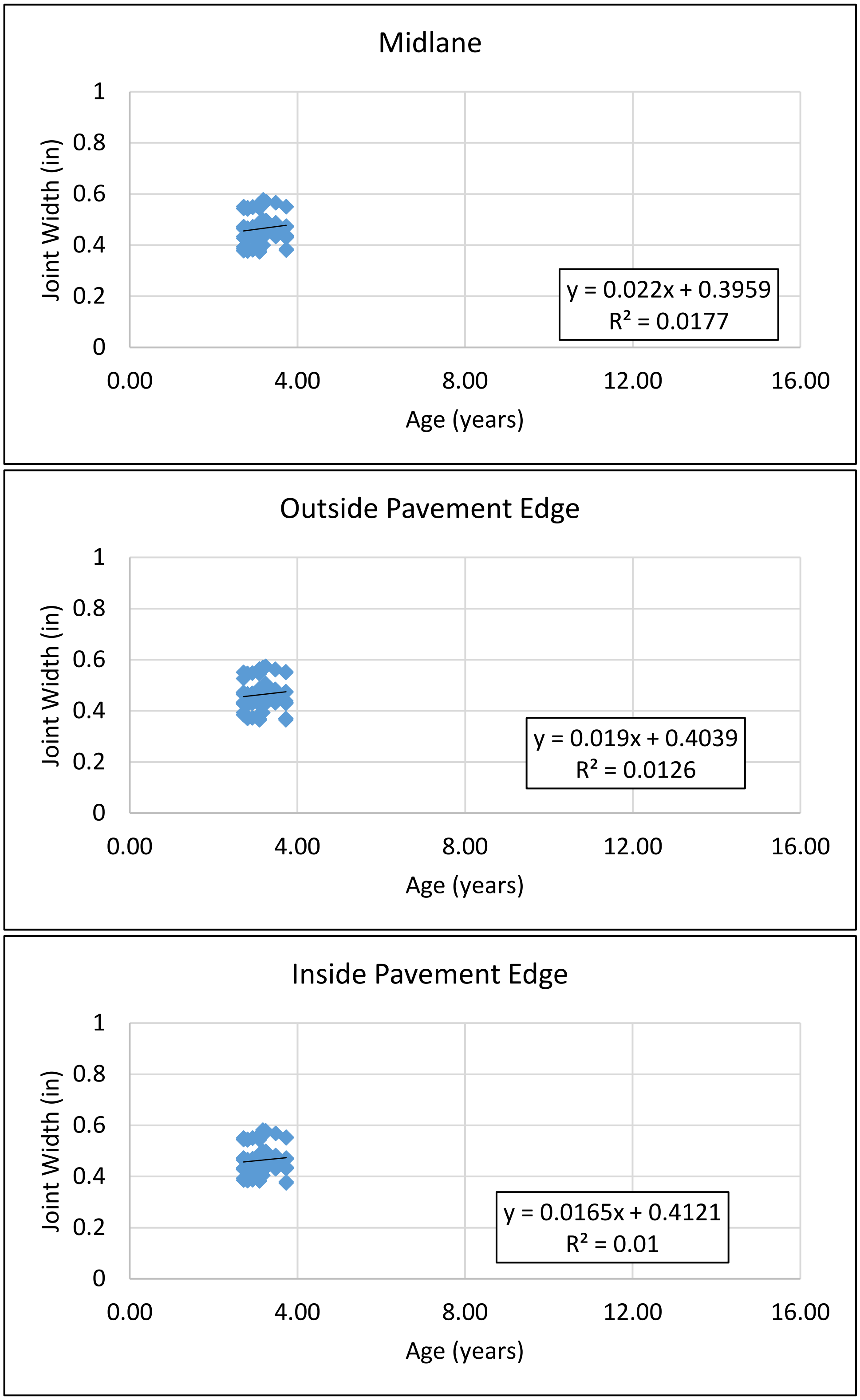


Figure 28. Linear Regression of Joint Widths Against Time for Six Joints Measured on 390204.

8.0 SUMMARY AND CONCLUSIONS

The analyses reported in this document were intended to:

- Compare measured joint movements to those predicted for the four SMP SPS-2 sections.
- Compare predicted joint movements for all SPS-2 sections to the LTE, faulting, and roughness performance of all SPS-2 sections, utilizing data from the LTPP database
- Compare measured and predicted joint movements of the four SMP SPS-2 sections to changes in measured concrete pavement temperature.
- Compare joint widths over time and compare joint widths to LTE for three of the SMP SPS-2 sections.

The following are highlights of the study:

- Predicted joint movement values were similar to the measured average joint movement values from two of the four SMP SPS-2 sections. The predicted joint movement values from one of the remaining SMP SPS-2 sections was higher than those measured whereas those for the other section were lower than the measured values.
- The joint movement estimator tool has limits on the cementitious materials amount (400 to 700 pounds per cubic yards), coefficient of thermal expansion (4 to $8*10^{-6}$/°F), and joint spacing (3 to 20 feet). Approximately one-half of the SPS-2 sections had one value that was outside the allowable range for these inputs.
- There was no statistically significant difference in predicted joint movement values for SPS-2 sections in dry climates compared to sections in wet climates, nor was there a statistically significant difference in predicted joint movement values for SPS-2 sections in freeze climates compared to sections in no-freeze climates.
- When separated into the four LTPP climate types, the dry-freeze and dry-no-freeze groups had very few sections and did not show any difference in predicted joint movement values. The wet-freeze group had higher joint movement values compared to the wet-no-freeze group.
- The measured average daily joint movement values from the four SMP SPS-2 sections did not correlate with changes in the average daily LTE, faulting, or pavement roughness values.
- The average daily joint movement values from the four SMP SPS-2 sections showed a negative correlation with change in daily PCC temperature during testing. However, this correlation was only statistically significant for one section: Ohio (390204).
- There was no correlation between predicted joint movement values and LTE, faulting, or pavement roughness values for all SPS-2 sections.
- Comparisons between predicted joint movement values and lifetime changes in LTE, faulting, and pavement roughness values for all SPS-2 sections showed there was no correlation.
- Joint gage measurements were converted to joint widths for three of the four SMP SPS-2 section (Arizona [040215], Nevada [320204], and Ohio [390204].
    - LTE values did not appear to be influenced by joint width.
    - Occasionally, some joints at 040215 would narrow as other joints became wider.
    - Joints on sections 040215 and 390204 did not appear to perform uniformly. Joint widths were not uniform across the six joints measured and some joints widened over time while others narrowed over time.

- Some joints had relatively constant joint widths over time, suggesting that either most of the joint movement occurred before joint gage measurements were conducted, or the joints possibly never activated. Joints were not checked for activation during construction by LTPP project staff.
- Joints on section 320204 appeared to narrow over time, though this could be caused by the small sample size of joint width measurements performed or possibly due to materials-related distress in the PCC that resulted in the section being removed from the study.

The current models to estimate average joint movement for sealant selection may not be appropriate. Measurement of actual joint openings over time reveals a lack of uniformity. Within a given section, it has been observed that some joints will widen more than the average value, whereas other joints experience little movement, or even narrow. Using a model that predicts average joint movement can result in underpredicting movement in certain joints, resulting in significant sealant elongation that is not accounted for in design and material selection. This could result in early sealant failure at these joints.

Appendix A

SUMMARY OF INPUTS USED IN THE ACPA JOINT MOVEMENT ESTIMATOR TOOL FOR EACH SPS-2 SECTION

Table A.1. Summary of inputs for ACPA tool, for all SPS-2 Sections.

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE (10^{-6})[2]	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
4	040213	Phoenix	Type II	500	4.44	7.9	15	9	Membrane Curing Compound
4	040214	Phoenix	Type II	959	4.44	8.3	15	9	Membrane Curing Compound
4	040215	Phoenix	Type II	500	4.50	11	15	9	Membrane Curing Compound
4	040216	Phoenix	Type II	799	4.42	11.2	15	9	Membrane Curing Compound
4	040217	Phoenix	Type II	500	4.44	8.1	15	9	Membrane Curing Compound
4	040218	Phoenix	Type II	959	4.44	8.3	15	9	Membrane Curing Compound
4	040219	Phoenix	Type II	500	4.44	10.8	15	9	Membrane Curing Compound
4	040220	Phoenix	Type II	799	4.44	11.2	15	9	Membrane Curing Compound
4	040221	Phoenix	Type II	500	4.44	8.1	15	9	Membrane Curing Compound
4	040222	Phoenix	Type II	799	4.44	8.6	15	9	Membrane Curing Compound
4	040223	Phoenix	Type II	500	4.44	11.1	15	9	Membrane Curing Compound
4	040224	Phoenix	Type II	799	4.44	10.6	15	9	Membrane Curing Compound

[2] Highlighted CTE values indicate CTE testing not performed for this section, and CTE value was assumed for input in the ACPA joint movement tool.

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
4	040262	Phoenix	Type II	400	4.44	8.1	13.5	9	Membrane Curing Compound
4	040263	Phoenix	Type II	500	4.44	8.2	13.5	9	Membrane Curing Compound
4	040264	Phoenix	Type II	500	4.50	11.5	13.5	9	Membrane Curing Compound
4	040265	Phoenix	Type II	500	4.42	10.8	13.5	9	Membrane Curing Compound
4	040266	Phoenix	Type II	500	4.44	12.3	15	9	Membrane Curing Compound
4	040267	Phoenix	Type II	500	4.44	11.3	15	9	Membrane Curing Compound
4	040268	Phoenix	Type II	500	4.44	8.5	15	9	Membrane Curing Compound
5	050213	Little Rock	Type I	380	5.08	7.4	15	10	Membrane Curing Compound
5	050214	Little Rock	Type I	827	5.49	8.4	15	10	Membrane Curing Compound
5	050215	Little Rock	Type I	380	5.00	11.5	15	10	Membrane Curing Compound
5	050216	Little Rock	Type I	827	5.28	11	15	10	Membrane Curing Compound
5	050217	Little Rock	Type I	380	5.28	8.3	15	10	Membrane Curing Compound
5	050218	Little Rock	Type I	827	5.28	8.2	15	10	Membrane Curing Compound
5	050219	Little Rock	Type I	380	5.30	11.1	15	10	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
5	050220	Little Rock	Type I	827	5.44	10.7	15	10	Membrane Curing Compound
5	050221	Little Rock	Type I	380	5.28	8.3	15	10	Membrane Curing Compound
5	050222	Little Rock	Type I	827	5.47	8.3	15	10	Membrane Curing Compound
5	050223	Little Rock	Type I	380	5.28	10.9	15	10	Membrane Curing Compound
5	050224	Little Rock	Type I	827	5.28	10.9	15	10	Membrane Curing Compound
6	060201	Fresno	Type II	470	5.00	8.3	15	4	Membrane Curing Compound
6	060202	Fresno	Type II	799	5.00	8	15	4	Membrane Curing Compound
6	060203	Fresno	Type II	470	5.00	11.4	15	9	Membrane Curing Compound
6	060204	Fresno	Type II	799	4.93	11.1	15	4	Membrane Curing Compound
6	060205	Fresno	Type II	470	5.00	8.2	15	4	Membrane Curing Compound
6	060206	Fresno	Type II	799	5.00	8	15	4	Membrane Curing Compound
6	060207	Fresno	Type II	470	5.06	11	15	4	Membrane Curing Compound
6	060208	Fresno	Type II	799	5.00	10.7	15	4	Membrane Curing Compound
6	060209	Fresno	Type II	470	5.00	8.4	15	4	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
6	060210	Fresno	Type II	799	5.00	8.6	15	4	Membrane Curing Compound
6	060211	Fresno	Type II	470	5.00	12.1	15	9	Wet Burlap
6	060212	Fresno	Type II	799	5.00	11.1	15	4	Membrane Curing Compound
8	080213	Denver	Type I/II	499	4.72	8.6	15	10	Membrane Curing Compound
8	080214	Denver	Type I/II	899	4.72	8.4	15	10	Membrane Curing Compound
8	080215	Denver	Type I/II	499	4.72	11.5	15	10	Membrane Curing Compound
8	080216	Denver	Type I/II	899	4.72	11.9	15	10	Membrane Curing Compound
8	080217	Denver	Type I/II	499	4.67	8.6	15	9	Membrane Curing Compound
8	080218	Denver	Type I/II	899	4.81	7.6	15	10	Membrane Curing Compound
8	080219	Denver	Type I/II	499	4.72	9.9	15	10	Membrane Curing Compound
8	080220	Denver	Type I/II	899	4.72	11.2	15	9	Membrane Curing Compound
8	080221	Denver	Type I/II	499	4.72	8.3	15	9	Membrane Curing Compound
8	080222	Denver	Type I/II	899	4.72	8.5	15	9	Membrane Curing Compound
8	080223	Denver	Type I/II	499	4.72	11.7	15	9	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
8	080224	Denver	Type I/II	899	4.72	11.6	15	9	Membrane Curing Compound
8	080259	Denver	Type I/II	678	4.72	11.9	15	7	Membrane Curing Compound
10	100201	Wilmington	Type I	564	4.72	8.3	15	10	Membrane Curing Compound
10	100202	Wilmington	Type I	736	4.72	8.8	15	11	Membrane Curing Compound
10	100203	Wilmington	Type I	564	4.72	11.7	15	6	Membrane Curing Compound
10	100204	Wilmington	Type I	735	4.72	11	15	7	Membrane Curing Compound
10	100205	Wilmington	Type I	564	5.61	9.2	15	10	Membrane Curing Compound
10	100206	Wilmington	Type I	735	4.72	8.9	15	11	Membrane Curing Compound
10	100207	Wilmington	Type I	564	4.72	11.3	15	6	Membrane Curing Compound
10	100208	Wilmington	Type I	735	4.28	12.1	15	7	Membrane Curing Compound
10	100209	Wilmington	Type I	564	4.72	8.2	15	10	Membrane Curing Compound
10	100210	Wilmington	Type I	611	4.72	8.3	15	6	Membrane Curing Compound
10	100211	Wilmington	Type I	564	4.25	11.8	15	6	Membrane Curing Compound
10	100212	Wilmington	Type I	735	4.72	12.4	15	7	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
10	100259	Wilmington	Type I	564	5.17	10.2	15	7	Membrane Curing Compound
10	100260	Wilmington	Type I	564	4.50	10.2	15	6	Membrane Curing Compound
19	190213	Des Moines	Type I	400	4.28	8.7	15	7	Membrane Curing Compound
19	190214	Des Moines	Type I	850	4.28	8.4	15	7	Membrane Curing Compound
19	190215	Des Moines	Type I	400	4.31	11.7	15	7	Membrane Curing Compound
19	190216	Des Moines	Type I	850	4.28	11.6	15	7	Membrane Curing Compound
19	190217	Des Moines	Type I	400	3.89	7.8	15	7	Membrane Curing Compound
19	190218	Des Moines	Type I	850	4.28	8.3	15	7	Membrane Curing Compound
19	190219	Des Moines	Type I	400	4.43	11.3	15	7	Membrane Curing Compound
19	190220	Des Moines	Type I	850	4.59	11.4	15	7	Membrane Curing Compound
19	190221	Des Moines	Type I	400	4.28	9	15	7	Membrane Curing Compound
19	190222	Des Moines	Type I	850	4.28	8.3	15	7	Membrane Curing Compound
19	190223	Des Moines	Type I	400	4.28	12	15	7	Membrane Curing Compound
19	190224	Des Moines	Type I	850	4.28	11	15	7	Wet Burlap

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
20	200201	Topeka	Type II	532	4.95	7.7	15	7	Membrane Curing Compound
20	200202	Topeka	Type II	862	4.95	7.5	15	7	Membrane Curing Compound
20	200203	Topeka	Type II	532	4.95	11.2	15	7	Membrane Curing Compound
20	200204	Topeka	Type II	862	4.95	11.3	15	7	Membrane Curing Compound
20	200205	Topeka	Type II	532	4.95	7.3	15	7	Membrane Curing Compound
20	200206	Topeka	Type II	862	4.95	7.7	15	7	Membrane Curing Compound
20	200207	Topeka	Type II	532	4.95	10.9	15	7	Membrane Curing Compound
20	200208	Topeka	Type II	862	4.95	10.9	15	7	Membrane Curing Compound
20	200209	Topeka	Type II	532	4.95	8.4	15	7	Membrane Curing Compound
20	200210	Topeka	Type II	862	4.95	8.5	15	7	Membrane Curing Compound
20	200211	Topeka	Type II	532	4.95	11.2	15	7	Membrane Curing Compound
20	200212	Topeka	Type II	862	4.95	11.1	15	7	Membrane Curing Compound
20	200259	Topeka	Type II	620	4.95	11.9	27	7	Membrane Curing Compound
26	260213	Detroit	Type I	376	4.48	8.3	15	9	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
26	260214	Detroit	Type I	750	4.48	8.8	15	9	Membrane Curing Compound
26	260215	Detroit	Type I	376	4.48	11.1	15	9	Membrane Curing Compound
26	260216	Detroit	Type I	750	5.33	11.3	15	9	Membrane Curing Compound
26	260217	Detroit	Type II	376	4.48	8.4	15	9	Membrane Curing Compound
26	260218	Detroit	Type I	750	4.06	7.3	15	9	Membrane Curing Compound
26	260219	Detroit	Type I	376	3.45	11.3	15	9	Membrane Curing Compound
26	260220	Detroit	Type I	750	5.11	11.2	15	9	Membrane Curing Compound
26	260221	Detroit	Type I	376	4.94	8.1	15	9	Membrane Curing Compound
26	260222	Detroit	Type I	750	4.00	8.3	15	9	Membrane Curing Compound
26	260223	Detroit	Type I	376	4.48	11	15	9	Membrane Curing Compound
26	260224	Detroit	Type I	750	4.48	11.1	15	9	Membrane Curing Compound
26	260259	Detroit	Type I	564	4.48	11.3	15	8	Membrane Curing Compound
32	320201	Elko	Type I	423	4.70	9.2	15	7	Membrane Curing Compound
32	320202	Elko	Type I	846	4.70	8.2	15	7	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
32	320203	Elko	Type I	423	4.70	11.9	15	7	Membrane Curing Compound
32	320204	Elko	Type I	846	4.70	11.8	15	7	Membrane Curing Compound
32	320205	Elko	Type I	423	4.70	8.5	15	7	Membrane Curing Compound
32	320206	Elko	Type I	846	4.70	7.8	15	7	Membrane Curing Compound
32	320207	Elko	Type I	423	4.70	10.9	15	7	Membrane Curing Compound
32	320208	Elko	Type I	846	4.70	11	15	7	Membrane Curing Compound
32	320209	Elko	Type I	423	4.70	8.9	15	7	Membrane Curing Compound
32	320210	Elko	Type I	846	4.70	10.1	15	7	Membrane Curing Compound
32	320211	Elko	Type I	423	4.70	11.3	15	7	Membrane Curing Compound
32	320259	Elko	Type I	611	4.70	10.8	15	7	Membrane Curing Compound
37	370201	Greensboro	Type I	429	4.47	9.2	15	11	Membrane Curing Compound
37	370202	Greensboro	Type I	787	4.47	8.9	15	11	Membrane Curing Compound
37	370203	Greensboro	Type I	429	4.06	11.9	15	11	Membrane Curing Compound
37	370204	Greensboro	Type I	787	5.78	11.6	15	11	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
37	370205	Greensboro	Type I	429	4.06	8	15	11	Membrane Curing Compound
37	370206	Greensboro	Type I	787	4.47	8.4	15	11	Membrane Curing Compound
37	370207	Greensboro	Type I	429	4.42	11.7	15	11	Membrane Curing Compound
37	370208	Greensboro	Type I	787	5.17	11.2	15	11	Membrane Curing Compound
37	370209	Greensboro	Type I	429	4.47	8.6	15	11	Membrane Curing Compound
37	370210	Greensboro	Type I	787	4.47	9.1	15	11	Membrane Curing Compound
37	370211	Greensboro	Type I	429	4.47	11.5	15	11	Membrane Curing Compound
37	370212	Greensboro	Type I	787	4.47	11.2	15	11	Membrane Curing Compound
37	370259	Greensboro	Type I	502	4.47	10.8	15.1	10	Membrane Curing Compound
37	370260	Greensboro	Type I	429	4.47	11.6	15	11	Membrane Curing Compound
38	380213	Fargo	Type I	376	5.28	8.1	15	10	Membrane Curing Compound
38	380214	Fargo	Type I	776	5.28	8	15	10	Membrane Curing Compound
38	380215	Fargo	Type I	376	5.28	11	15	10	Membrane Curing Compound
38	380216	Fargo	Type I	776	5.28	11.1	15	10	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
38	380217	Fargo	Type I	376	5.28	7.9	15	10	Membrane Curing Compound
38	380218	Fargo	Type I	776	5.28	7.9	15	10	Membrane Curing Compound
38	380219	Fargo	Type I	376	5.28	10.9	15	10	Membrane Curing Compound
38	380220	Fargo	Type I	776	5.28	11	15	10	Membrane Curing Compound
38	380221	Fargo	Type I	376	5.28	8	15	10	Membrane Curing Compound
38	380222	Fargo	Type I	776	5.28	8.1	15	9	Membrane Curing Compound
38	380223	Fargo	Type I	376	5.28	11.1	15	9	Membrane Curing Compound
38	380224	Fargo	Type I	776	5.28	10.9	15	10	Membrane Curing Compound
38	380259	Fargo	Type I	592	5.28	9.7	15	9	Membrane Curing Compound
38	380260	Fargo	Type I	592	5.28	11	15	10	Membrane Curing Compound
38	380261	Fargo	Type I	376	5.28	11	15	10	Membrane Curing Compound
38	380262	Fargo	Type I	376	5.28	11.1	15	10	Membrane Curing Compound
38	380263	Fargo	Type I	376	5.28	11	15	9	Membrane Curing Compound
38	380264	Fargo	Type I	592	5.28	11	15	10	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
39	390201	Columbus	Type I	602	4.94	7.9	15	10	Membrane Curing Compound
39	390202	Columbus	Type I	863	4.94	8.3	15	9	Membrane Curing Compound
39	390203	Columbus	Type I	602	4.94	11.2	15	10	Membrane Curing Compound
39	390204	Columbus	Type I	863	4.94	11.1	15	8	Membrane Curing Compound
39	390205	Columbus	Type I	602	5.17	8	15	9	Membrane Curing Compound
39	390206	Columbus	Type I	863	5.13	7.9	15	9	Membrane Curing Compound
39	390207	Columbus	Type I	602	4.75	11.2	15	10	Membrane Curing Compound
39	390208	Columbus	Type I	863	4.78	11.1	15	11	Membrane Curing Compound
39	390209	Columbus	Type I	602	4.94	8.3	15	10	Membrane Curing Compound
39	390210	Columbus	Type I	863	4.94	8	15	9	Membrane Curing Compound
39	390211	Columbus	Type I	602	4.94	11.3	15	10	Membrane Curing Compound
39	390212	Columbus	Type I	863	4.94	10.8	15	9	Membrane Curing Compound
39	390259	Columbus	Type I	863	4.94	10.9	15	8	Membrane Curing Compound
39	390260	Columbus	Type I	602	4.94	11.6	15	10	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
39	390261	Columbus	Type I	602	4.94	11.1	15	10	Membrane Curing Compound
39	390262	Columbus	Type I	602	4.94	11.5	15	10	Membrane Curing Compound
39	390263	Columbus	Type I	602	4.94	11.1	15	10	Membrane Curing Compound
39	390265	Columbus	Type I	602	4.94	11.2	15	9	Membrane Curing Compound
53	530201	Spokane	Type II	465	4.33	8.7	15	9	Membrane Curing Compound
53	530202	Spokane	Type II	925	4.33	8.3	15	9	Membrane Curing Compound
53	530203	Spokane	Type II	465	4.33	11.1	15	9	Membrane Curing Compound
53	530204	Spokane	Type II	925	4.33	11.2	15	9	Membrane Curing Compound
53	530205	Spokane	Type II	465	4.33	8.5	15	9	Membrane Curing Compound
53	530206	Spokane	Type II	925	4.33	8.6	15	9	Membrane Curing Compound
53	530207	Spokane	Type II	423	4.33	11.1	15	9	Membrane Curing Compound
53	530208	Spokane	Type II	925	4.33	11.2	15	9	Membrane Curing Compound
53	530209	Spokane	Type II	423	4.33	9	15	9	Membrane Curing Compound
53	530210	Spokane	Type II	925	4.33	8.3	15	9	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
53	530211	Spokane	Type II	465	4.33	11.8	15	9	Membrane Curing Compound
53	530212	Spokane	Type II	925	4.33	11.3	15	9	Membrane Curing Compound
53	530259	Spokane	Type II	541	4.33	10.3	15	10	Membrane Curing Compound
55	550213	Green Bay	Type II	565	4.44	8.5	15	9	Membrane Curing Compound
55	550214	Green Bay	Type II	650	4.44	8.8	15	9	Membrane Curing Compound
55	550215	Green Bay	Type II	565	4.44	11.5	15	8	Membrane Curing Compound
55	550216	Green Bay	Type II	650	4.44	11.1	15	9	Membrane Curing Compound
55	550217	Green Bay	Type II	565	4.44	8.5	15	9	Membrane Curing Compound
55	550218	Green Bay	Type II	650	4.44	8.5	15	9	Membrane Curing Compound
55	550219	Green Bay	Type II	565	4.44	11.6	15	8	Membrane Curing Compound
55	550220	Green Bay	Type II	650	4.44	11.4	15	9	Membrane Curing Compound
55	550221	Green Bay	Type II	565	4.44	8.4	15	9	Membrane Curing Compound
55	550222	Green Bay	Type II	650	4.06	8.8	15	9	Membrane Curing Compound
55	550223	Green Bay	Type II	565	4.61	11.6	15	9	Membrane Curing Compound

State Code	SHRP ID	City	Cement Type	Cementitious Materials Content (lb/cy)	CTE $(10^{-6})^2$	PCC Thickness (in)	Joint Spacing (ft)	Month of Construction	Curing Method
55	550224	Green Bay	Type II	650	4.44	11.7	15	9	Membrane Curing Compound
55	550259	Green Bay	Type II	565	4.44	11.5	18	8	Membrane Curing Compound
55	550260	Green Bay	Type II	565	4.67	11.3	18	8	Membrane Curing Compound
55	550261	Green Bay	Type II	565	4.44	9.4	15	9	Membrane Curing Compound
55	550262	Green Bay	Type II	650	4.44	8.7	15	9	Membrane Curing Compound
55	550263	Green Bay	Type II	565	4.44	10.4	18	8	Membrane Curing Compound
55	550264	Green Bay	Type II	565	4.44	11	18	10	Membrane Curing Compound
55	550265	Green Bay	Type II	565	4.44	11.1	18	10	Membrane Curing Compound
55	550266	Green Bay	Type II	565	4.44	11	18.1	10	Membrane Curing Compound

Appendix B

PREDICTED JOINT MOVEMENT VALUES FOR ALL SPS-2 SECTIONS

Table B.1. Predicted joint movement values for all SPS-2 Sections.

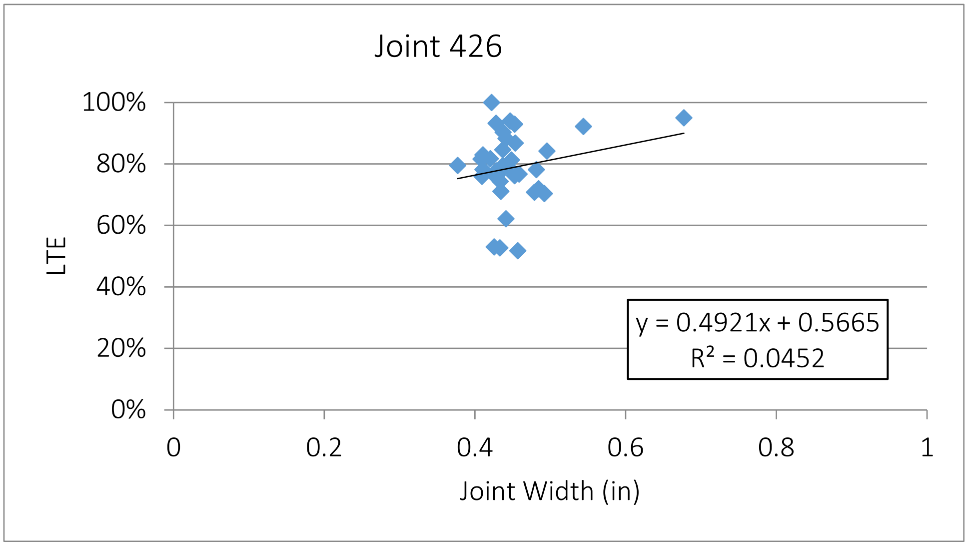
State Code	SHRP ID	Predicted Strain (microstrain)	Predicted Joint Movement (in.)		State Code	SHRP ID	Predicted Strain (microstrain)	Predicted Joint Movement (in.)
4	040213	790	0.142		6	060206	658	0.118
4	040214	884	0.159		6	060207	548	0.099
4	040215	758	0.137		6	060208	638	0.115
4	040216	852	0.153		6	060209	565	0.102
4	040217	787	0.142		6	060210	652	0.117
4	040218	884	0.159		6	060211	647	0.116
4	040219	760	0.137		6	060212	636	0.114
4	040220	856	0.154		8	080213	645	0.116
4	040221	787	0.142		8	080214	712	0.128
4	040222	880	0.158		8	080215	621	0.112
4	040223	758	0.136		8	080216	684	0.123
4	040224	860	0.155		8	080217	765	0.138
4	040262	738	0.120		8	080218	722	0.130
4	040263	786	0.127		8	080219	632	0.114
4	040264	755	0.122		8	080220	822	0.148
4	040265	760	0.123		8	080221	768	0.138
4	040266	750	0.135		8	080222	845	0.152
4	040267	756	0.136		8	080223	740	0.133
4	040268	782	0.141		8	080224	820	0.148
5	050213	629	0.113		8	080259	833	0.168
5	050214	739	0.133		10	100201	682	0.123
5	050215	603	0.109		10	100202	601	0.108
5	050216	724	0.130		10	100203	835	0.150
5	050217	621	0.112		10	100204	953	0.171
5	050218	741	0.133		10	100205	675	0.121
5	050219	605	0.109		10	100206	600	0.108
5	050220	725	0.131		10	100207	837	0.151
5	050221	621	0.112		10	100208	922	0.166
5	050222	740	0.133		10	100209	683	0.123
5	050223	605	0.109		10	100210	877	0.158
5	050224	724	0.130		10	100211	810	0.146
6	060201	566	0.102		10	100212	946	0.170
6	060202	658	0.118		10	100259	895	0.161
6	060203	689	0.124		10	100260	843	0.152
6	060204	636	0.114		19	190213	883	0.159
6	060205	567	0.102		19	190214	1017	0.183

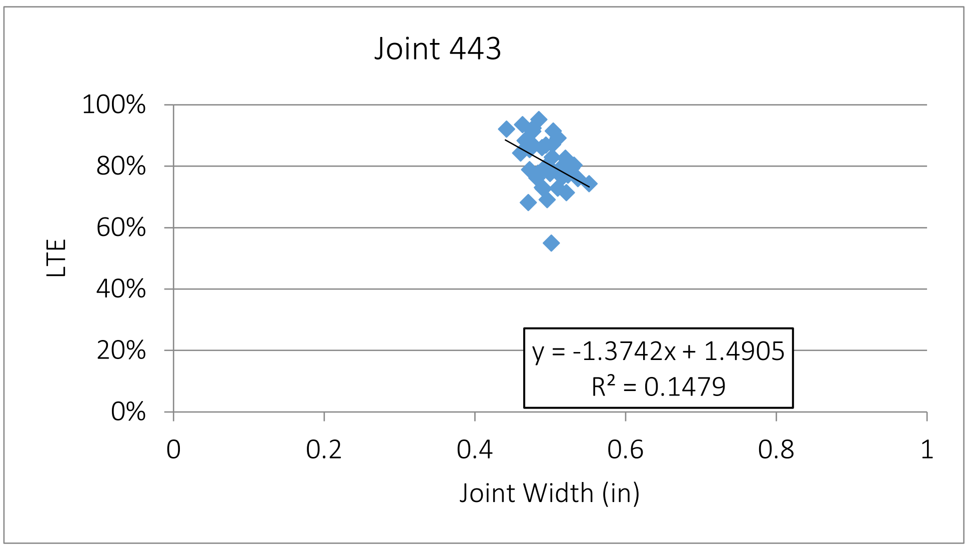
State Code	SHRP ID	Predicted Strain (microstrain)	Predicted Joint Movement (in.)		State Code	SHRP ID	Predicted Strain (microstrain)	Predicted Joint Movement (in.)
19	190220	1028	0.185		32	320211	811	0.146
19	190221	881	0.158		32	320259	894	0.161
19	190222	1017	0.183		37	370201	501	0.090
19	190223	865	0.156		37	370202	587	0.106
19	190224	958	0.172		37	370203	466	0.084
20	200201	895	0.161		37	370204	572	0.103
20	200202	974	0.175		37	370205	491	0.088
20	200203	876	0.158		37	370206	591	0.106
20	200204	954	0.172		37	370207	486	0.087
20	200205	898	0.162		37	370208	574	0.103
20	200206	971	0.175		37	370209	505	0.091
20	200207	878	0.158		37	370210	586	0.105
20	200208	956	0.172		37	370211	488	0.088
20	200209	890	0.160		37	370212	574	0.103
20	200210	967	0.174		37	370259	609	0.110
20	200211	876	0.158		37	370260	487	0.088
20	200212	955	0.172		38	380213	695	0.125
20	200259	915	0.220		38	380214	781	0.141
26	260213	763	0.137		38	380215	678	0.122
26	260214	879	0.158		38	380216	763	0.137
26	260215	745	0.134		38	380217	696	0.125
26	260216	865	0.156		38	380218	782	0.141
26	260217	720	0.130		38	380219	679	0.122
26	260218	840	0.151		38	380220	764	0.137
26	260219	637	0.115		38	380221	696	0.125
26	260220	865	0.156		38	380222	943	0.170
26	260221	764	0.138		38	380223	815	0.147
26	260222	823	0.148		38	380224	764	0.138
26	260223	746	0.134		38	380259	892	0.161
26	260224	866	0.156		38	380260	733	0.132
26	260259	896	0.161		38	380261	678	0.122
32	320201	827	0.149		38	380262	678	0.122
32	320202	956	0.172		38	380263	815	0.147
32	320203	807	0.145		38	380264	733	0.132
32	320204	926	0.167		39	390201	714	0.129
32	320205	835	0.150		39	390202	876	0.158
32	320206	961	0.173		39	390203	693	0.125

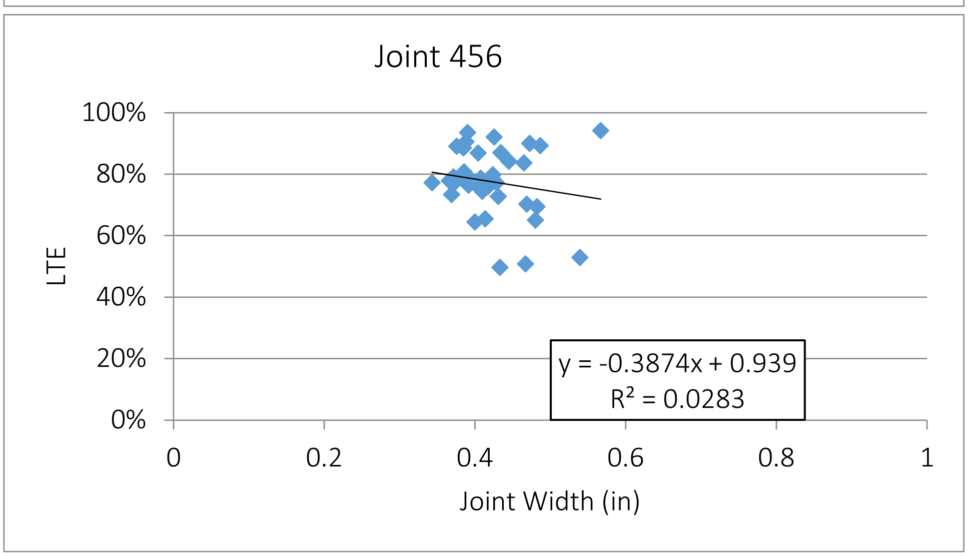
State Code	SHRP ID	Predicted Strain (microstrain)	Predicted Joint Movement (in.)		State Code	SHRP ID	Predicted Strain (microstrain)	Predicted Joint Movement (in.)
32	320207	813	0.146		39	390204	948	0.171
32	320208	931	0.168		39	390205	838	0.151
32	320209	830	0.149		39	390206	879	0.158
32	320210	937	0.169		39	390207	693	0.125
39	390208	589	0.106		53	530212	747	0.135
39	390209	711	0.128		53	530259	556	0.100
39	390210	878	0.158		55	550213	787	0.142
39	390211	692	0.125		55	550214	817	0.147
39	390212	859	0.155		55	550215	872	0.157
39	390259	949	0.171		55	550216	807	0.145
39	390260	691	0.124		55	550217	787	0.142
39	390261	693	0.125		55	550218	818	0.147
39	390262	691	0.124		55	550219	872	0.157
39	390263	693	0.125		55	550220	806	0.145
39	390265	817	0.147		55	550221	787	0.142
53	530201	674	0.121		55	550222	765	0.138
53	530202	765	0.138		55	550223	773	0.139
53	530203	661	0.119		55	550224	805	0.145
53	530204	748	0.135		55	550259	872	0.188
53	530205	676	0.122		55	550260	873	0.189
53	530206	763	0.137		55	550261	782	0.141
53	530207	645	0.116		55	550262	817	0.147
53	530208	748	0.135		55	550263	876	0.189
53	530209	656	0.118		55	550264	637	0.138
53	530210	765	0.138		55	550265	637	0.138
53	530211	658	0.118		55	550266	637	0.138

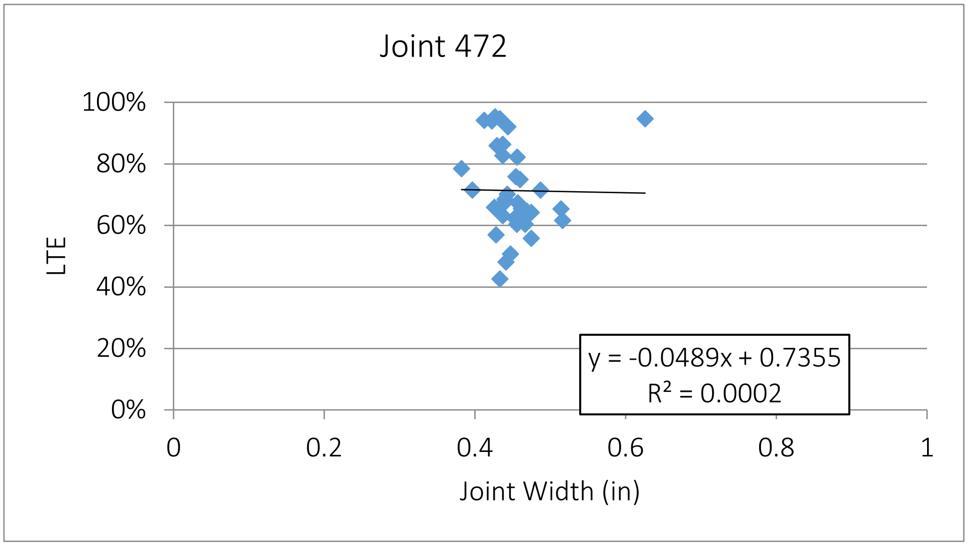
Appendix C

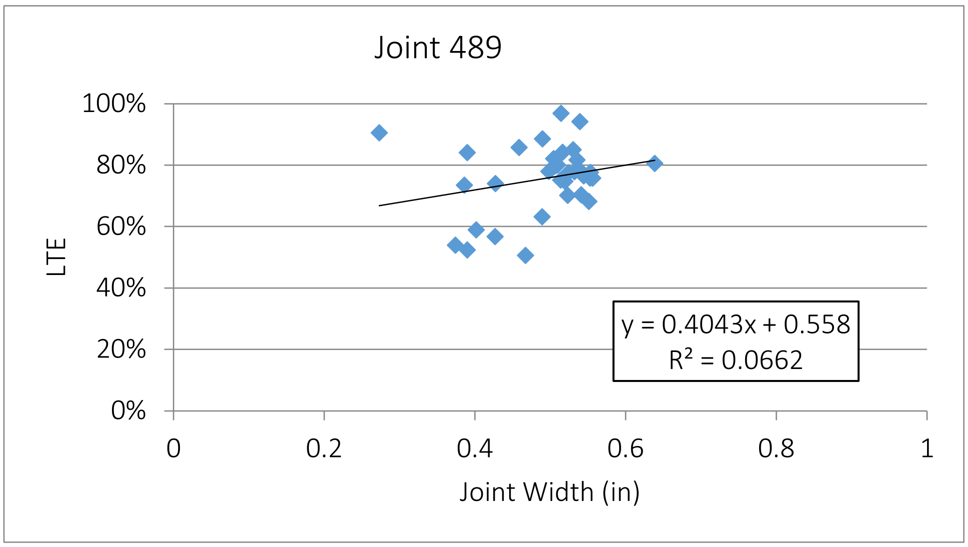
CHANGE IN JOINT WIDTHS FOR EACH JOINT MEASURED ON ARIZONA (040215) TEST SECTIONS

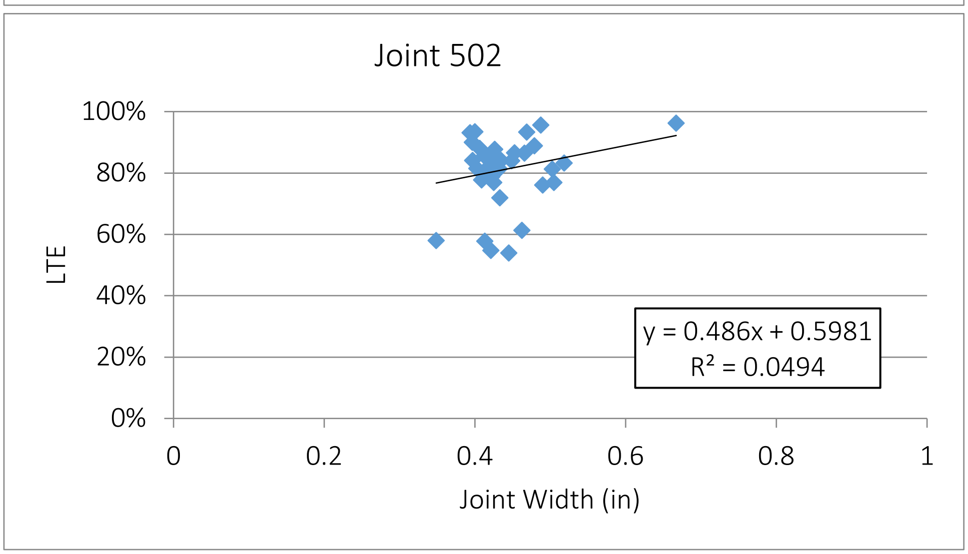

Joint 426
100%
80%
60%
40%
20%
0%
LTE
y = 0.4921x + 0.5665
R² = 0.0452
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

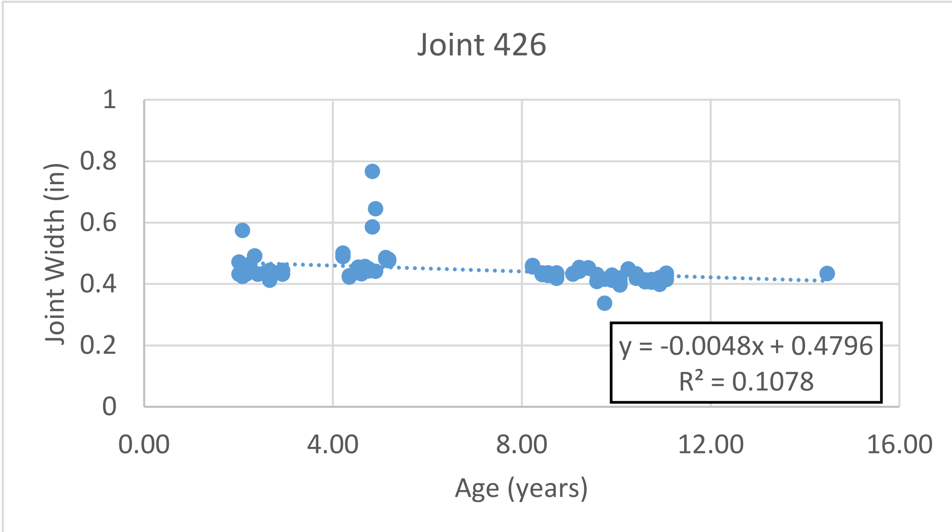

Joint 443
100%
80%
60%
40%
20%
0%
LTE
y = -1.3742x + 1.4905
R² = 0.1479
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

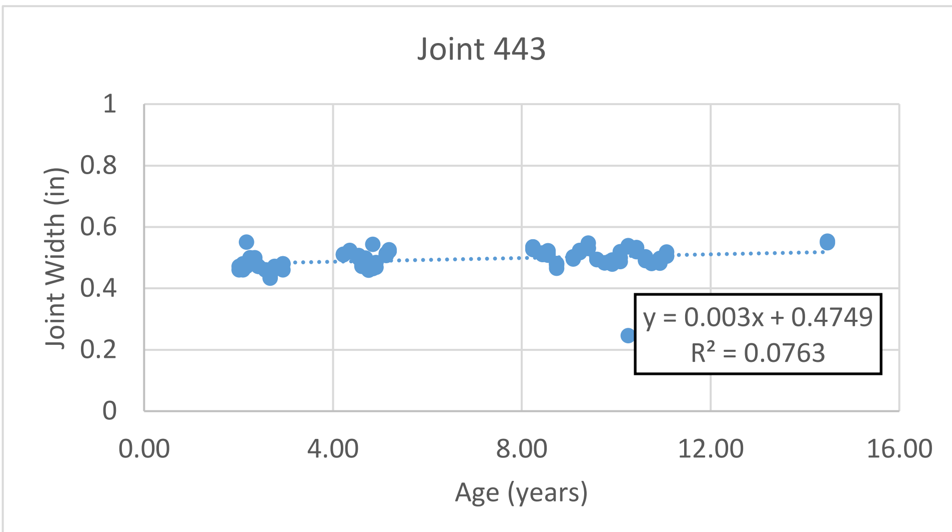

Joint 456
100%
80%
60%
40%
20%
0%
LTE
y = -0.3874x + 0.939
R² = 0.0283
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

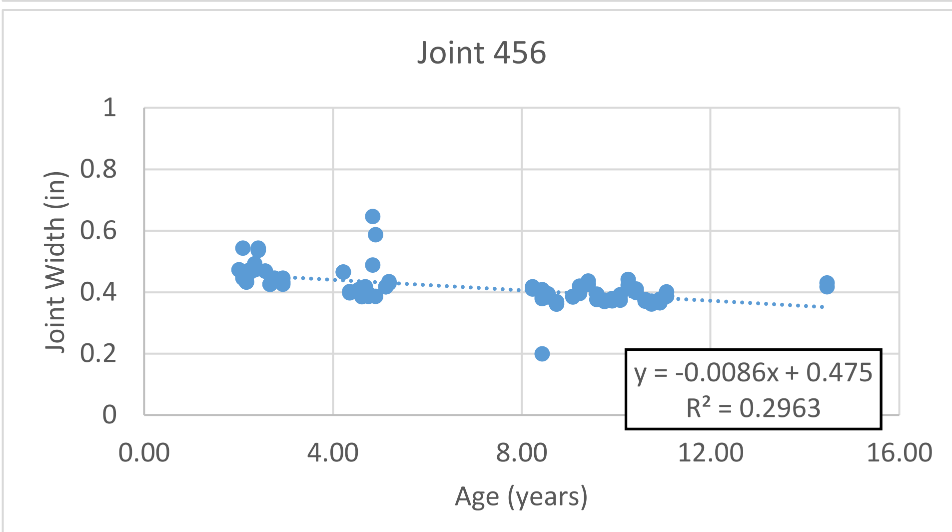

Joint 472
100%
80%
60%
40%
20%
0%
LTE
y = -0.0489x + 0.7355
R² = 0.0002
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

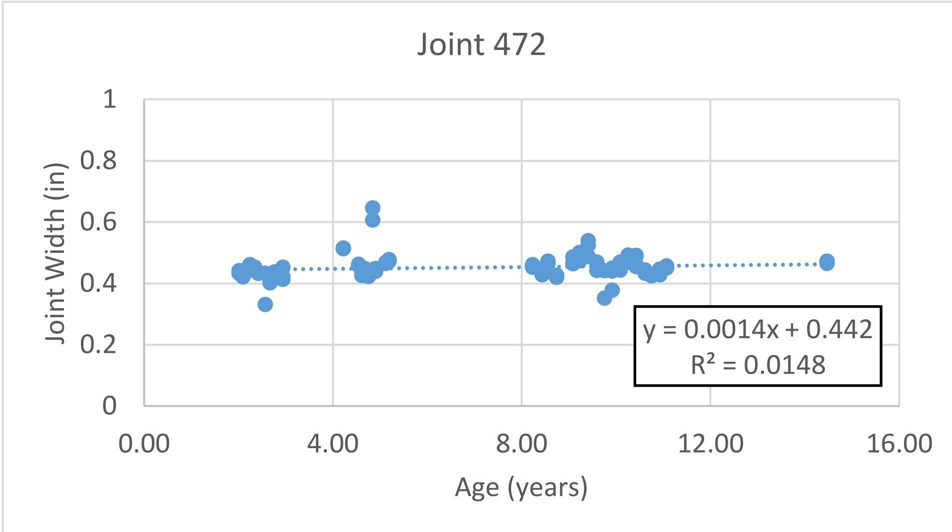

Joint 489
100%
80%
60%
40%
20%
0%
LTE
y = 0.4043x + 0.558
R² = 0.0662
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

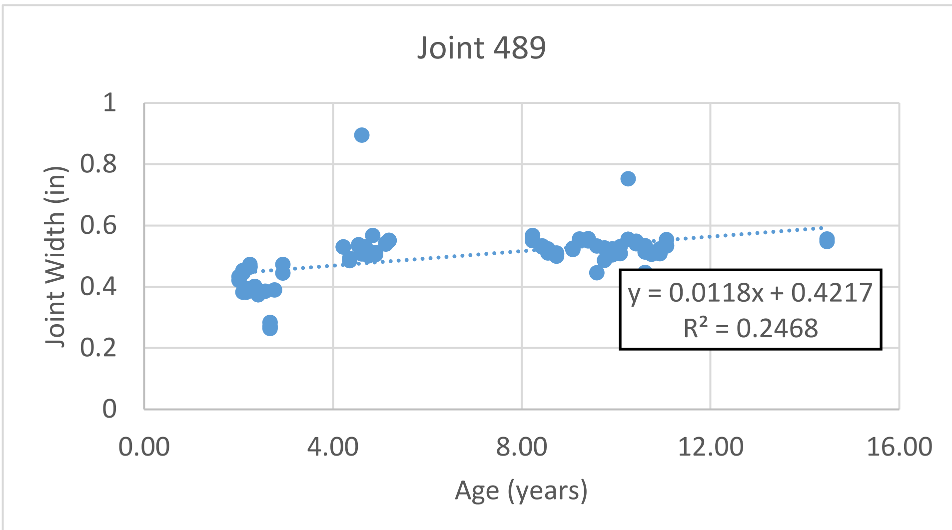

Joint 502
100%
80%
60%
40%
20%
0%
LTE
y = 0.486x + 0.5981
R² = 0.0494
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

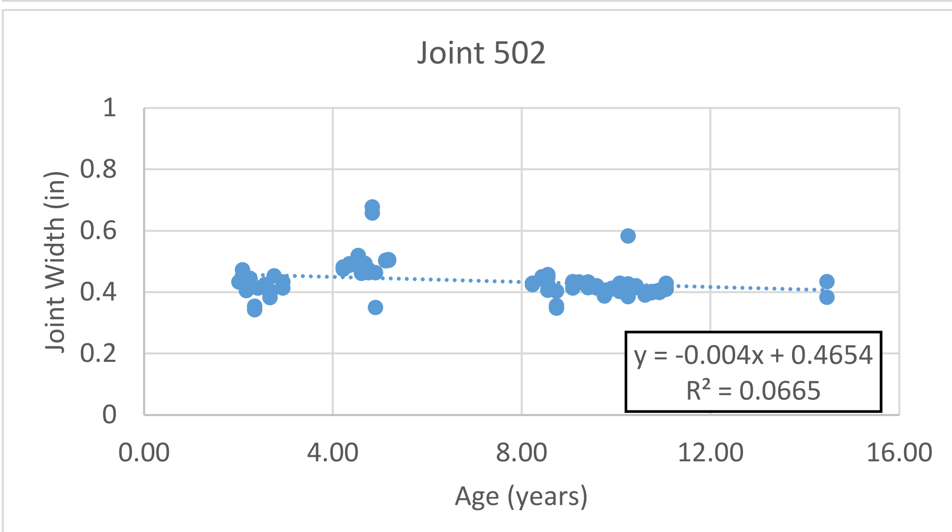

Joint 426
Joint Width (in)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Age (years)
y = -0.0048x + 0.4796
R² = 0.1078


Joint 443
Joint Width (in)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Age (years)
y = 0.003x + 0.4749
R² = 0.0763


Joint 456
Joint Width (in)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Age (years)
y = -0.0086x + 0.475
R² = 0.2963

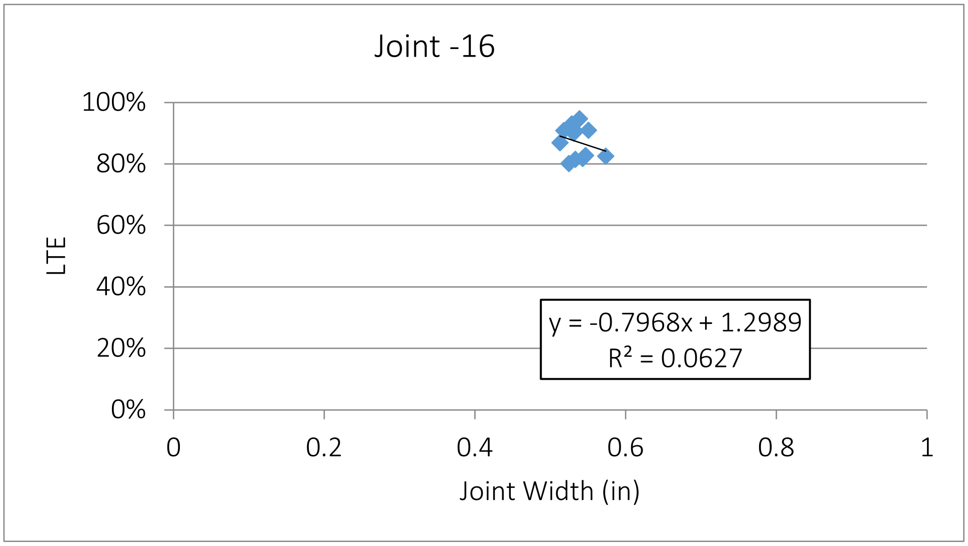

Joint 472
Joint Width (in)
Age (years)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
y = 0.0014x + 0.442
R² = 0.0148

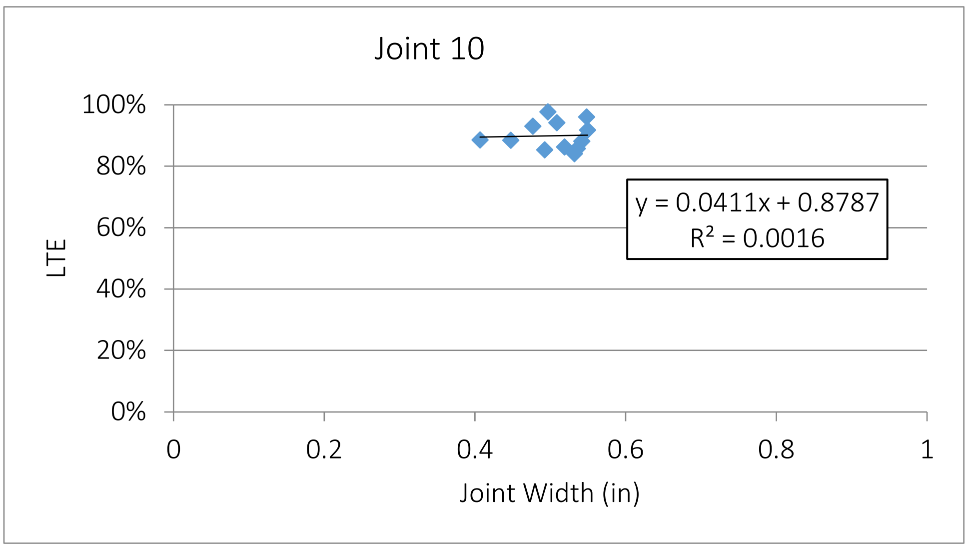

Joint 489
Joint Width (in)
Age (years)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
y = 0.0118x + 0.4217
R² = 0.2468

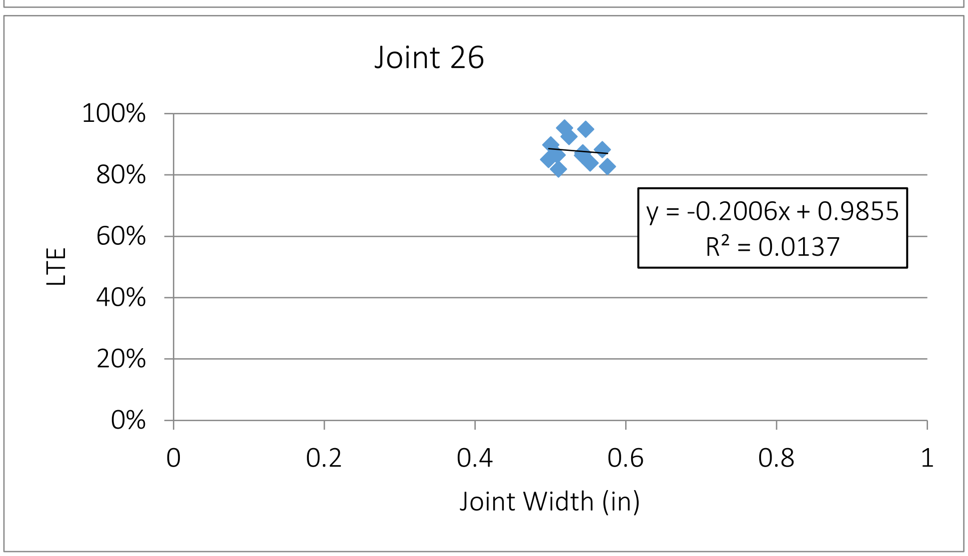

Joint 502
Joint Width (in)
Age (years)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
y = -0.004x + 0.4654
R² = 0.0665

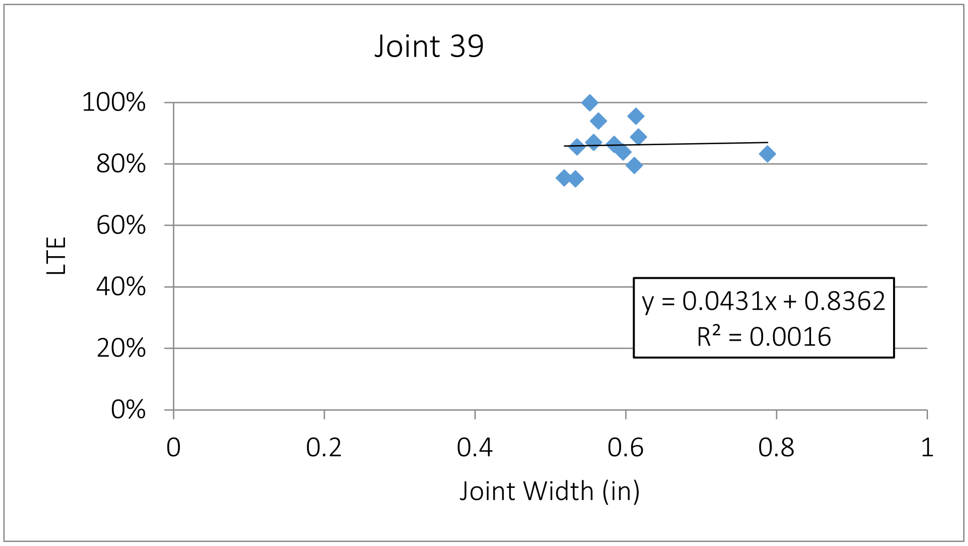
Appendix D

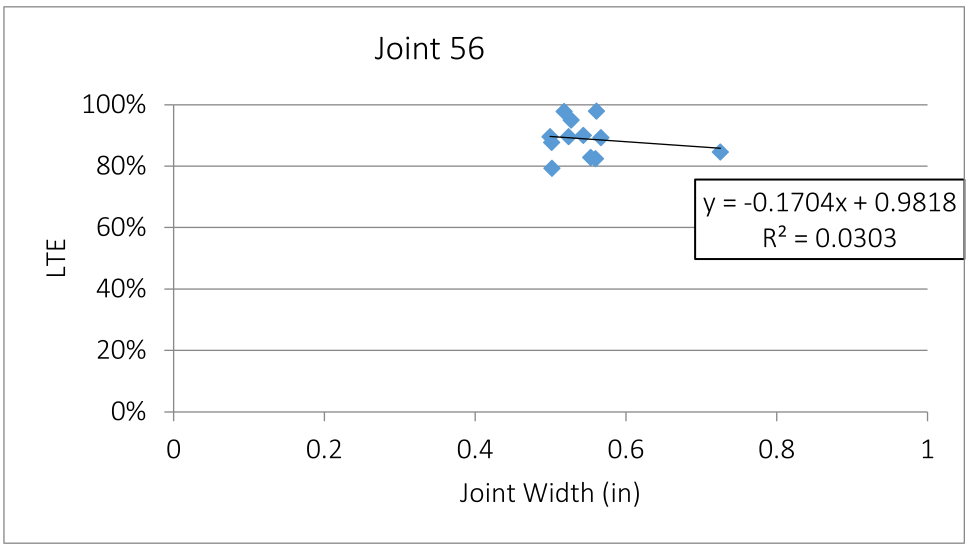
CHANGE IN JOINT WIDTHS FOR EACH JOINT MEASURED ON NEVADA (320204) TEST SECTIONS

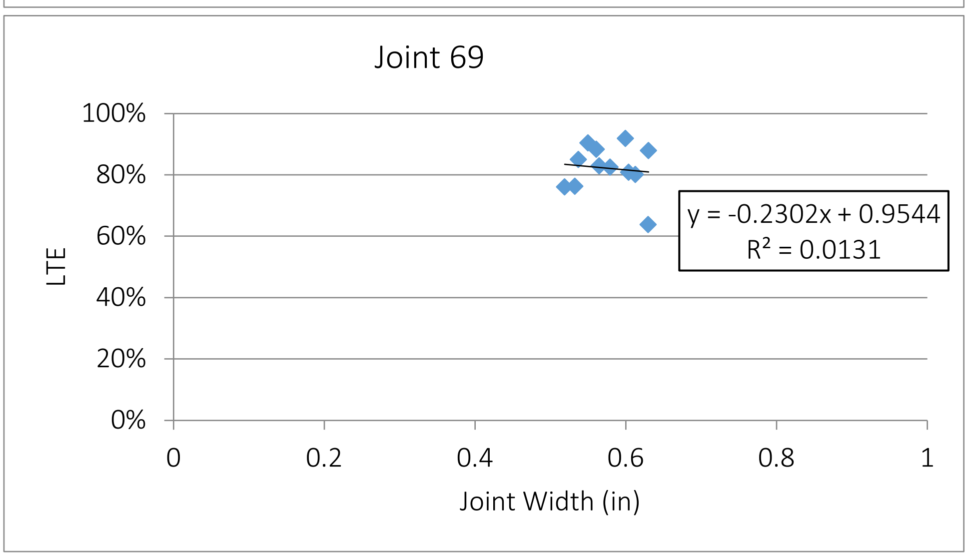

Joint -16
100%
80%
60%
40%
20%
0%
LTE
y = -0.7968x + 1.2989
R² = 0.0627
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

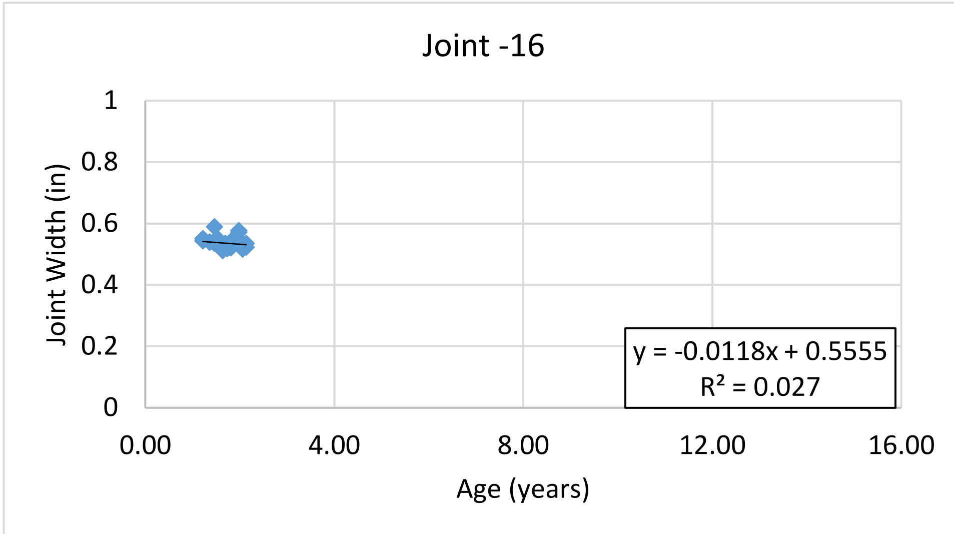

Joint 10
100%
80%
60%
40%
20%
0%
LTE
y = 0.0411x + 0.8787
R² = 0.0016
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

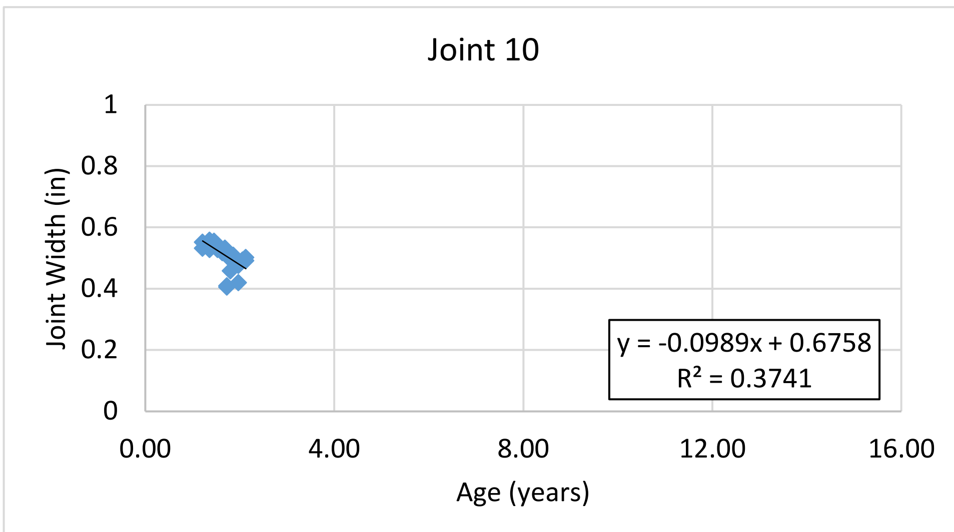

Joint 26
100%
80%
60%
40%
20%
0%
LTE
y = -0.2006x + 0.9855
R² = 0.0137
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

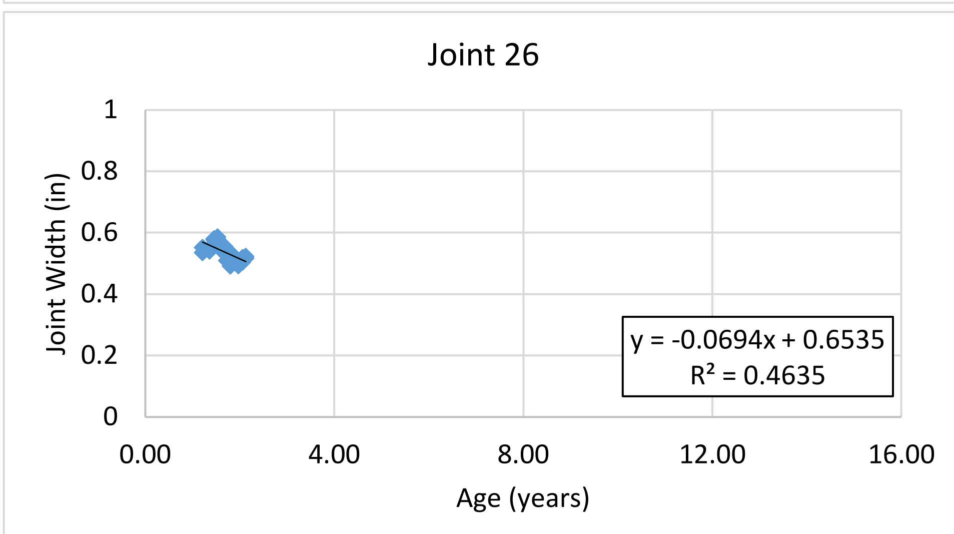

Joint 39
100%
80%
60%
40%
20%
0%
LTE
y = 0.0431x + 0.8362
R² = 0.0016
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

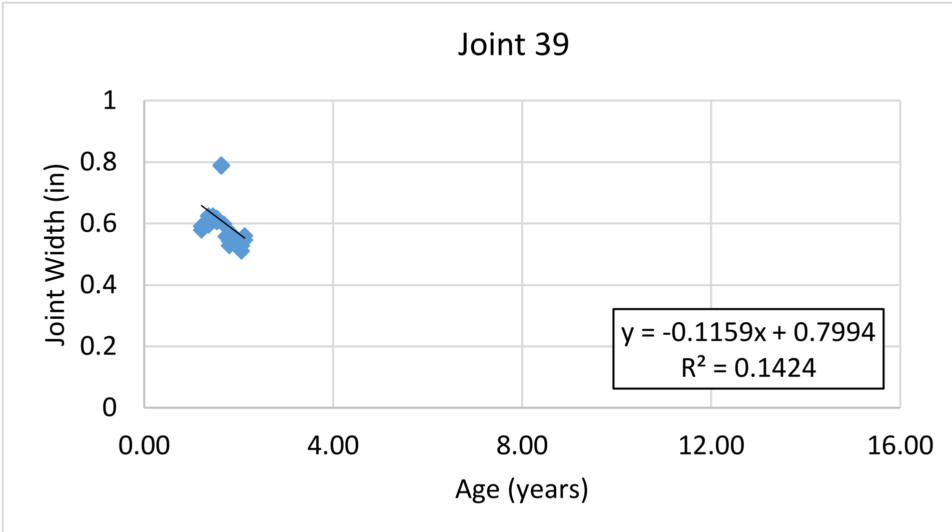

Joint 56
100%
80%
60%
40%
20%
0%
LTE
y = -0.1704x + 0.9818
R² = 0.0303
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

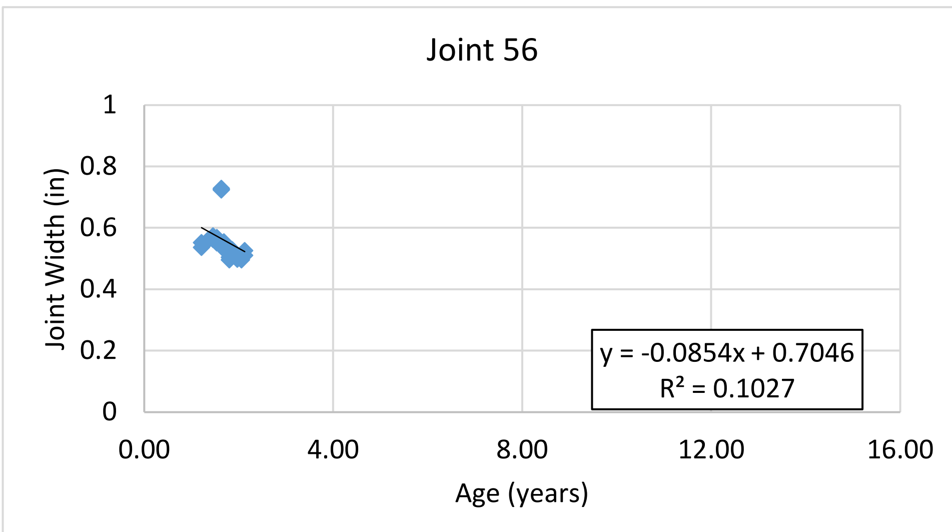

Joint 69
100%
80%
60%
40%
20%
0%
LTE
y = -0.2302x + 0.9544
R² = 0.0131
0
0.2
0.4
0.6
0.8
1
Joint Width (in)

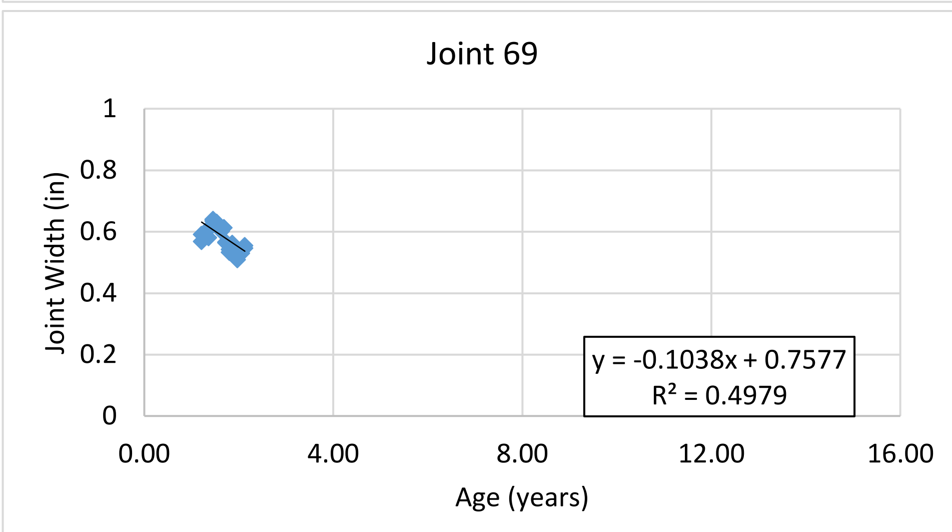

Joint -16
Joint Width (in)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Age (years)
y = -0.0118x + 0.5555
R² = 0.027


Joint 10
Joint Width (in)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Age (years)
y = -0.0989x + 0.6758
R² = 0.3741


Joint 26
Joint Width (in)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Age (years)
y = -0.0694x + 0.6535
R² = 0.4635

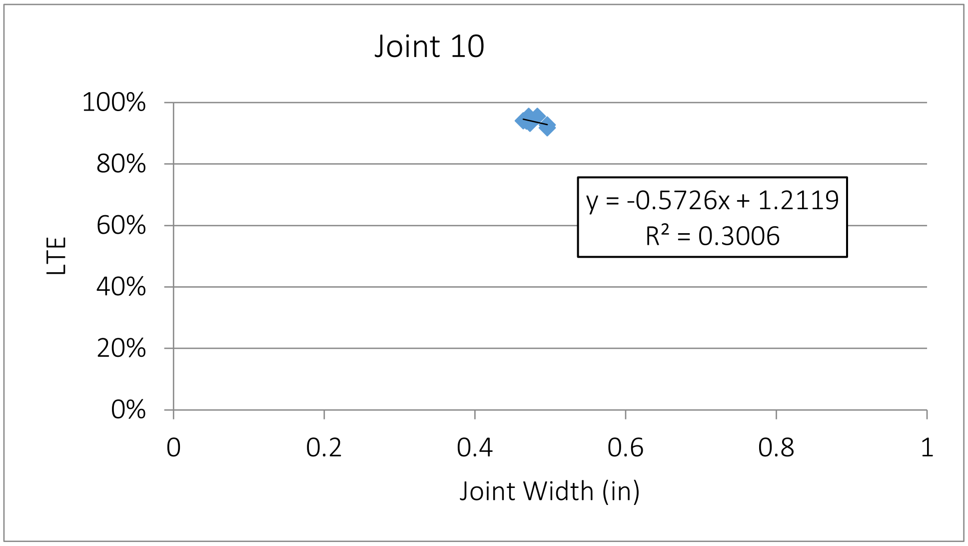

Joint 39
Joint Width (in)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Age (years)
y = -0.1159x + 0.7994
R² = 0.1424

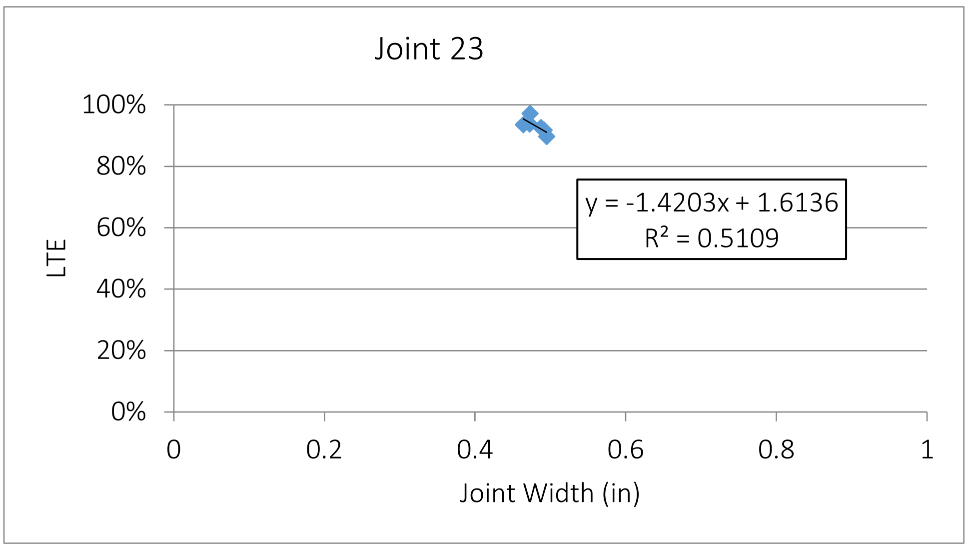

Joint 56
Joint Width (in)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Age (years)
y = -0.0854x + 0.7046
R² = 0.1027

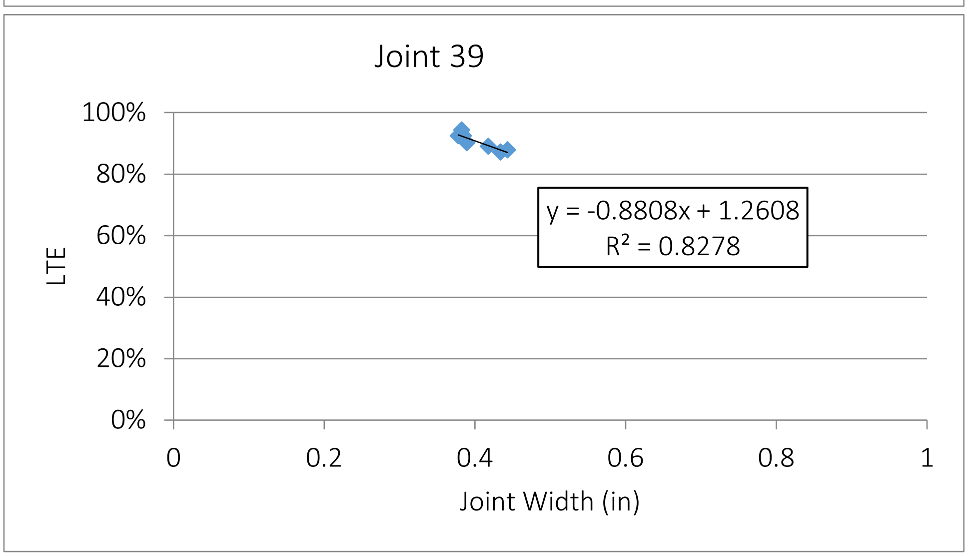

Joint 69
Joint Width (in)
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Age (years)
y = -0.1038x + 0.7577
R² = 0.4979

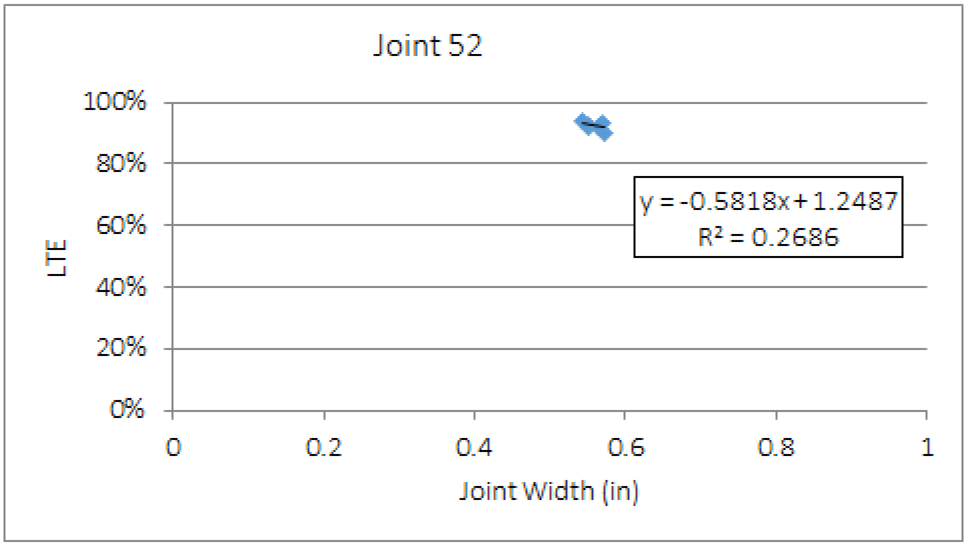
Appendix E

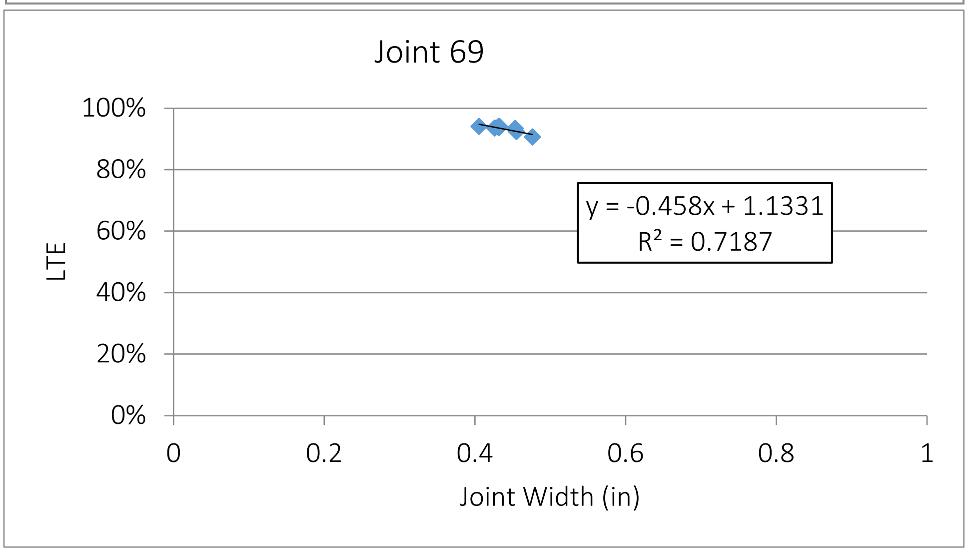
CHANGE IN JOINT WIDTHS FOR EACH JOINT MEASURED ON OHIO (390204) TEST SECTIONS

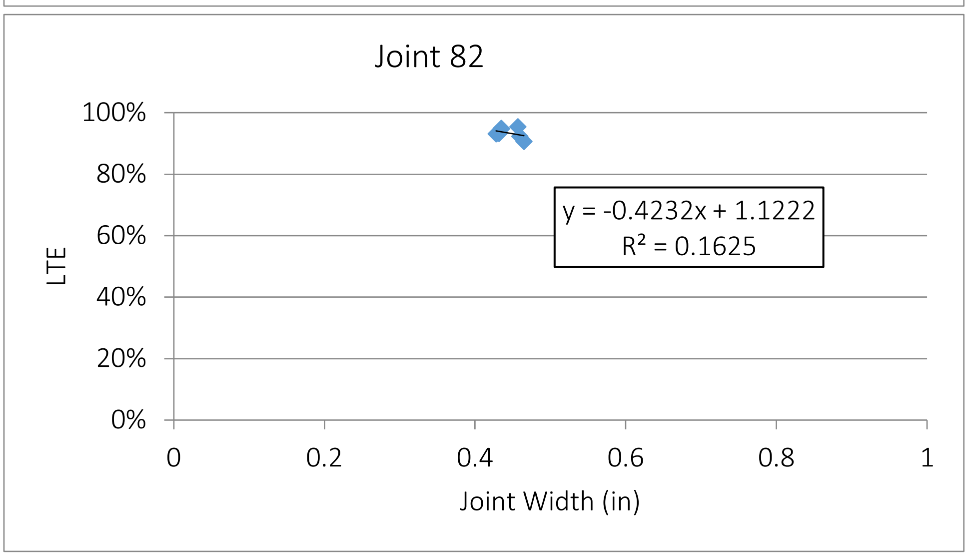

Joint 10
100%
80%
60%
40%
20%
0%
LTE
0
0.2
0.4
0.6
0.8
1
Joint Width (in)
y = -0.5726x + 1.2119
R² = 0.3006

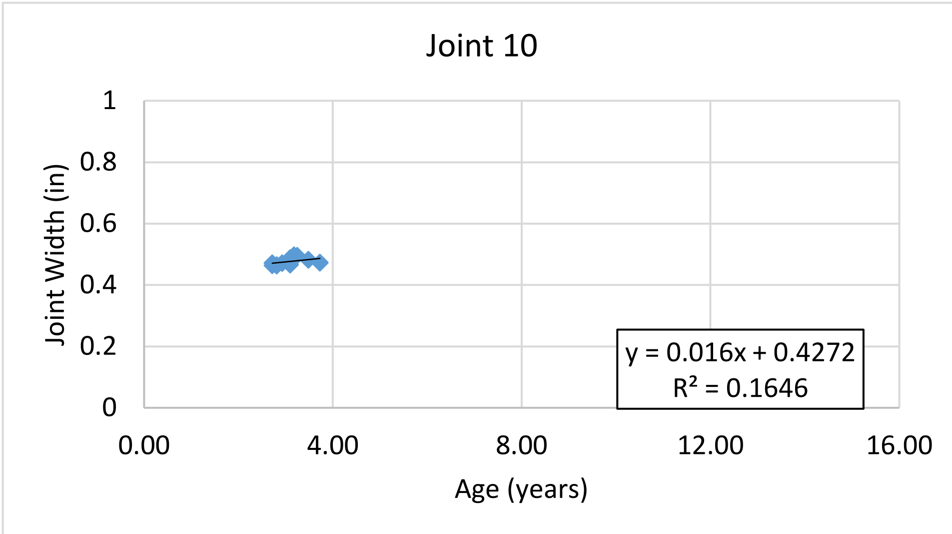

Joint 23
100%
80%
60%
40%
20%
0%
LTE
0
0.2
0.4
0.6
0.8
1
Joint Width (in)
y = -1.4203x + 1.6136
R² = 0.5109

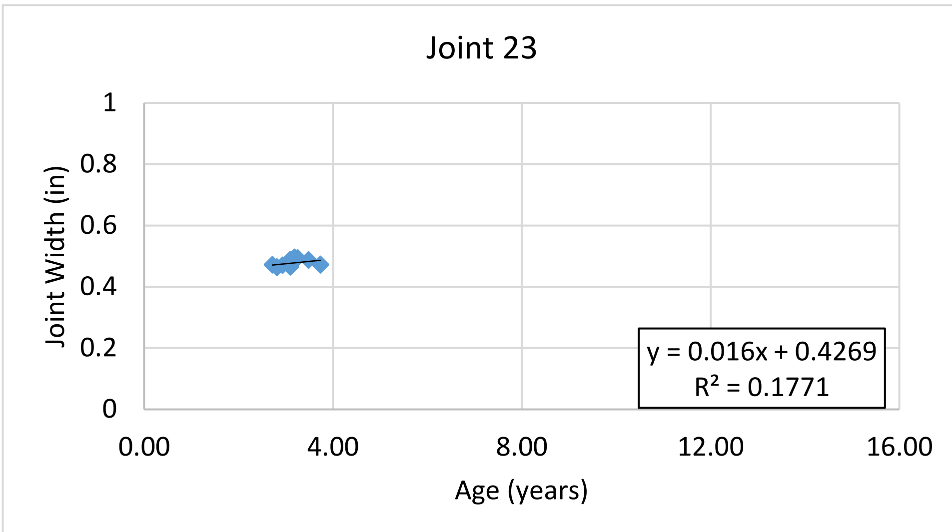

Joint 39
100%
80%
60%
40%
20%
0%
LTE
0
0.2
0.4
0.6
0.8
1
Joint Width (in)
y = -0.8808x + 1.2608
R² = 0.8278

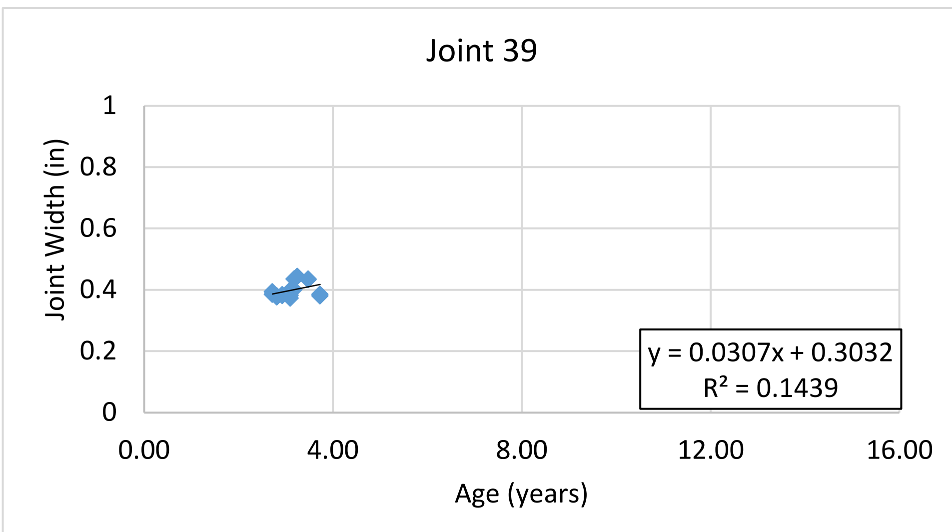

Joint 52
100%
80%
60%
40%
20%
0%
LTE
0
0.2
0.4
0.6
0.8
1
Joint Width (in)
y = -0.5818x + 1.2487
R² = 0.2686

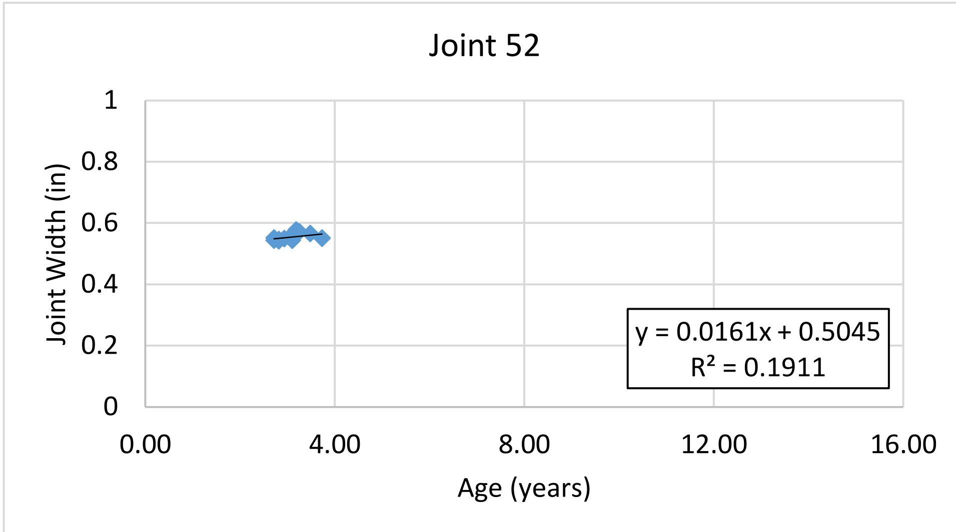

Joint 69
100%
80%
60%
40%
20%
0%
LTE
0
0.2
0.4
0.6
0.8
1
Joint Width (in)
y = -0.458x + 1.1331
R² = 0.7187

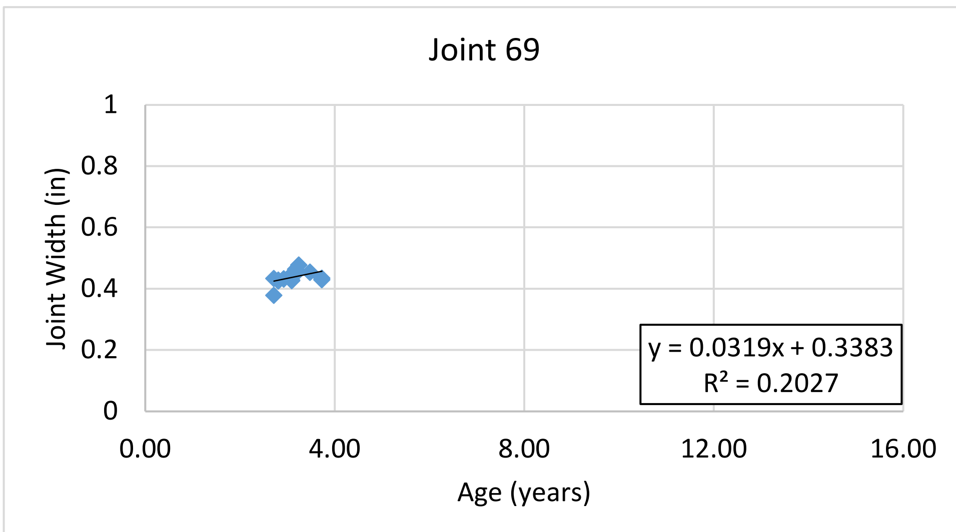

Joint 82
100%
80%
60%
40%
20%
0%
LTE
0
0.2
0.4
0.6
0.8
1
Joint Width (in)
y = -0.4232x + 1.1222
R² = 0.1625

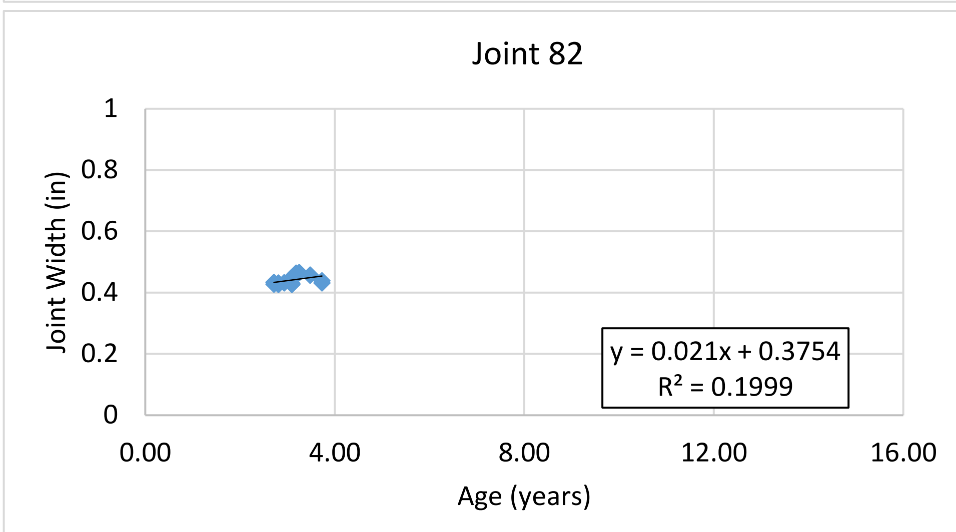

Joint 10
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Joint Width (in)
Age (years)
y = 0.016x + 0.4272
R² = 0.1646


Joint 23
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Joint Width (in)
Age (years)
y = 0.016x + 0.4269
R² = 0.1771


Joint 39
1
0.8
0.6
0.4
0.2
0
0.00
4.00
8.00
12.00
16.00
Joint Width (in)
Age (years)
y = 0.0307x + 0.3032
R² = 0.1439


Joint 52
1
0.8
0.6
0.4
0.2
0
Joint Width (in)
0.00
4.00
8.00
12.00
16.00
Age (years)
y = 0.0161x + 0.5045
R² = 0.1911


Joint 69
1
0.8
0.6
0.4
0.2
0
Joint Width (in)
0.00
4.00
8.00
12.00
16.00
Age (years)
y = 0.0319x + 0.3383
R² = 0.2027


Joint 82
1
0.8
0.6
0.4
0.2
0
Joint Width (in)
0.00
4.00
8.00
12.00
16.00
Age (years)
y = 0.021x + 0.3754
R² = 0.1999