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TPF-5(291) FINAL REPORT:

MEPDG SENSITIVITY ANALYSIS OF THE PCC-BASE FRICTION-LOSS

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

This report presents the results of the MEPDG sensitivity analysis, including comparisons of pavement age to deterioration rate, design factors to deterioration rate, measured and predicted deterioration rates; analysis of the impact of the friction-loss parameter on predicted deterioration rate; and a comparison of percent (transversely) cracked slabs (PCS) computation methods.

2.0 OVERVIEW

An initial comprehensive MEPDG analysis of SPS-2 test sections was conducted early in the TPF-5(291) study. The analysis found very few cases, once distresses either manifested or were predicted to manifest, where the predicted performance from the MEPDG software correlated to the actual performance of the pavement. The inaccurate predictions were especially evident in the test sections with LCB base layers. The LCB base test sections were predicted to perform the best by MEPDG, but in the field, they typically performed worse than test sections with DGAB or PATB layers.

A stronger correlation between predicted and actual performance was expected considering the MEPDG program, AASHTOWare PavementME Design (PMED), utilized data from LTPP for the empirical component of the analysis. However, there were potentially many reasons why the PMED performance prediction did not correlate to the actual performance. In general, the foremost reason for the lack of correlation would be that some assumptions in the analysis regarding properties and conditions of the constructed pavement may have deviated from reality. This includes assumptions about material properties, uniformity, and behavior of the pavement under loading.

Following the initial MEPDG analysis, the research team conducted a series of workshops at participating agencies, referred to as SPS-2 Tech Days. At one of these workshops, there was a suggestion that the assumption of the default bond condition between PCC pavement the LCB base may have played a significant factor in the poor prediction of test sections with the LCB base type. The initial MEPDG prediction assumed the default contact friction between PCC and base (regardless of type) as full friction with friction-loss after 240 months (20 years), consistent with the recommendation of the PMED developers. However, friction-loss may have occurred much sooner, including at the time of construction (if pavement was assumed as unbonded). Coring was not performed on SPS-2 test sections to assess bond condition between the pavement and base. A forensic investigation of the bond condition of the pavement as it exists today would not answer the question of when friction-loss occurred, but could determine if the sections were unbonded. As part of the SPS-2 design conditions, the unbonded condition was supposed to be attained through a variety of acceptable methods; foremost among them, the application of a debonding agent during construction. However, as noted above, the success of achieving an unbonded condition was never measured.

As a continuation of the initial MEPDG analysis, the research teams designed a sensitivity analysis to determine impact of the friction-loss input parameter on the predicted performance of SPS-2 test sections. Each of the 205 PCC SPS-2 test sections were analyzed in three scenarios with a different input for friction-loss. The first scenario used the default friction-loss parameter of 240 months. The second scenario used a friction-loss parameter of 120 months. The third scenario used a friction-loss parameter of 0 (zero) months (unbonded). All other design parameters remained the same throughout the three scenarios.

The initial MEPDG analysis was conducted using PMED Version 2.3, the latest version of available at the time. The current version of PMED is 2.6. With the version upgrade, newer performance models and quality control range checks for design inputs were incorporated. These newer range checks often flagged layer modulus inputs that were used in the initial PMED Version 2.3 analysis. Specifically, layer moduli (elastic modulus for PCC and resilient modulus for base and subgrade) and cement volume inputs used in Version 2.3 were frequently flagged as out of range and precluded the prediction analysis from running. SPS-2 test sections were constructed to achieve flexural strengths of either 550 psi or 900 psi per the experimental design. However, 550 psi and 900 psi are, respectively, unconventionally low and high design strengths for concrete pavements. The amount of cementitious material needed to achieve 900 psi would be quite high and, in some cases, slightly exceeded the maximum allowable input for cement volume in PMED.

To run the three scenarios for the sensitivity analysis using Version 2.6, the layer modulus (Level 3) inputs were updated. In most cases, the layer modulus was derived from FWD back-calculation. However, in cases where the back-calculated modulus failed the PMED range checks, or was unavailable, modulus was substituted from other sources such as the best-fit back-calculation modulus, modulus material testing, or – in rare circumstances – the average values of similar layers from the same SPS-2 project. If a reasonable modulus could not be estimated by means of the aforementioned methods, then the elastic modulus parameter was deactivated. However, while these updated layer moduli values should be a good estimate based on the available data, they may not equate to the actual 28-day elastic modulus. No predictions were run using Level 1 or Level 2 inputs for PCC strength.

The sensitivity analysis examined differences in deterioration rates for performance measures, including mean roughness index (MRI) (average International Roughness Index [IRI] in the left and right wheel path of the test section), average wheel-path faulting (AWF), and PCS. The analysis compared the deterioration rates of performance measures for each scenario of SPS-2 test sections. The impact of design factors on the predicted deterioration rates was then assessed.

The percent error in the predicted deterioration rate was also calculated for each scenario in terms of the actual deterioration rate. In other words, the difference between the predicted value and the measured value divided by the measured value and multiplied by 100. The absolute value of the results was not taken, as a positive or negative error was significant in determining overprediction versus underprediction.

The percent change in deterioration rate relative to the no-friction (unbonded) assumption was also calculated to evaluate the impact of the friction-loss parameter on deterioration rate. For this value, the differences between the 120-month (10 years until friction-loss) scenario and no-friction scenario were divided by the deterioration rate of the no-friction scenario and multiplied by 100. The same calculation was performed on the 240-month (20 years until friction-loss) scenario relative to the no-friction scenario. This gives a sense of how the time until friction-loss affected results across different design factors.

Additionally, the method used to calculate the measured PCS was reviewed. In previous analyses, PCS was calculated based on manual distress surveys as a percent of slabs cracked transversely out of the total number of slabs in the test section. In addition, LTPP also provides

PCS computed using High-Performance Monitoring System data, the ME-2016 calculation, and the ME-2019 calculation. The ME-2016 calculation was a function of the total number of transverse cracks, the section length, and joint spacing. ME-2016 was later updated to the ME-2019 computation, which computed PCS in accordance with the model assumptions used in PMED.

3.0 COMPARISON OF PAVEMENT AGE AND DETERIORATION RATES

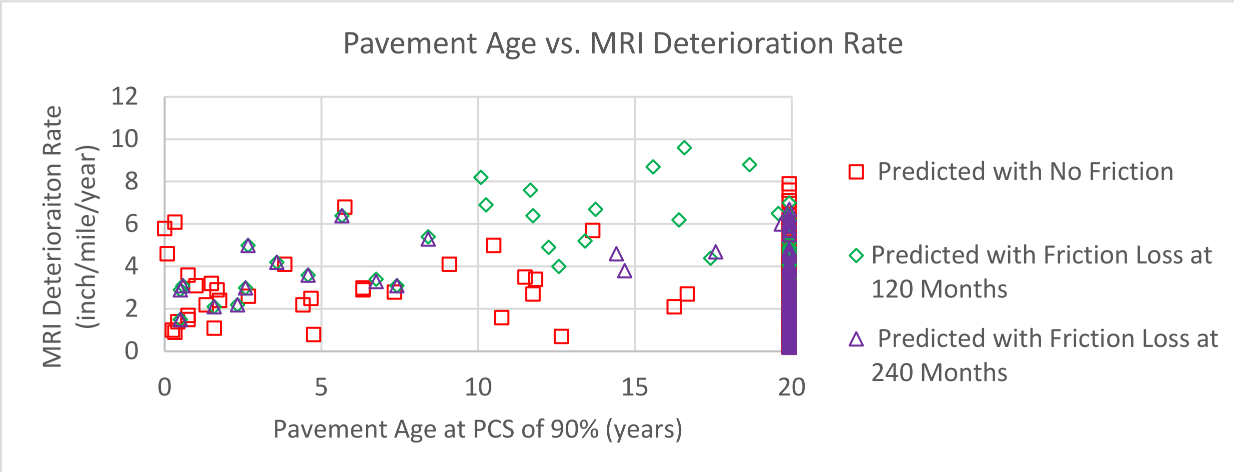
Pavement deterioration rates, whether in terms of MRI, AWF, or PCS, are not always linear. This was especially true in the case of PCS, which has a fixed upper limit of 100%. To accurately define the deterioration rate for PCS per test sections, only the predicted PCS values from 0% to 90% were used. After 90% or more of the total slabs in a test section had cracked, the deterioration rate from that point forward tended to flatten. Therefore, analyses of the PCS deterioration rate reflect the predicted PCS values from the time of traffic opening (PCS of 0%) to time when 90% of slabs have cracked transversely.

Figure 1 compares the age of a test section when 90% of total slabs have cracked transversely to the linear deterioration rate of MRI during the entire 20-year analysis period. If a test section did not meet the criteria of 90% PCS, then they were plotted with a pavement age of 20 years (the limit of the analysis period). Because of how the data is presented, there are limitations on what observation can be made. However, there was clearly not a linear correlation between the MRI deterioration rate and pavement age at 90% PCS. This was expected as these were performance measures computed on test sections with varying design properties.

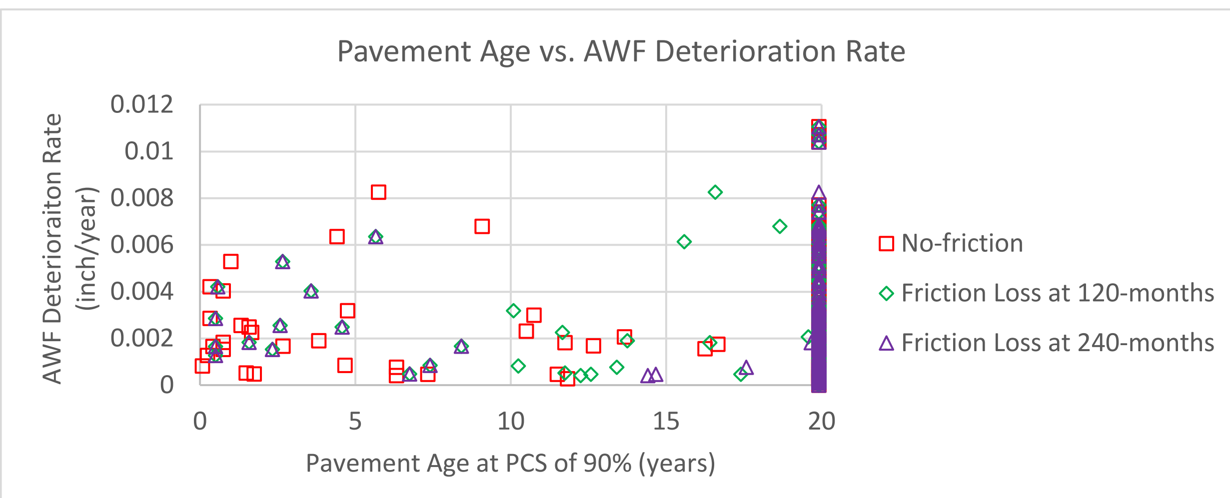
There was some overlap between data points of different scenarios (different parameters for PCC-base friction-loss). Specifically, there were some data points within the 0-to-10-year range that appeared to line up well between test sections predicted with friction-loss at 120 months and those predicted with friction-loss at 240 months. This overlap is reasonable considering at the 120-month (10-year) mark there would be no difference in the bond condition between the 120-month scenario and the 240-month scenario; in both scenarios, the pavement would be modeled as having full-friction within this range. The no-friction scenario had less overlap in this range. Additionally, there were more test sections in the no-friction scenario that appeared to have shorter life (in terms of PCS) than test sections in either of the full-friction scenarios.

In the 10-to-20-year range for pavement age (excluding all test sections at year 20 that never achieved 90% PCS), there was no overlap in data points between the three scenarios. Within this range, there were 14 test sections in the 120-month scenario (10 years until friction-loss), most with relatively high MRI deterioration rates. In the 240-month scenario (20 years until friction-loss), there were only 3 test sections during this period, all with MRI deterioration rates around 5 inch/mile/year. This implies that the loss of PCC-base friction during this period caused more test sections to deteriorate faster in terms of MRI. Additionally, test sections in the no-friction scenario during this period had relatively lower MRI deterioration rates than in other scenarios.

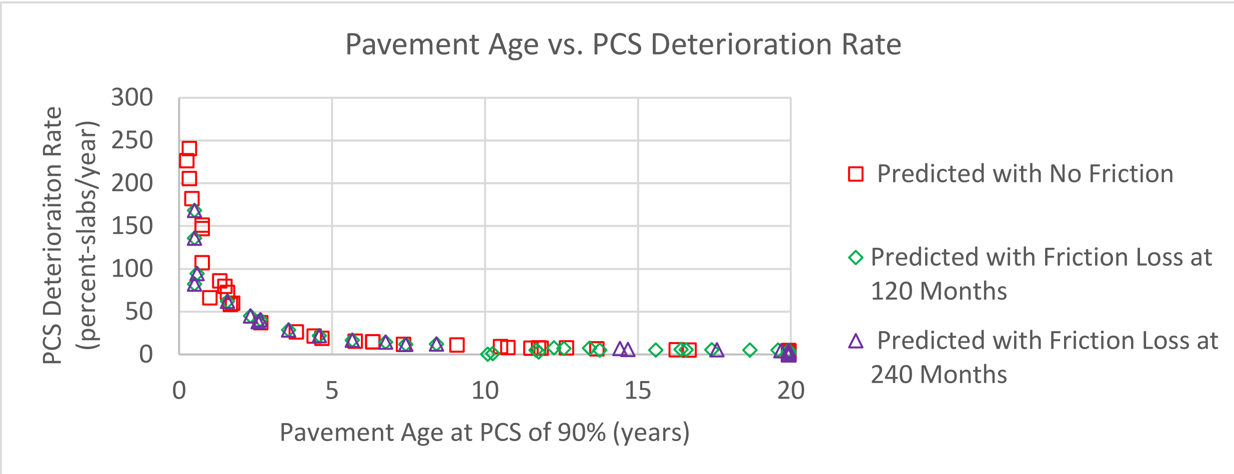
The difference the in the overlap of friction-loss scenarios (or lack thereof) between in the 0-to-10-year range versus the 10-to-20-year range demonstrates PMED's methodology in modeling friction-loss; where pavement performance is modeled as fully bonded until the time of friction-loss and thereafter modeled as fully unbonded. A linear deterioration rate of the 120-month (10-year) friction-loss scenario would equate the average of the performance model used during the first 10 years and the last 10 years.



For AWF, Figure 2 is similar to Figure 1, where there was overlap between test sections in the 120-month scenario and the 240-month scenario during the pavement age range of 0-to-10 years, but not in the range of 10-to-20 years. All scenarios had identical predicted AWF values, which indicates that PCC-base friction-loss does not factor into the MEPDG model for AWF. The reason the data points in Figure 3 do not line up despite having the same predicted AWF is because test sections with different friction-loss assumptions still performed differently in terms of PCS deterioration. Based on Figure 3, there is no relationship between predicted AWF and predicted PCS among test sections with different design properties.



The Figure 3 shows the expected pattern for PCS, as it demonstrates a negative correlation between the pavement age at 90% PCS and the PCS deterioration rate – with the rate decreasing as the age increases. This is logical as age and deterioration rate, in this case, describe the same performance measure. When the PCS deterioration rate exceeds 100%-slabs per year, the test section was predicted to completely deteriorate in less than a year.



As seen in Figures 1 and 2, test sections in the 120-month and 240-month scenarios with a pavement age range of 0-to-10 years match up in terms of PCS deterioration. Only after the 10 years do test sections in the 120-month and 240-scenarios show different PCS deterioration rates. Test sections in the no-friction scenario were predicted to deteriorate faster than test sections with full-friction.

4.0 COMPARISON OF DESIGN FACTORS AND DETERIORATION RATES

The preceding analysis was able to establish that the friction-loss parameter did influence the life of the test section, specifically in terms of PCS. This analysis determined how accurate the predictions using different friction-loss parameters were to the actual (measured) performance of the test sections. The analysis grouped test sections, by state and the SPS-2 design factors, to determine how design features compounded with the friction-loss parameter in predicting performance.

Appendix A includes graphs comparing measured and predicted MRI, AWF, and PCS for each design factor. Specifically, the following categorical factors of the SPS-2 experimental design were used:

- Pavement thickness:
  - Thin pavements (8-inches nominally)
  - Thick pavements (11-inches nominally)
- Base type
  - DGAB
  - LCB
  - PATB
- PCC design strength
  - Low-strength (550 psi design)
  - High-strength (900 psi design)
- Lane width
  - Standard (12-foot-wide lanes)
  - Widened (14 foot-wide lanes)

The project-wide deterioration rates in the Appendix A graphs come from averaging the rates of the 12 core test sections for each state within each scenario. The supplemental test sections were excluded to remove biases in the comparison.

4.1 Common Trends in Measured and Predicted Deterioration Rates

In general, Michigan, Nevada, and Ohio were outliers and had higher measured MRI deterioration rates compared to the other states. This can be seen in the Appendix A graphs, where these outlier states had unusually high average rates for MRI, AWF, and PCS. This does not mean that all test sections in these states deteriorated quickly, but that several were early failures and their high deterioration rates biased the average. For readability, the maximum deterioration rate displayed in the Appendix A graphs has been capped at 5 inch/mile/year for MRI, ±0.01 inch per year for AWF, and 10%-slabs-cracked per year for PCS. Some of the average deterioration rates are not shown in full, but these are also too large to compare to the measured deterioration rate.

Delaware and Wisconsin – having the lowest traffic loading amongst the SPS-2 projects – had nearly identical predicted performance in every Appendix A graph despite different assumptions for PCC-base friction-loss. In every graph, Delaware typically had measured values greater than the predicted value, whereas Wisconsin usually had predicted deterioration rates larger than the measured deterioration rates. Arizona, Arkansas, and California generally did not follow the overall trends and instead had the highest predicted MRI deterioration when friction-loss was assumed at 120 months.

The AWF was identical for each scenario, but the predicted deterioration rates were still compared to the measured deterioration rates across all states (for example, see Figure A-2). The following observations were made as recurring trends for AWF deteriorate rates is seen in the Appendix A graphs:

- Nevada (an outlier, as previously mentioned) had a negative measured AWF rate average in every comparison.
- Arkansas also had a negative measured AWF average for some test sections with LCB base type (as seen in Figure A-11).
- Ohio (also an outlier) had the highest predicted AWF average in every comparison, even though the measured AWF rate was relatively low.
- North Dakota had higher measured deterioration rate averages than predicted rate averages in 5 design factors: thick pavements, LCB base type, PATB base type, low-strength PCC, and widened lanes (as seen in Figures A-5, A-11, A-14, A-17, and A-26).
- Washington also had higher measured deterioration rate averages than predicted rate averages in 4 design factors: LCB base type, PATB base type, low-strength PCC, and standard (12-foot) lanes (as seen in Figures A-11, A-14, A-17, and A-22).

The PCS deterioration rate averages were generally much higher for Arizona, Arkansas, California, Colorado, and Kansas, especially for test sections in the no-friction scenario (as seen in Figures A-3, A-6, etc.). Because some test sections had very high PCS-predicted deterioration rates, the averages for Arizona, Arkansas, California, Colorado, and Kansas were biased by the higher deterioration rates of these test sections. For example, in Figures A-3 and A-6, the thin pavement sections in Arizona, California, Colorado, and Kansas that have been excluded from Figure A-6 show average deterioration rates that are much lower than those in Figure A-3.

Table 1 shows a list of test sections that were predicted (no-friction scenario) to have very high PCS deterioration rates – 50 or greater PCS per year (100% failure in 2 years or less). This is a sample of core test sections that have biased the average deterioration rates by states as shown in the Appendix A graphs.

Table 1. Test Sections with Predicted PCS Deterioration Rates (no-friction scenario) Greater Than 50 PCS Per Year.

State	SHRP ID	PCS Deterioration Rate (PCS per year)	PCC Thickness (in.)	Base Type	PCC Strength (psi)	Lane Width (ft)
AZ	040213	86	7.9	DGAB	Low	14
AZ	040221	151	8.1	PATB	Low	14
AR	050213	59	7.4	DGAB	Low	14
AR	050215	182	11.5	DGAB	Low	12
AR	050221	241	8.3	PATB	Low	14
AR	050223	226	10.9	PATB	Low	12
CA	060202	107	8	DGAB	High	13
CA	060205	80	8.2	LCB	Low	12
CA	060209	60	8.4	PATB	Low	12
CA	060210	73	8.6	PATB	High	13
CO	080222	206	8.5	PATB	High	12
KS	200209	67	8.4	PATB	Low	12

4.2 Pavement Thickness

Predicted MRI deterioration, with some exceptions, was often slightly more than the measured MRI IRI deterioration. The initial IRI used in the prediction was based on measured values. Typically, the measured deterioration rate was closest to the predicted deterioration rate of the 240-month friction-loss scenario regardless of pavement thickness. However, in Arkansas, the measured deterioration was closest to the 120-month friction-loss scenario.

Predicted PCS deterioration rates for several thin pavement test sections in Arizona, Arkansas, California, Colorado, and Kansas were much higher than the measured rate. For thick pavement test sections, only Arkansas' predicted PCS deterioration rates were exceedingly high. Arizona, Arkansas, and California had higher-than-average traffic loading, so it was expected that thin pavement at these sites would deteriorate faster than at other sites. However, the traffic loading for Kansas and Colorado was more moderate. This suggests that the high PCS deterioration rates were influenced by a combination of factors that included pavement thickness and traffic loading.

4.2.1 THIN PAVEMENTS

Observations from Appendix A comparisons of MRI, AWF, and PCS deterioration rates include:

- MRI deterioration (Figure A-1) shows that Arizona, Arkansas, and California (high traffic loading sites) had higher deterioration with friction-loss at 120 months than the no-friction or 240-month friction-loss scenario.
- AWF deterioration (Figure A-2) shows that California, Iowa, and Kansas had, on average, measured AWF deterioration rates that were less than 0.002 inch/ year, but significantly higher predicted rates.

- PCS deterioration (Figure A-3) shows the measured rates, on average, do not match up with the predicted rates except in states where the average deterioration rate was near zero.

4.2.2 THICK PAVEMENTS

Observations from Appendix A comparisons of MRI, AWF, and PCS deterioration rates include:

- MRI deterioration (Figure A-4) shows California and Delaware had large differences between the predicted and measured deterioration rate averages. In California, thicker pavements did not deteriorate in MRI as quickly as predicted, whereas in Delaware, thick PCC test sections deteriorated in MRI faster than predicted, on average. The California and Delaware SPS-2 projects differ quite significantly in terms of climate and traffic loading.
- AWF deterioration (Figure A-5) shows Kansas had a large gap between the measured and predicted average AWF. Delaware, North Dakota, and Arizona had higher measured average rate of AWF than predicted.
- PCS deterioration (Figure A-6) shows Arkansas had significantly high predictions for PCS deterioration – even higher than the average predicted PCS rates for thin pavements. In contrast, Arizona, California, and Colorado had lower predicted deterioration rate averages for thicker pavements and thin pavements.

4.3 Base Type

PCC-base friction-loss parameter expresses the bond condition between the pavement and the base. Therefore, base type should be the most sensitive design factor to determine which scenario (no-friction, 120-month fiction loss, or 240-month friction-loss) would be the best fit for LCB base test sections.

LCB test sections were typically constructed with a bond-breaker (e.g., asphalt emulsion) to reduce the friction between pavement and the LCB base. However, it is not uncommon for conventional bond-breakers to be unsuccessful in mitigating friction. Therefore, the effectiveness of the bond breaker and the assumed friction-loss parameter were expected to be a key component of achieving good correlations between the measured and predicted performance.

The actual bond condition between pavement and base could not be ascertained without periodic forensics. LTPP data collection typically performs coring only during construction of the test section. Thus, it would not be possible to determine when friction-loss actually occurred.

To supplement the friction-loss sensitivity analysis of LCB test sections, PMED predictions using friction-loss scenarios were also performed on DGAB and PATB test sections. Since DGAB is a granular material, it should not be possible for it bond to the pavement. The expectation, therefore, was for the predicted deterioration rates for different friction-loss scenarios to be akin to each other. However, this was not the case. Using different friction-loss values for DGAB test sections resulted in varying deterioration rates for PCS. For DGAB test sections with significant predicted PCS, the predicted MRI deterioration rates were also shown to vary.

Friction-loss sensitivity analysis of the PATB test sections, similarly, showed varying predicted deterioration rates. The friction between base and PCC is typically mitigated by the PATB being a flexible layer. However, predicted PCS deterioration rate varied by friction-loss scenario.

DGAB and PATB test sections with very high PCS deterioration showed little difference between the 120-month scenario and the 240-month scenario. The significant amount of variability in predicted PCS deterioration derives from the no-friction scenario. This was different for LCB test sections, where each scenario produced a slightly different PCS deterioration rate.

4.3.1 DGAB BASE

Observations from Appendix A comparisons of MRI, AWF, and PCS deterioration rates include:

- MRI deterioration (Figure A-7) shows that Arizona, Arkansas, California, and Kansas had a higher average deterioration rate in the 120-month scenario than in the 240-month and no-friction scenarios. This implies that the PCC-base friction-loss parameter does affect the predict MRI deterioration when the base is non-stabilized material. Typically, the average measured MRI deterioration rates were lower than the average predicted rates (except in Arizona, Arkansas, and Delaware).
- AWF deterioration (Figure A-8) shows Iowa and Kansas once again had a large difference between the measured and predicted average deterioration rates.
- PCS deterioration (Figure A-9) shows that most DGAB test sections had low measured deterioration rates on average, but, as seen in previous PCS deterioration graphs, the average of the predicted deterioration rate was high for Arizona, California, and Colorado.

4.3.2 LCB BASE

Observations from Appendix A comparisons of MRI, AWF, and PCS deterioration rates include:

- MRI deterioration (Figure A-10) shows that most states (except for Arizona, Arkansas, and California) had measured average MRI deterioration rates close to the predicted average rates. For these states, predicted rates for test sections in 120-month scenario or 240-month scenario were closer to the averages for the measured prediction rate.
- AWF deterioration (Figure A-11) showed no consistency between the averages for predicted and measured AWF deterioration rates – differences were more significant in Iowa and Kansas.
- PCS deterioration (Figure A-12), like the MRI deterioration rate averages, showed that the average for measured PCS deterioration was closer to predicted averages for test sections in the 120-month and 240-month scenarios. This supports the possibility that PCC-base friction-loss for LCB test sections in Arizona, Arkansas, and California, occurred between 10 to 20 years.

4.3.3 PATB BASE

Observations from Appendix A comparisons of MRI, AWF, and PCS deterioration rates include:

- MRI deterioration (Figure A-13) shows that the average predicted MRI deterioration rates for PATB test sections were closer to the average for measured rates than for test

sections with other base types in the states of Arkansas, Delaware, Michigan, Nevada, Ohio, and Washington. The average measured MRI deterioration rates were typically lower than the predicted MRI deterioration rates. Therefore, test sections in the 240-month scenario – with lower average deterioration rates – were typically closer to the measured deterioration rates.
- AWF deterioration (Figure A-14) shows no consistency between the averages for predicted and measured AWF deterioration rates – differences were more significant in Arizona, California, Iowa, and Kansas.
- PCS deterioration (Figure A-15) shows, like Figure A-9 and A-12, that predicted PCS deterioration rates on average were higher for test section in Arizona, Arkansas, and California. However, in the case of test sections with PATB base, the average predicted deterioration rate for Colorado and Kansas were also high. Like in all PCS deterioration graphs, the averages were influenced by certain test sections in these states that had unusually high PCS deterioration predictions. Also, the average predicted PCS deterioration was consistently reduced for test sections in the 120-month and 240-month scenarios. However, the difference between the 120-month and 240-month scenario was very small.

4.4 PCC Strength

There was not as much difference in the deterioration rates between low-strength and high-strength test sections. The relatively more significant difference was in the comparison of PCS deterioration. Several of the test sections predicted with very high PCS deterioration were low-strength PCC sections. For example, in Table 1 above, 9 of the 12 test sections were low-strength. PCS deterioration rates varied by friction-loss scenario – in expected order – with higher rates in the no-friction scenario and lower rates in the 240-month scenario.

4.4.1 LOW-STRENGTH PCC

Observations from Appendix A comparisons of MRI, AWF, and PCS deterioration rates include:

- MRI deterioration (Figure A-16) shows that low-strength PCC test sections in most states had an average measured MRI deterioration rate lower than that of the average predicted rate (except for Arkansas). In Arkansas, the average measured MRI deterioration was more in-line with the average predicted deterioration rate for 120-month scenario. In other states, low-strength PCC test sections had average MRI deterioration rates closer to the averages for the 240-month scenario.
- AWF deterioration (Figure A-17) shows no consistency between the averages for predicted and measured AWF deterioration rates – differences were more significant in Arizona, Iowa, and Kansas.
- PCS deterioration (Figure A-18), as in all PCS deterioration graphs, had higher predicted deterioration rates observed for certain test sections in Arizona, Arkansas, California, Colorado, and Kansas. While average measured PCS deterioration rates in Arizona, Arkansas, California, and Colorado were higher than those in other states, they were not as severe as predicted on the selected test sections.

4.4.2 HIGH-STRENGTH PCC

Observations from Appendix A comparisons of MRI, AWF, and PCS deterioration rates include:

- MRI deterioration (Figure A-19) shows predicted MRI deterioration rates between scenarios were very similar for high-strength PCC pavement (except in Arkansas, California, and North Carolina). In Arkansas, California, and North Carolina, the average measured MRI deterioration rate was closest to the average predicted rate for test sections in the 240-month scenario.
- AWF deterioration (Figure A-20) shows no consistency between the averages for predicted and measured AWF deterioration rates – differences were more significant in Arkansas, California, Iowa, and Kansas.
- PCS deterioration (Figure A-21) shows high-strength PCC test sections in Arizona were not predicted to have high rates of PCS deterioration, unlike the low-strength test sections in Arizona. The predicted PCS deterioration rates of high-strength test sections in Arkansas and Kansas also showed improvement compared to the low-strength sections in the same states.

4.5 Lane Width

Like PCC strength comparison, there was not much difference in the deterioration rates between standard width and widened lane test sections. Even among test sections with high PCS deterioration, there were almost equal numbers of test sections with standard and widened lane widths. Also, there were higher predicted PCS deterioration rates in the no-friction scenario than in the other scenarios.

4.5.1 STANDARD

Observations from Appendix A comparisons of MRI, AWF, and PCS deterioration rates include:

- MRI deterioration (Figure A-22) shows that the average measured MRI deterioration rate for test sections with a 12-foot lane width was close to the average predicted MRI rate for test sections in the 240-month scenario. Only California, Kansas, North Dakota, and Wisconsin had average measured deterioration rates significantly below the average predicted rates.
- AWF deterioration (Figure A-23) shows no consistency between the averages for predicted and measured AWF deterioration rates – differences were more significant in California, Iowa, and Kansas.
- PCS deterioration (Figure A-24) shows the average predicted PCS deterioration rate for 12-foot-wide test sections in Arkansas and Colorado was much higher than the average measured rate. Test sections in Arizona and California with 12-foot-wide lanes in the 240-month scenario were predicted to deteriorate at a closer-to-average rate than the test sections in other scenarios.

4.5.2 WIDENED

Observations from Appendix A comparisons of MRI, AWF, and PCS deterioration rates include:

- MRI deterioration (Figure A-25) shows very similar trends to that of 12-foot-wide lanes in Figure A-22, except that the average measured deterioration rate of widened-lane test sections in Arkansas are more in-line with average predicted rates of test sections in the 120-month scenario. Lane width did not have a significant influence in predicting MRI deterioration for test sections with different assumptions for PCC-base friction-loss.
- AWF deterioration (Figure A-26) shows no consistency between the averages for predicted and measured AWF deterioration rates – differences were more significant in Iowa and Kansas.
- PCS deterioration (Figure A-27) shows that widened-lane test sections in Colorado were predicted with lower PCS deterioration rates than 12-foot-wide test sections. Conversely, in Arizona, widened-lane test sections had higher average predicted PCS deterioration rates than 12-foot-wide test sections. As seen in all PCS deteriorate rate graphs, some test sections with very high PCS deterioration biased the project-wide average.

4.6 Findings

Overall, the scenario with friction-loss at 240 months was generally closest to the measured MRI values. For some states, MRI predicted using the 120-month scenario was closer to the measured MRI for certain design features. However, even the predicted MRI rates closest in value to the measured MRI rates often showed a significant difference between the two. The PCS comparisons demonstrated this most significantly, as there were several test sections in the no-friction scenario that generally had excessively high predicted PCS. The scenario with friction-loss at 240 months was much lower, and thus closer to the measured PCS. There were exceptions, but they were not frequent enough to warrant using a different friction-loss parameter.

For some states, such as Arkansas, MRI predicted using the 120-month scenario was closer to the measured MRI for certain design features. The MRI comparisons were more favorable than the PCS comparisons, as the PCS comparisons were especially skewed by test sections with very high PCS deterioration rates – specifically test sections in Arizona, Arkansas, California, and Colorado, where the average predicted rates could be as high as 70% slabs per year.

A project-wide average of deterioration rates is not sufficient to determine the accuracy of predicted rates. The subsequent analysis determined the percent error in the predicted deterioration rate for each of the 205 SPS-2 sections. This analysis demonstrates how SPS-2 design features influenced predicted deterioration rates by scenario. For example, the difference in average MRI deterioration rate between scenarios (different assumptions for friction-loss) was significant in test sections with DGAB and LCB base types, but not as much for test sections with PATB base types. Low-strength test sections in different scenarios had significant differences in MRI deterioration, but the predicted MRI deterioration rates of high-strength test sections were more consistent between scenarios. Pavement thickness and lane width did not have a significant influence on the predicted MRI deterioration rate between scenarios.

5.0 COMPARISON OF MEASURED AND PREDICTED DETERIORATION RATES

The predicted rates for each scenario were compared to the measured rates to determine the accuracy of each MEPDG prediction. A desirable comparison would have a 1:1 slope, as this would indicate the predicted values and measured values were the same.

In Figure 4, all the scenarios are similar in the amount of scatter, with no significant trends present. Some test sections in the 120-month scenario showed higher MRI deterioration rates than in the no-friction scenario or the 240-month scenario.

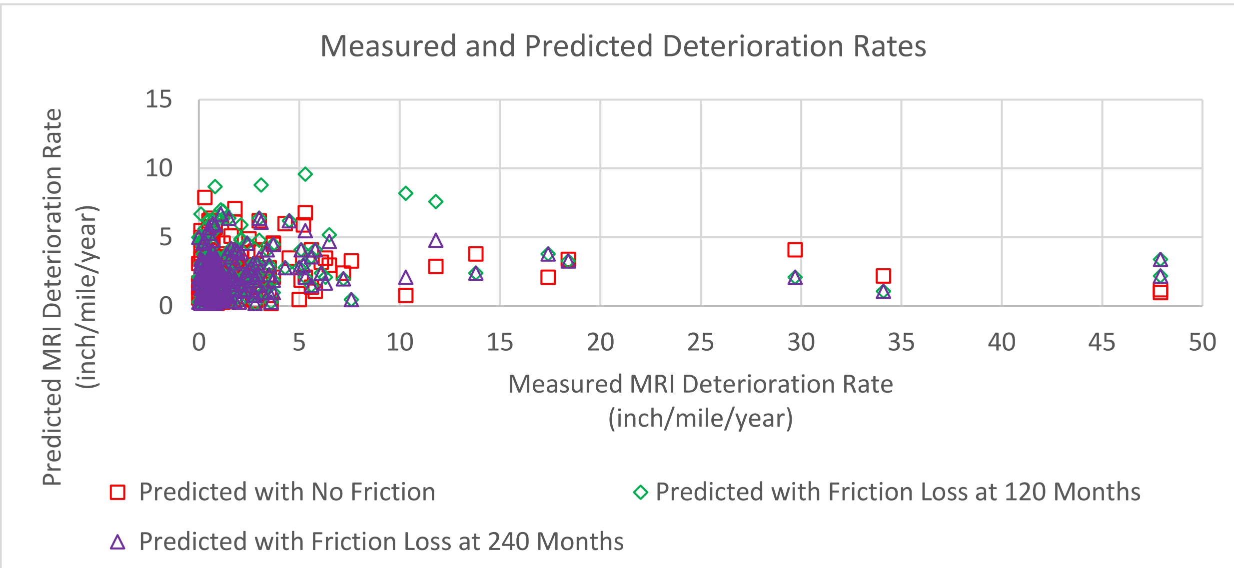


Figure 4. Comparison Between Predicted and Measured MRI Deterioration Rates for Each Test Section

As mentioned previously, the AWF values were identical for all scenarios. For this reason, predicted AWF deterioration rates for each test section overlap regardless of the criteria for PCC-base friction-loss (as shown in Figure 5). The measured rates, when compared to the predicted rates, still show significant scatter and no clear trends.

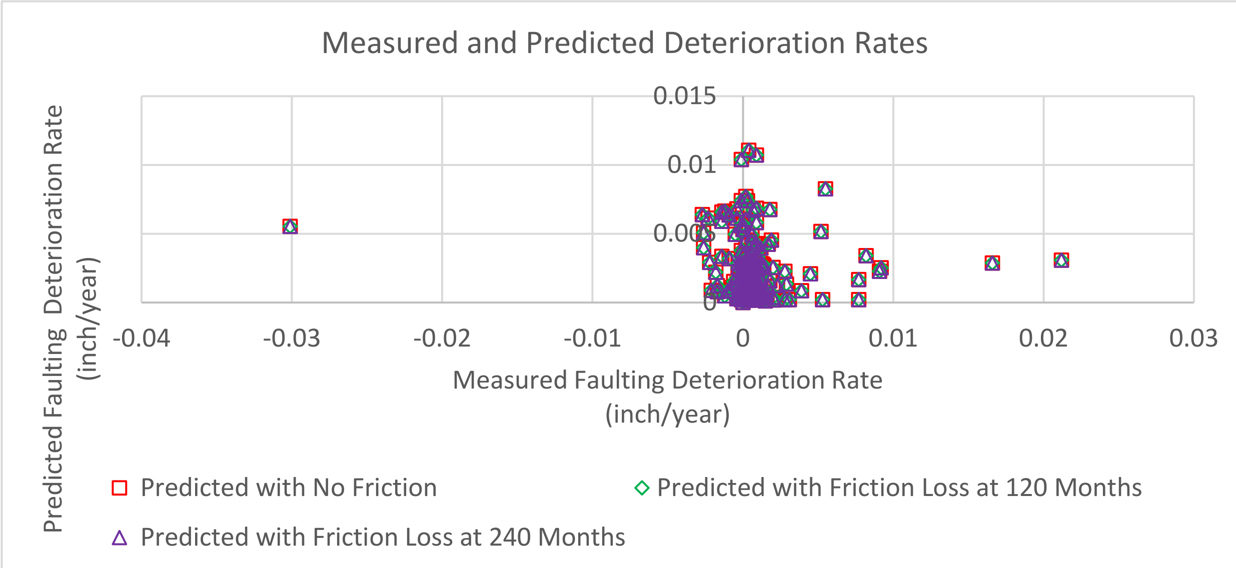


Figure 5. Comparison Between Predicted and Measured AWF Deterioration Rates for Each Test Section

The PCS measured and predicted deterioration rate comparisons in Figure 6 had little correlation, as there were some predicted rates that were up to 10 times higher than the largest measured deterioration rates. There were a few test sections where measured and predicted rates matched up; most of these test sections belonged to the 120-month scenario, but there were 2 or 3 test sections in both the no-friction scenario and 240-month scenario that came close to the measured deterioration rate.

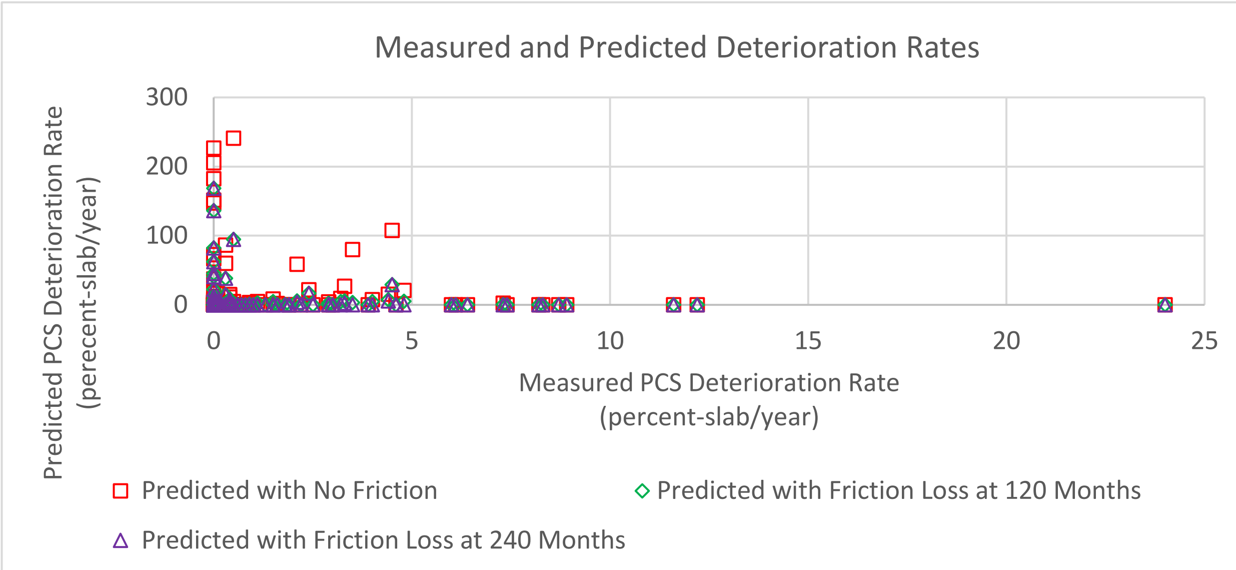


Figure 6. Comparison Between Predicted and measured PCS Deterioration Rates for Each Test Section

Overall, the predicted values did not line up well with the measured values. This confirms the findings from the earlier analyses that running PMED is not a reliable predictor how of test section performance. There were many test sections where both the measured and predicted deterioration was near zero, but that did not necessarily mean the prediction was accurate. Of the 3 graphs, the MRI comparison showed the best correlation between the measured and predicted values. The PCS graph may have shown a better correlation if accurate values for the time until PCC-base friction-loss were available for input in the MEPDG prediction.

6.0 COMPARISON OF PREDICTED DETERIORATION RATES WITH DIFFERENT PCC-BASE FRICTION-LOSS ASSUMPTIONS

The percent change was calculated for each design factor to determine how the friction-loss at 120 and 240 months affected the final deterioration rates compared to the no-friction condition. Since the AWF was identical for all scenarios, the percent change will be zero. In general, the scenario with no initial friction had overestimated the predicted rates, so a negative percent change would be an improvement – especially for PCS deterioration rates. However, since these values were not relative to the measured deterioration rates, they instead showed how the friction-loss parameter directly affected the deterioration rate of MRI, AWF, and PCS. Tables for the average percent difference in predicted deterioration rates can be found in Appendix B (see Tables B-1 through B-9).

The percent error was also calculated to determine how much predicted performance deviated from the measured performance for each test section – the closer the percent error was to zero, the more accurate the prediction. However, a percent error close to zero typically indicated that there was very little to no predicted or measured deterioration. An average of the percent error is presented in this analysis by state and design factor in Appendix V (see Figure B-1 through B-27)

6.1 Pavement Thickness

The predictions for thick pavement test sections were typically more accurate. Several sections with very high PCS deterioration rates were thin test sections and, consequently, contributed to biasing the average error by state. However, with MRI deterioration, the amount of error was less for thick test sections overall. Among the friction-loss scenarios, the 240-month scenario had relatively less error for some test sections.

6.2 Base Type

Test sections with very high PCS deterioration rates (see Table 1) typically had either DGAB or PATB base. For this reason, the predicted PCS deterioration error for LCB test section was relatively low. The error for MRI deterioration rate had mixed results among the friction-loss scenarios.

6.3 PCC Strength

Again, the test sections with very high PCS deterioration rates typically had low-strength PCC. For this reason, the predicted PCS deterioration error for the LCB test section was relatively low. The error for MRI deterioration rate had mixed results among the friction-loss scenarios.

6.4 Lane Width

Like PCC strength, test sections with high PCS deterioration rates were contributing to high error. Standard lane width test sections did not have more accurate predictions than widened lane test sections or vice-versa.

6.5 Findings

The intent of evaluating the percent change in deterioration by scenario or percent error with respect to measured deterioration rate was to quantify how the individual test sections varied in deterioration and accuracy of prediction with the change of the friction-loss parameter. The percent error and percent change values were averaged by state and design factor to identify common trends, but results echoed the deterioration rate comparison analysis from earlier in the report: a few test sections with very high PCS deteriorations biased the average and the friction-loss scenarios showed inconsistent results in terms of prediction accuracy.

7.0 COMPARISON OF PCS COMPUTATION METHODS

There are several methods used to determine PCS deterioration rates, each of which was compared to the predicted values to find the method that best fit the prediction. A 1:1 correlation was desirable to indicate a good correlation between the measured and predicted deterioration rates.

In Figure 7, each method performed similarly, with many of the methods producing nearly the same results. The methods varied more when the predicted rates were small. In general, there were no clear correlations to measured data.

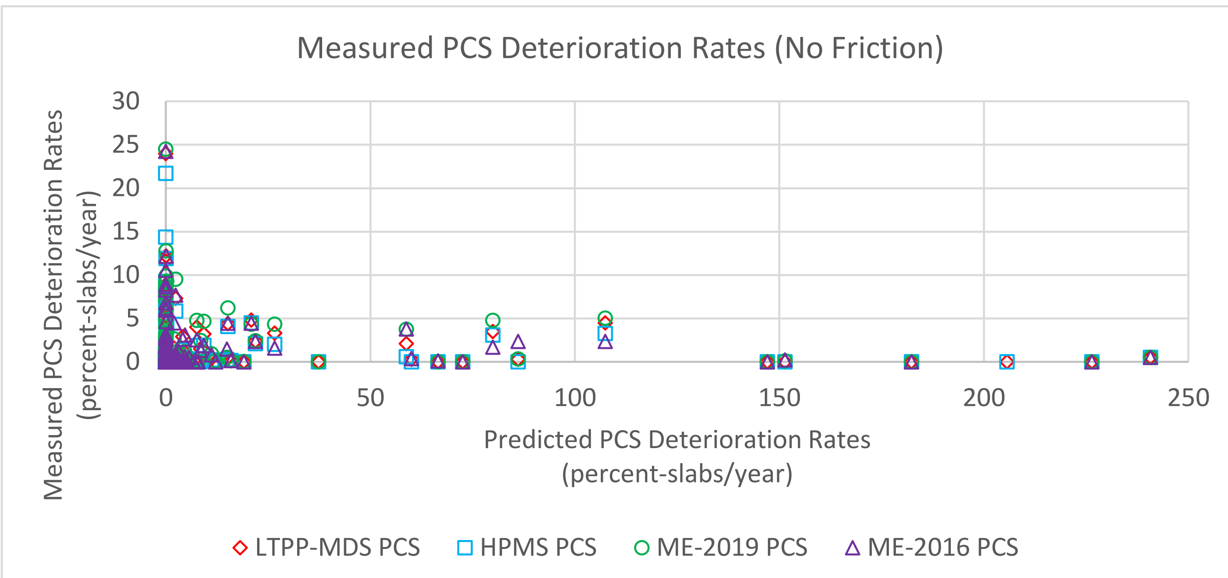


Figure 7. Comparison Between the Predicted PCS Rate from MEPDG and Other PCS Prediction Methods for the Scenario with No Initial Friction

Like the no-friction scenario, the comparison in Figure 8 for the 120-month scenario did not seem to display a linear correlation. The deterioration rate for each method was nearly identical for each test section, so no one method was more accurate than another. This graph did have reduced scatter compared to the no-friction scenario, which indicates more accurate results for some test sections.

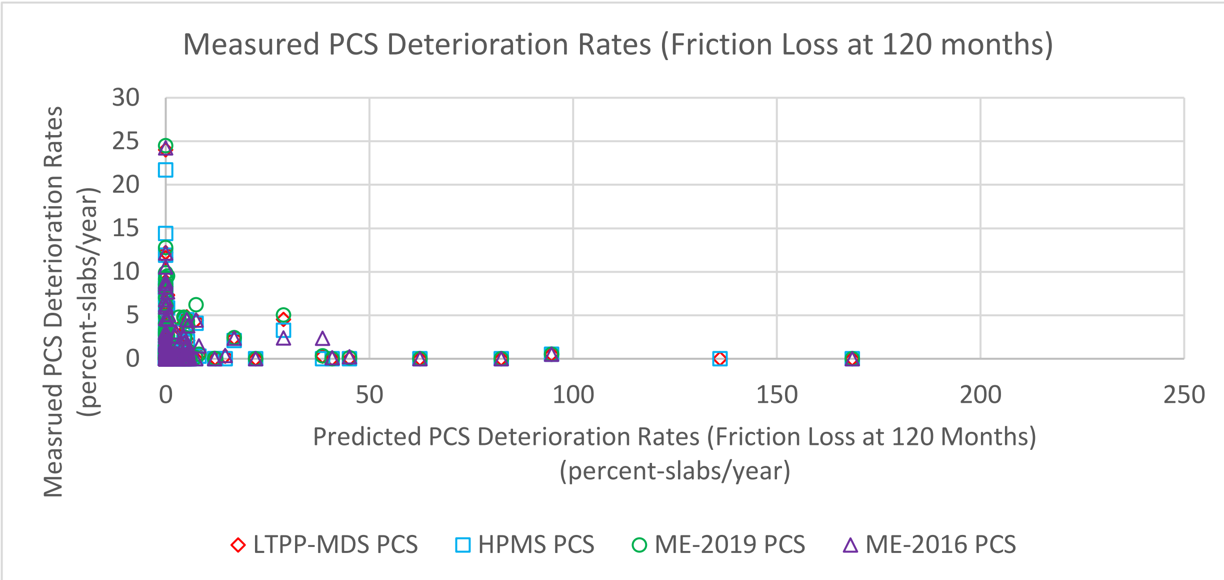


Figure 8. Comparison Between the Predicted PCS Rate from MEPDG and Other PCS Prediction Methods for the Scenario with Friction-Loss at 120 Months

The PCS deterioration rates in Figure 9 had very similar scatter to the 120-month scenario. There were some data points within the 0-to-5 %-slab per year range correlated between the measured and predicted rates, but most of the datapoints still did not display a correlation.

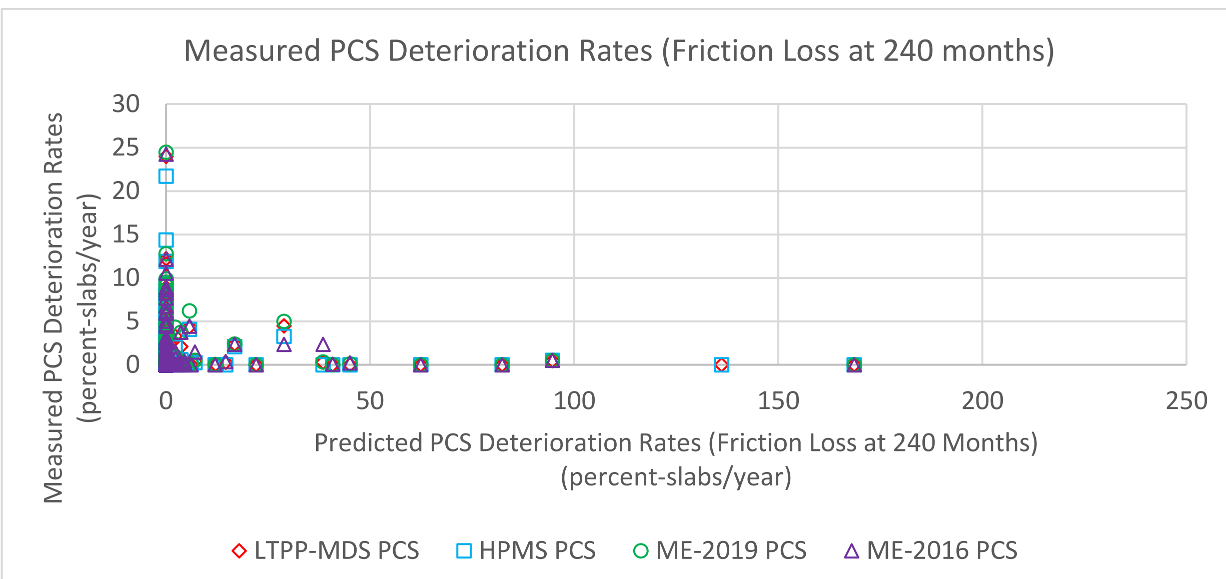


Figure 9. Comparison Between the Predicted PCS Rate from MEPDG and Other PCS Prediction Methods for the Scenario with Friction-Loss at 240 Months

Each method displayed similar results within each graph, and across each scenario. None of the graphs had a correlation between the measured and predicted rates, but the scenario with friction-loss at 120 and 240 months had more test sections with predicted PCS rates close to that of measured PCS rates.

8.0 SUMMARY OF FINDINGS

Overall, this sensitivity analysis proved useful in determining the impact of the PCC-base friction-loss parameter on PMED predictions. However, an improvement in the correlation of performance predictions to measured performance was not achieved. While using different bond conditions from the default value (full friction-loss at 240-months) did improve the accuracy of predicted values, it only did so for a few test sections. At the same, the predicted performance of other test sections became less accurate. In general, this study was not able to utilize PMED and the PCC-base friction-loss parameter to improve the performance prediction of SPS-test sections.

The empirical data PMED uses in its performance models include LTPP test sections, such as the SPS-2. However, there are many potential reasons why accurate predictions could not be achieved. Just as this study initially assumed to use the default value for PCC-base friction-loss, there may be other parameters where the default value would not sufficiently model pavements as-constructed. In that respect, all inputs used to model the SPS-2 test sections in study were derived from the available information in the LTPP database. In the case a property of an SPS-2 test section misrepresented how a parameter in PMED should be modeled, it is expected that the model may not correlate to the actual performance of that test section.

This sensitivity analysis is an extension of the *Comparison of PavementME and Actual Performance* analysis report conducted in December 2017 and included as part of this TPF-5(291) pooled-fund study. The 2017 report included all PMED inputs used to model the SPS-2 test sections in Version 2.3 of PMED. For this sensitivity analysis, the same inputs were used using Version 2.6 of PMED, with some exceptions. Because of the range checks on layer modulus values in Version 2.6, the layer modulus was estimated based primarily on falling weight deflectometer (FWD) back-calculation (see Appendix C) to be within the acceptable range of the parameter. Version 2.6 also came with a new interface for adding climate data; therefore, climate data were also an updated input. Because of the different versions and updated input, the predicted performance was different from 2017 analysis. In version 2.6, there were even cases of test sections that were predicted to fail very rapidly – within months.

Despite the poor correlation of predicted performance to actual performance, the analysis was able to showcase the primary objective of assessing the sensitivity of the PCC-base friction-loss parameter. The analysis evaluated the influence the SPS-2 design factors (i.e., pavement thickness, base type, PCC strength, and lane width) had on performance predictions in conjunction with different assumptions for friction-loss. All design factors had compounding effects with friction-loss in predicting performance. This is expected, because the time until friction loss only identifies the portion of the analysis period where pavement is modeled either as fully bonded or unbonded. The only performance measure that was not affected by friction-loss was faulting. The predicted rate of faulting remained the same regardless of scenario.

However, the study did not expect base types other than LCB would be sensitive to the friction-loss parameter. The analysis found there was a difference in deterioration rate when a DGAB or PATB test section was modeled as bonded or unbonded. Granular material like DGAB and flexible material like PATB may provide some friction at the PCC-base interface, but most of the friction would be mitigated because DGAB and PATB are not rigid materials.

An NCHRP 1-51 study on how to model the interaction between concrete pavements and the underlying subsurface found "many complications" that could not be limited to only the bond condition between PCC and base. These complications included unrealistic damage and low cracking predictions, the influence of parameters such as thickness and modulus on built-in curl, and internal default values for joint load transfer and built-in curl.[1] Based on the NCHRP 1-51 report, the PavmentME task force is in the process of updating global coefficients for PCC pavements.[2]

Since this sensitivity analysis was not able to use friction-loss to improve performance predictions, the findings from previous TPF-5(291) studies (*Comparison of PavementME and Actual Performance* and *Evaluating the Impact of Design Features on Pavement Performance*) remain applicable. These include:

- Performance prediction of most SPS-2 test sections cannot provide meaningful comparison to actual performance because many test sections are in still in good condition.
- LCB test sections perform worse-than-predicted with PMED, and PATB test sections typically perform better-than-predicted with PMED.
- High-strength PCC test sections tend to perform worse than predicted.

[1] Khazanovich, Lev. *A Model for Incorporating Slab/Underlying Layer Interaction into the MEPDG Concrete Pavement Analysis Procedures*. 2016. NCHRP 01-51. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3151

[2] "Looking forward to FY 2022 Enhancements." 2021. https://www.aashtoware.org/story/looking-forward-to-fy-2022-enhancements/

Appendix A

DESIGN FACTOR COMPARISON BY DETERIORATION RATES

1. Thin Pavements

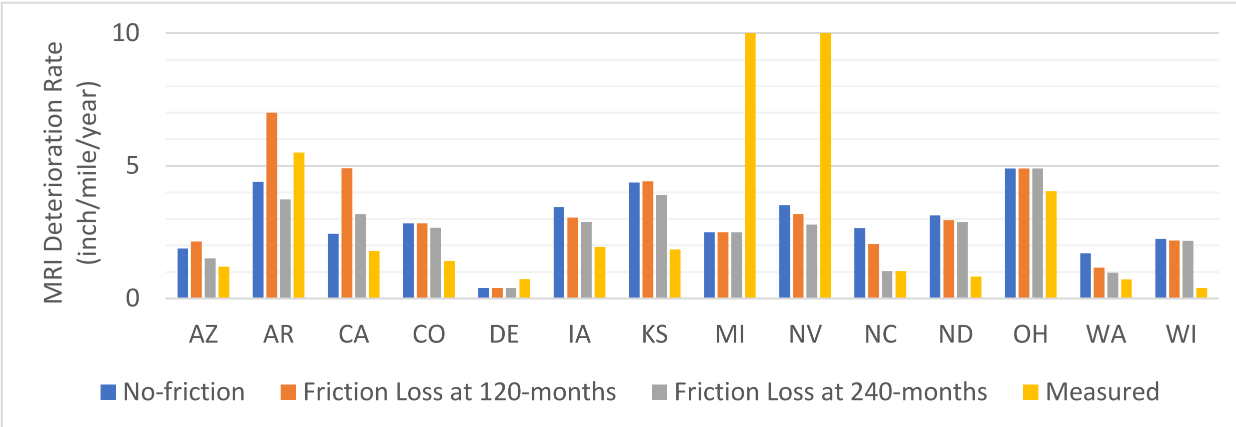


Figure A 1. Comparison Between Measured and Predicted Deterioration Rates for MRI on Average by State.

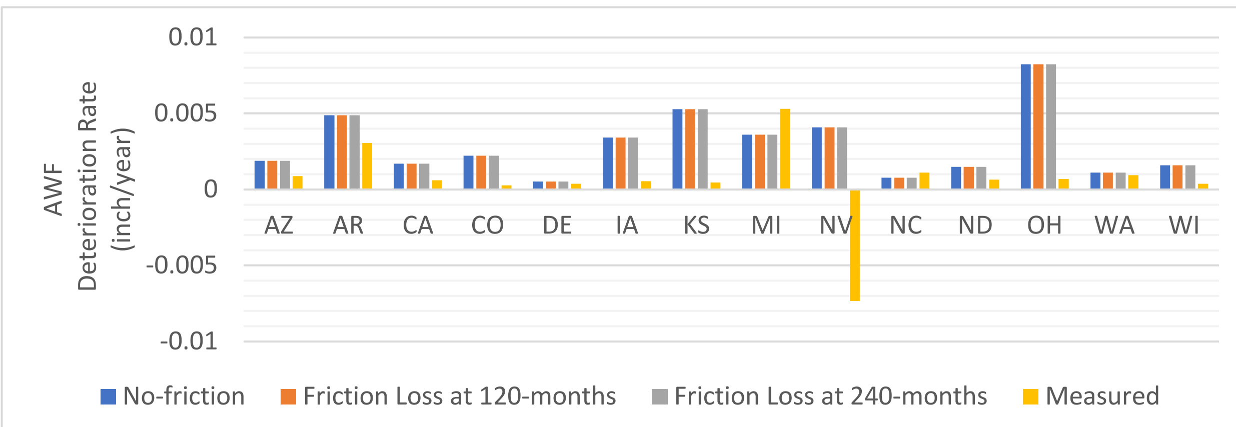


Figure A 2. Comparison Between Measured and Predicted Deterioration Rates for AWF on Average by State.

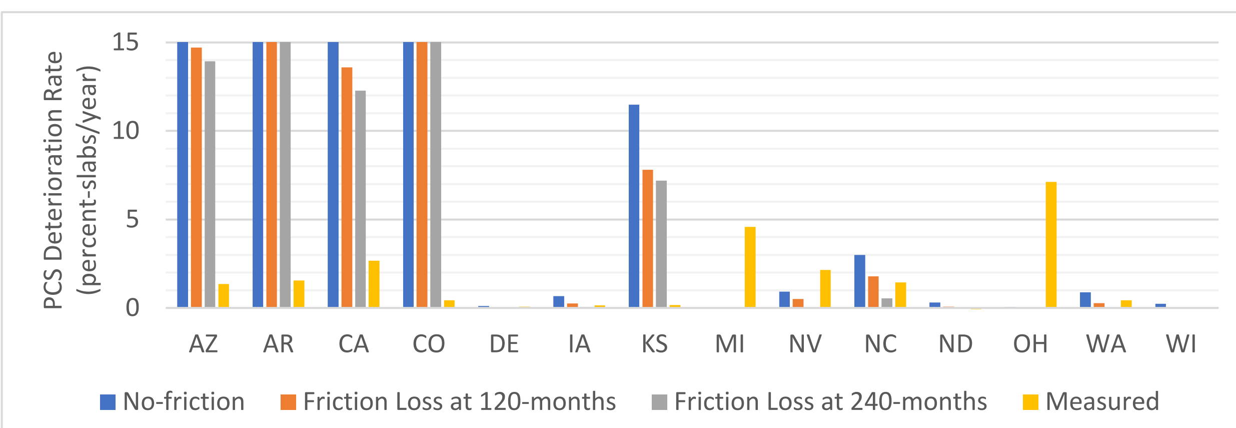


Figure A 3. Comparison Between Measured and Predicted Deterioration Rates for PCS on Average by State.

2. Thick Pavements

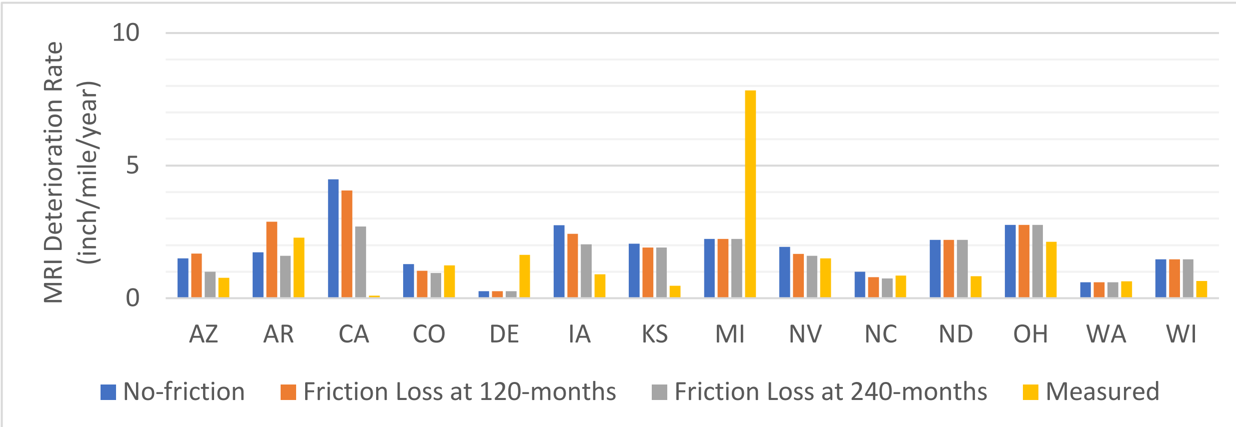


Figure A 4. Comparison Between Measured and Predicted Deterioration Rates for MRI on Average by State.

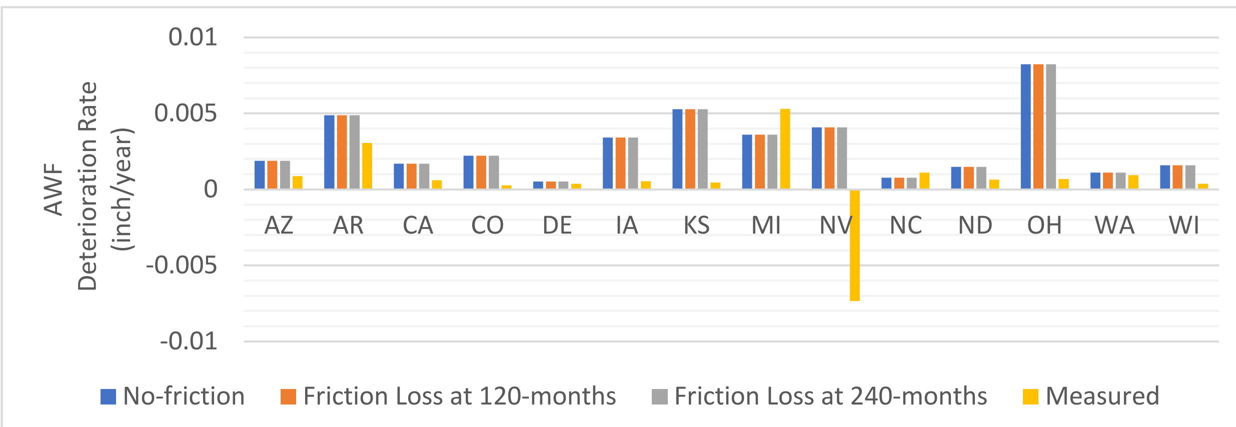


Figure A 5. Comparison Between Measured and Predicted Deterioration Rates for AWF on Average by State.

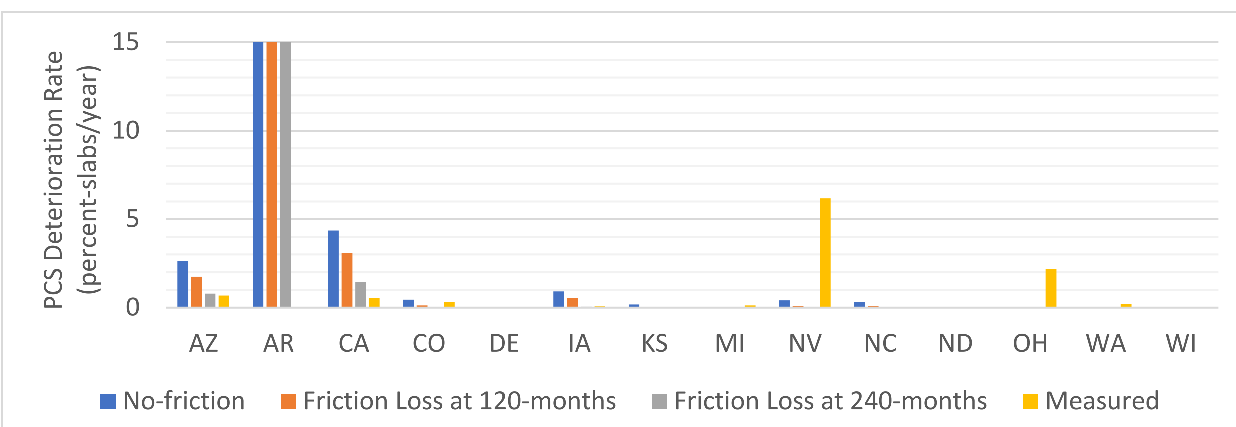


Figure A 6. Comparison Between Measured and Predicted Deterioration Rates for PCS on Average by State.

3. DGAB Base

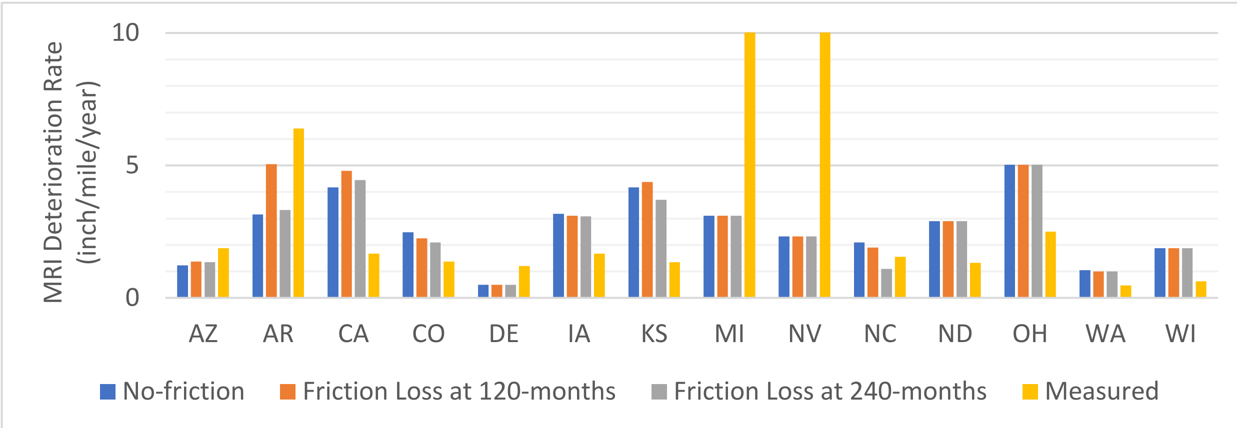


Figure A 7. Comparison Between Measured and Predicted Deterioration Rates for MRI on Average by State.

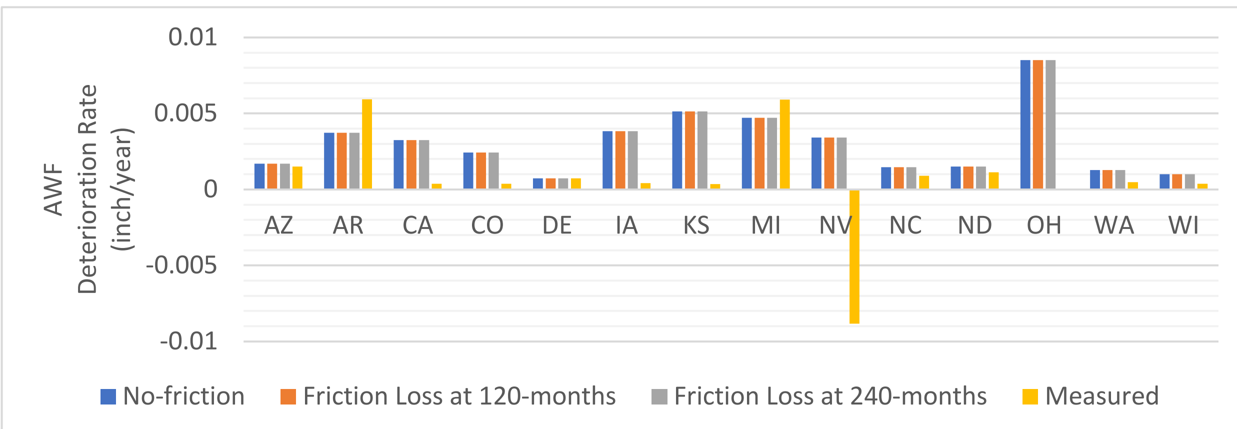


Figure A 8. Comparison Between Measured and Predicted Deterioration Rates for AWF on Average by State.

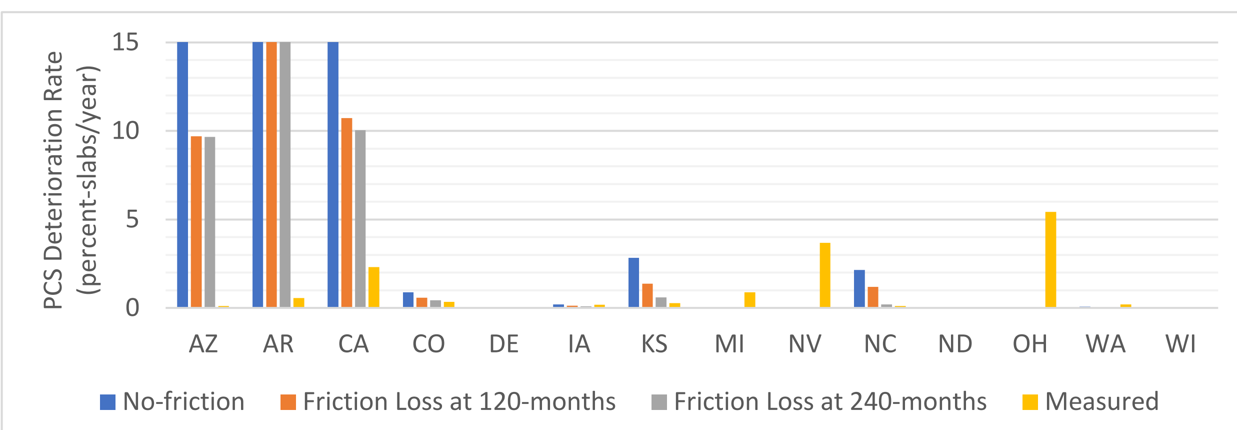


Figure A 9. Comparison Between Measured and Predicted Deterioration Rates for PCS on Average by State.

4. LCB Base

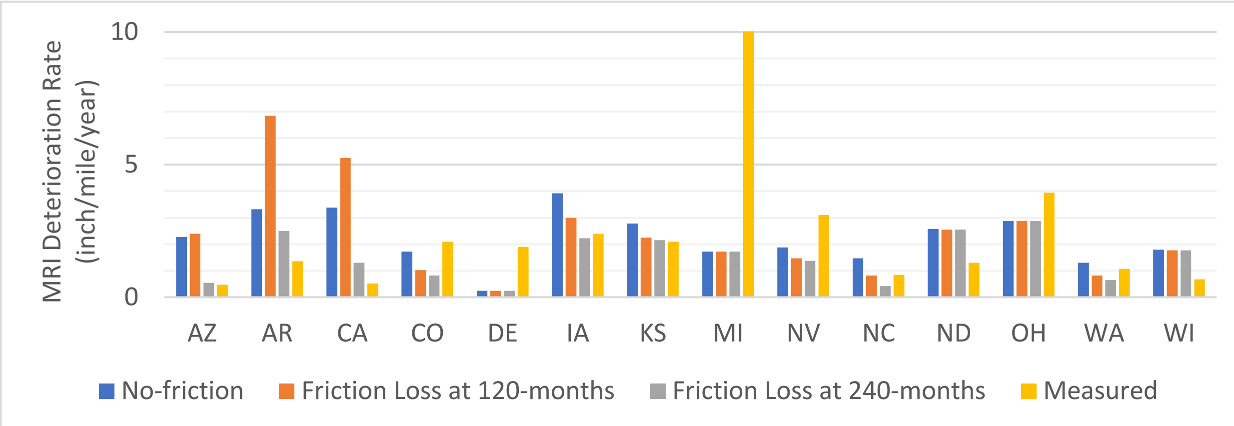


Figure A 10. Comparison Between Measured and Predicted Deterioration Rates for MRI on Average by State.

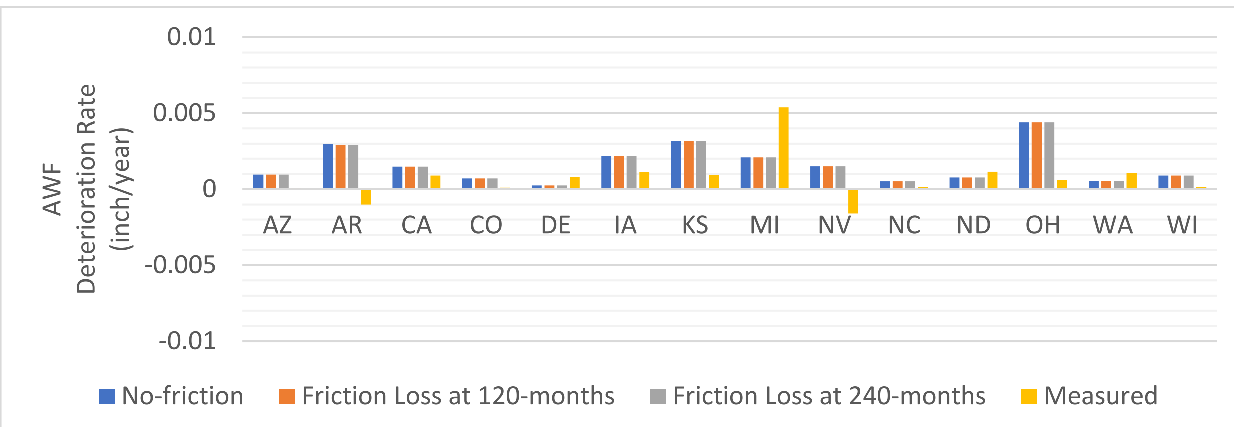


Figure A 11. Comparison Between Measured and Predicted Deterioration Rates for AWF on Average by State.

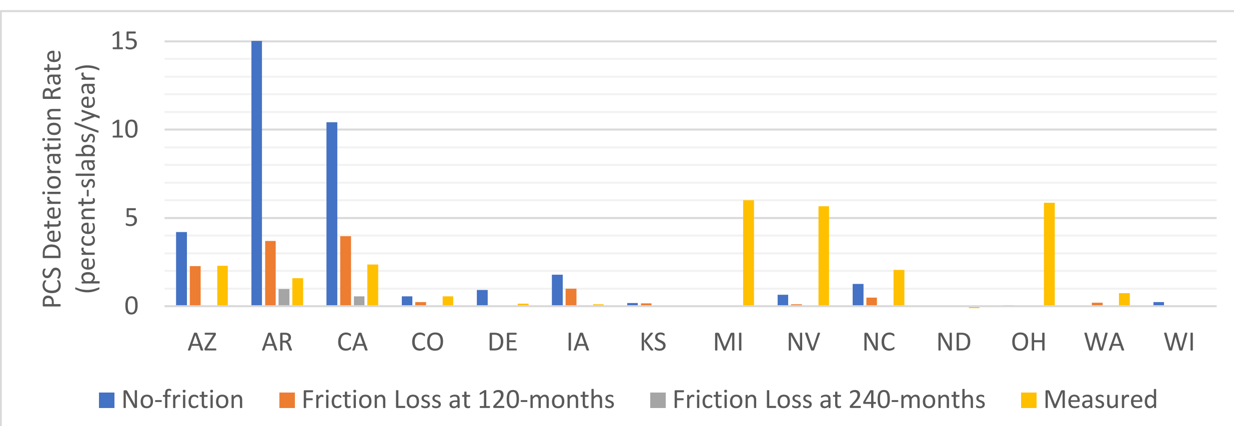


Figure A 12. Comparison Between Measured and Predicted Deterioration Rates for PCS on Average by State.

5. PATB Base

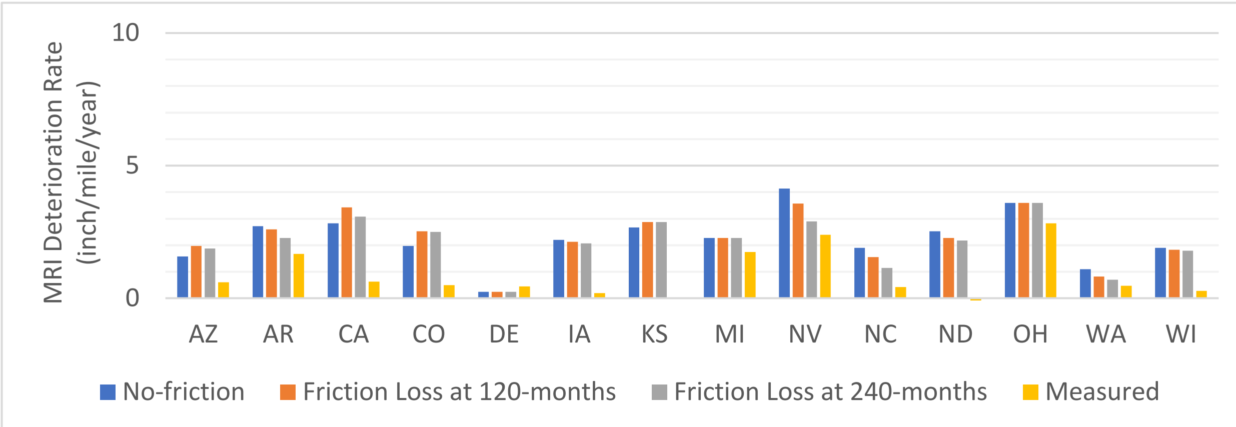


Figure A 13. Comparison Between Measured and Predicted Deterioration Rates for MRI on Average by State.

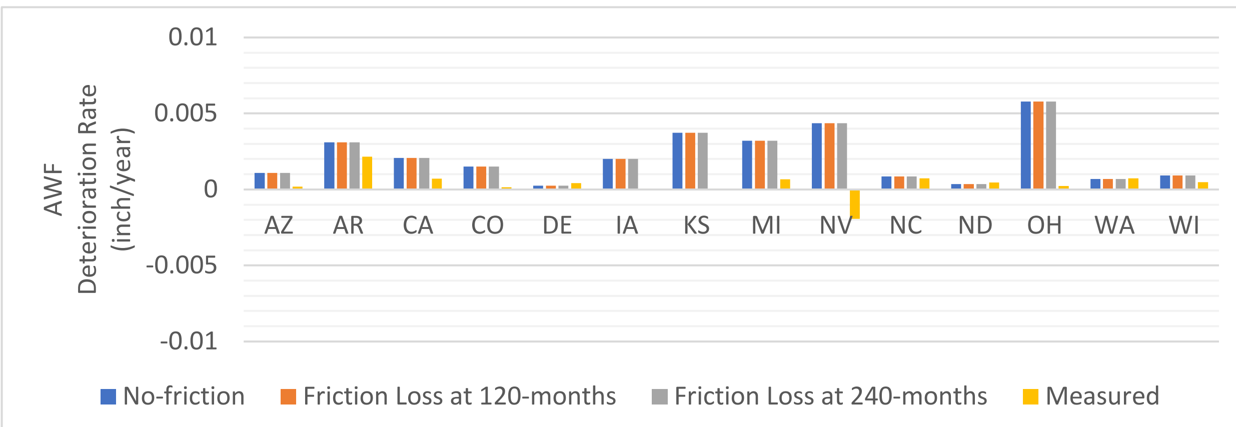


Figure A 14. Comparison Between Measured and Predicted Deterioration Rates for AWF on Average by State.

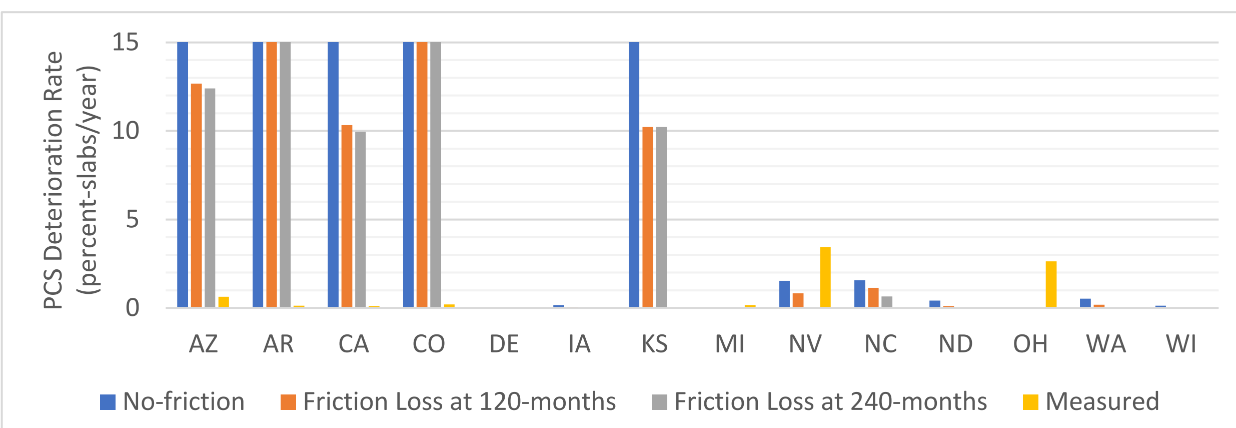


Figure A 15. Comparison Between Measured and Predicted Deterioration Rates for PCS on Average by State.

6. Low-Strength PCC

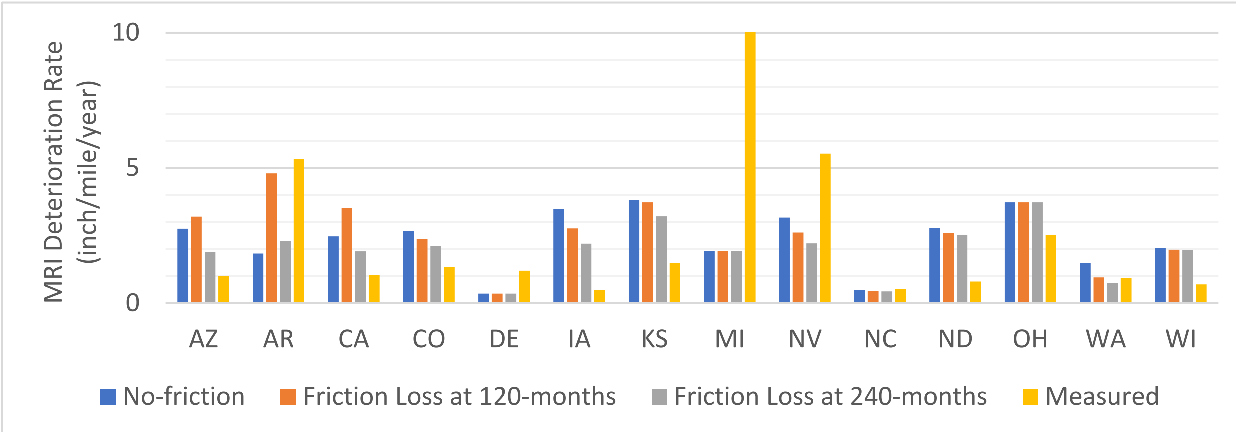


Figure A 16. Comparison Between Measured and Predicted Deterioration Rates for MRI on Average by State.

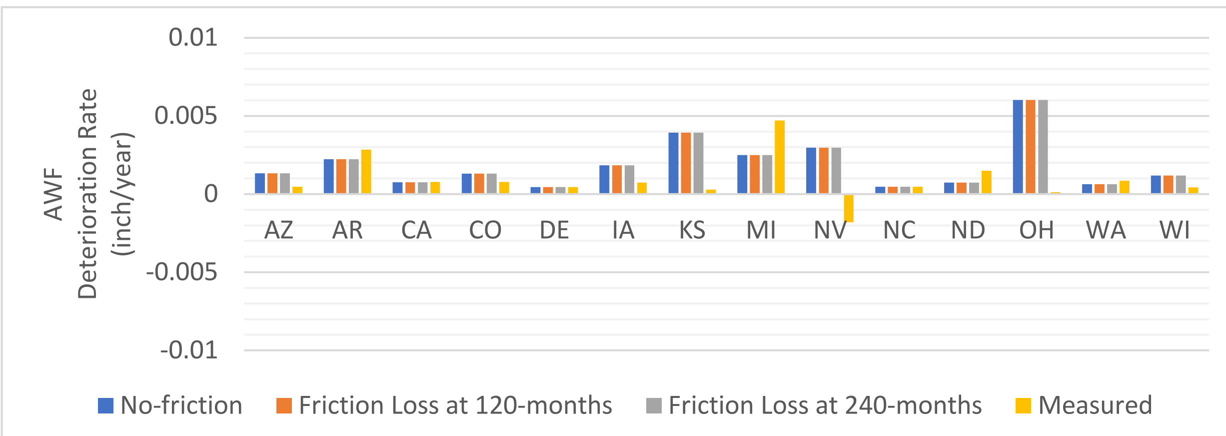


Figure A 17. Comparison Between Measured and Predicted Deterioration Rates for AWF on Average by State.

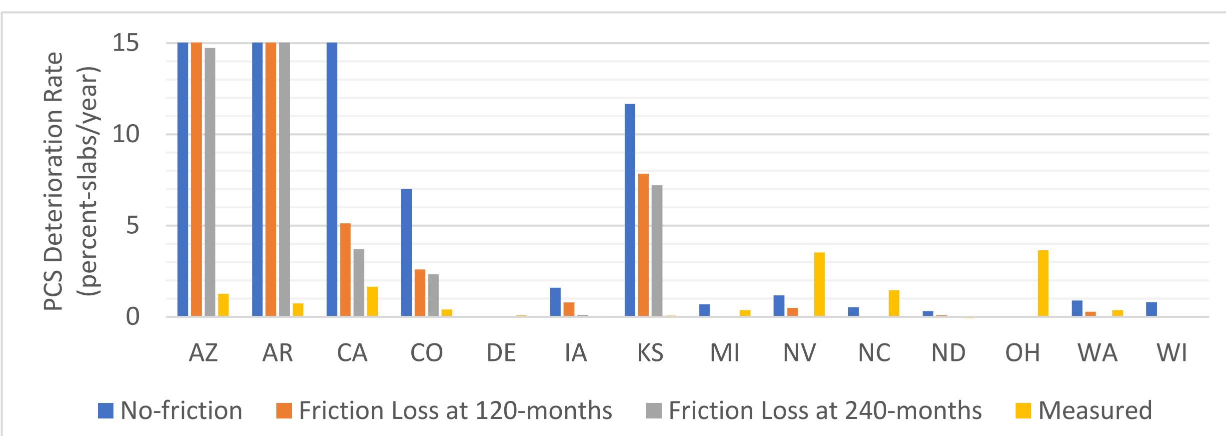
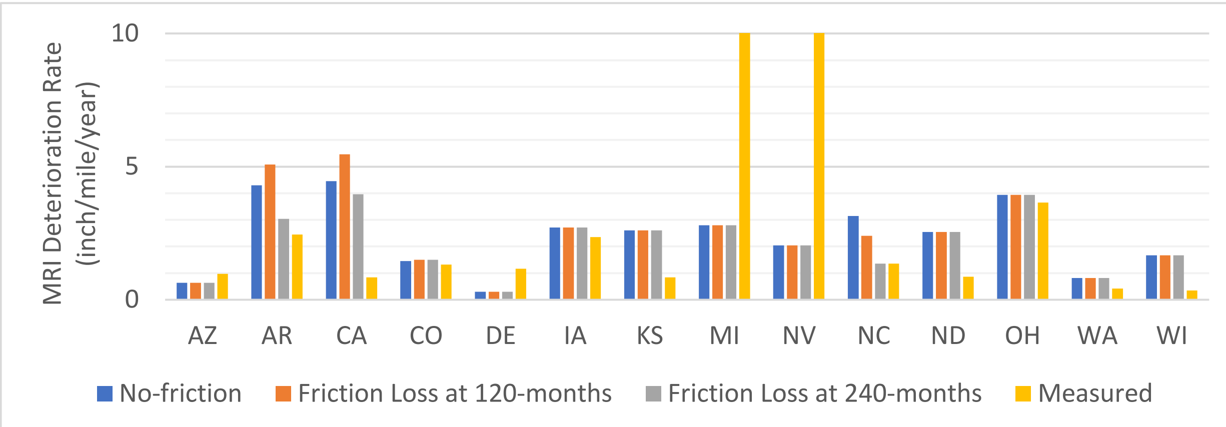


Figure A 18. Comparison Between Measured and Predicted Deterioration Rates for PCS on Average by State.

7. HIGH-STRENGTH PCC

Figure A 19. Comparison Between Measured and Predicted Deterioration Rates for MRI on Average by State.



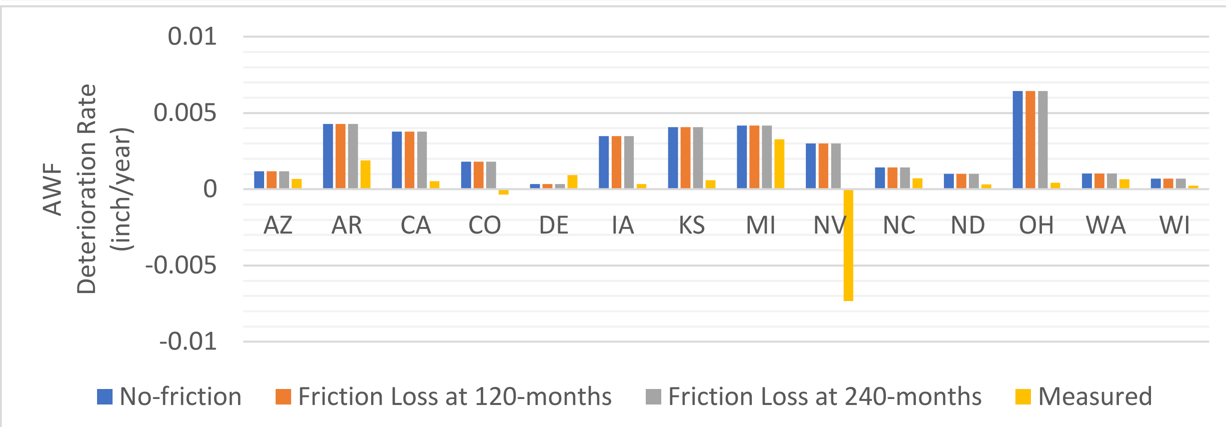


Figure A 20. Comparison Between Measured and Predicted Deterioration Rates for AWF on Average by State.

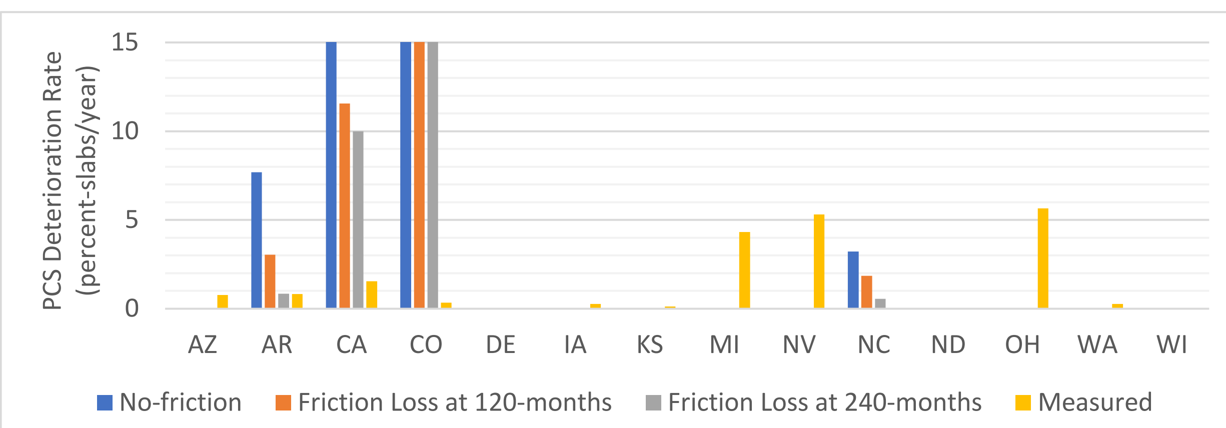


Figure A 21. Comparison Between Measured and Predicted Deterioration Rates for PCS on Average by State.

8. Standard Lane Width

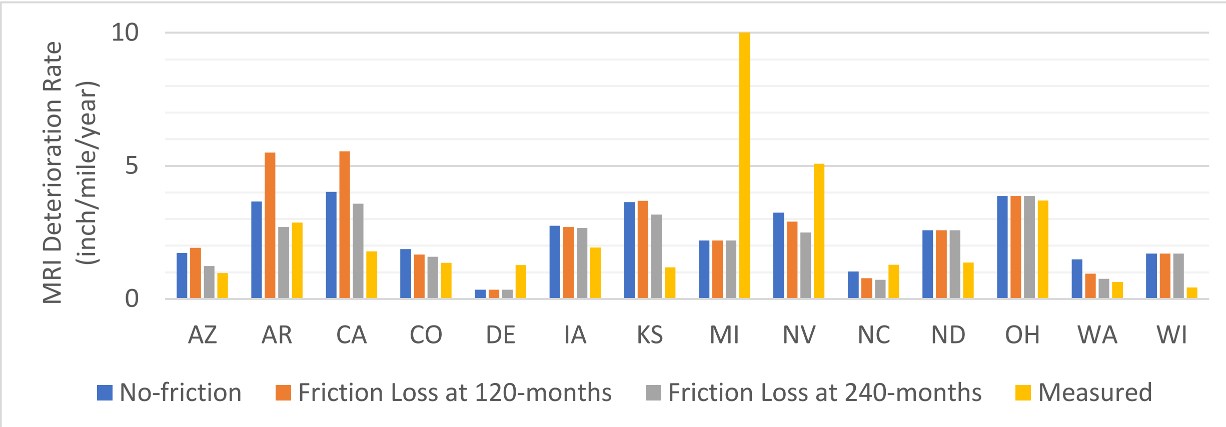


Figure A 22. Comparison Between Measured and Predicted Deterioration Rates for MRI on Average by State.

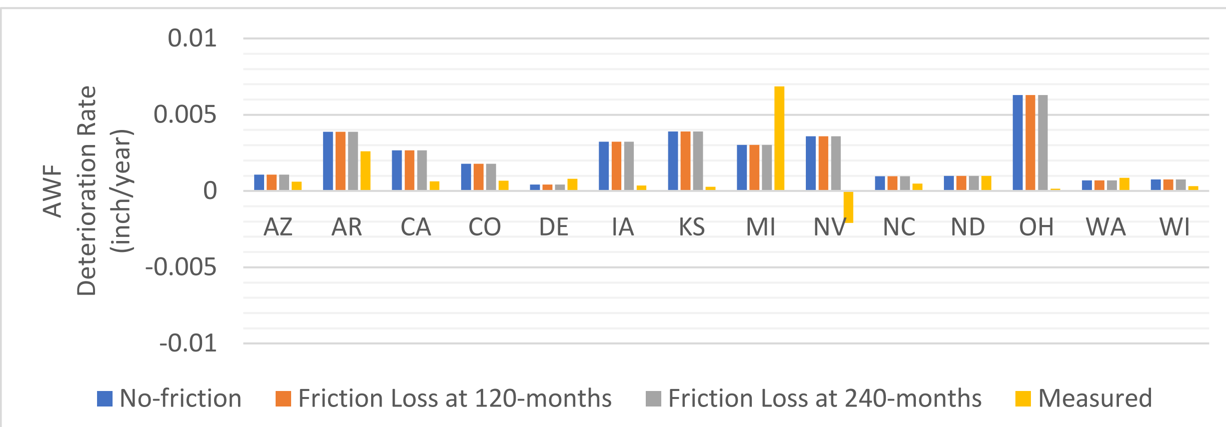


Figure A 23. Comparison Between Measured and Predicted Deterioration Rates for AWF on Average by State.

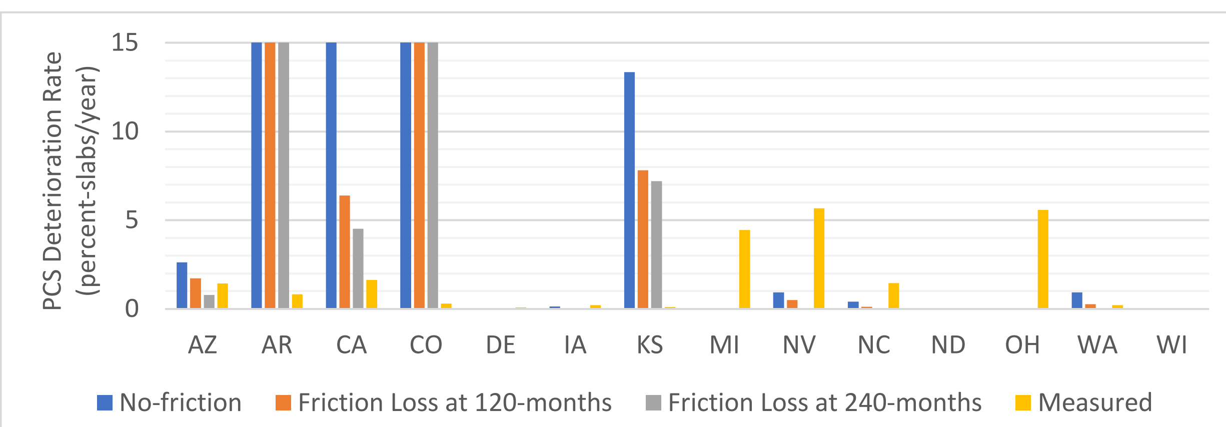


Figure A 24. Comparison Between Measured and Predicted Deterioration Rates for PCS on Average by State.

9. WIDENED LANE WIDTH

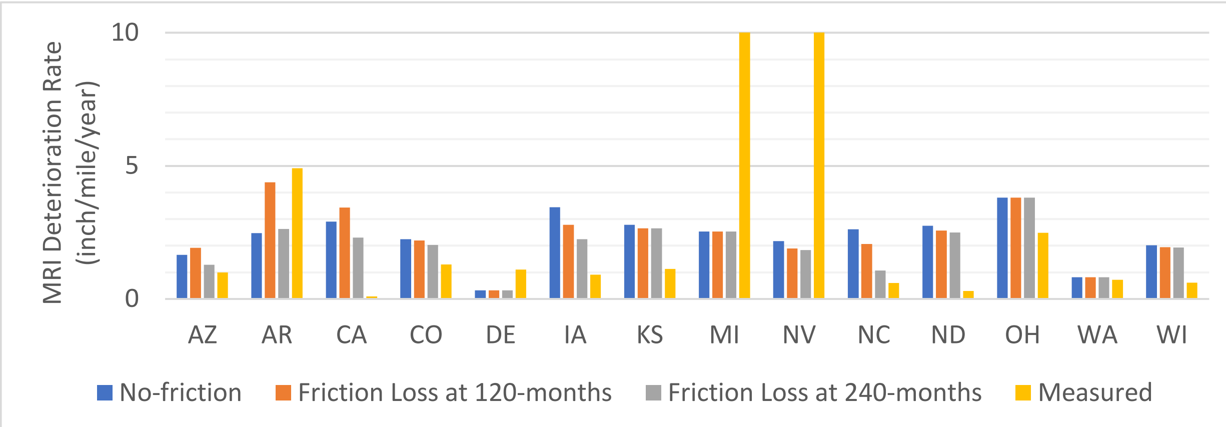


Figure A 25. Comparison Between Measured and Predicted Deterioration Rates for MRI on Average by State.

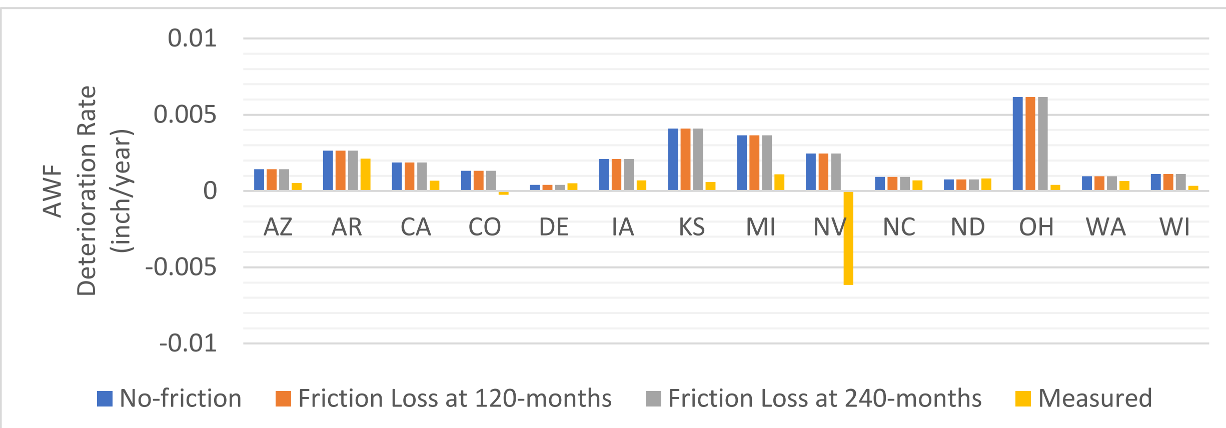


Figure A 26. Comparison Between Measured and Predicted Deterioration Rates for AWF on Average by State.

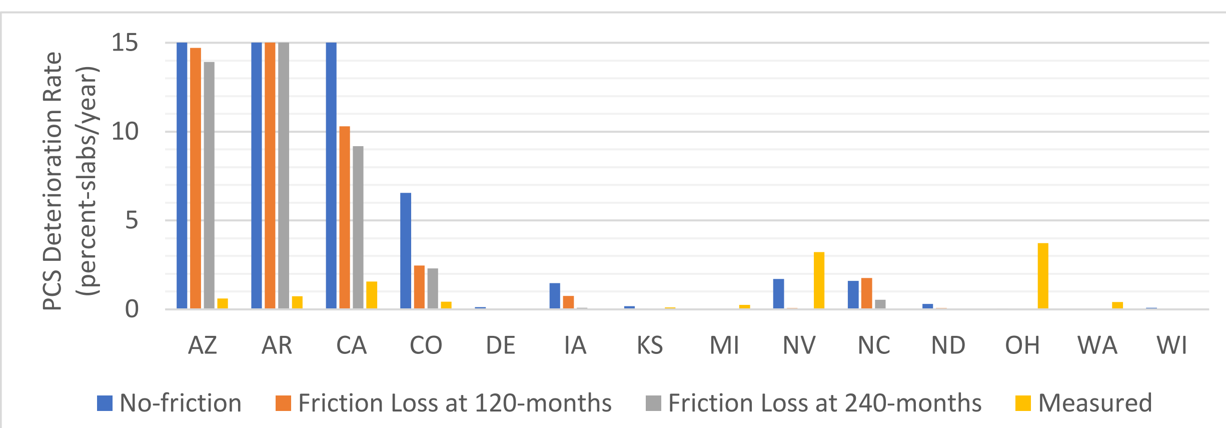


Figure A 27. Comparison Between Measured and Predicted Deterioration Rates for PCS on Average by State.

Appendix B

PREDICTED DETERIORATION RATE (PDR) COMPARISONS

1. Thin Pavements

Table B 1. Average Change in Predicted Deterioration Rate (PDR) with a Change in the Friction-Loss Parameter.

State	Average Percent Difference between Bonded and Unbonded Condition in PDR by State (%)					
	[120 Months PDR] vs. [No-Friction PDR]			[240 Months PDR] vs. [No-Friction PDR]		
	MRI	AWF	PCS	MRI	AWF	PCS
AZ	14.2	0	-75.1	1.5	0	-85.1
AR	89.5	0	-66.1	-3.8	0	-84.8
CA	123.7	0	-74.2	28.7	0	-78.7
CO	-0.2	0	-53.1	-5	0	-63
DE	0	0	N/A	0	0	N/A
IA	-8.4	0	-53.8	-11.9	0	-76.1
KS	-0.4	0	-58	-7.7	0	-86.2
MI	0	0	-50	0	0	-100
NV	-4.5	0	-72.9	-9.7	0	-98.5
NC	-20.1	0	-58.2	-43.1	0	-87.3
ND	-4.9	0	-85.3	-6.6	0	-98.7
OH	0	0	-41.5	0	0	-43.9
WA	-19.4	0	-72.1	-26.2	0	-97.4
WI	-2.5	0	-83.8	-3.1	0	-99

N/A – PDR could not be predicted because there was no deterioration

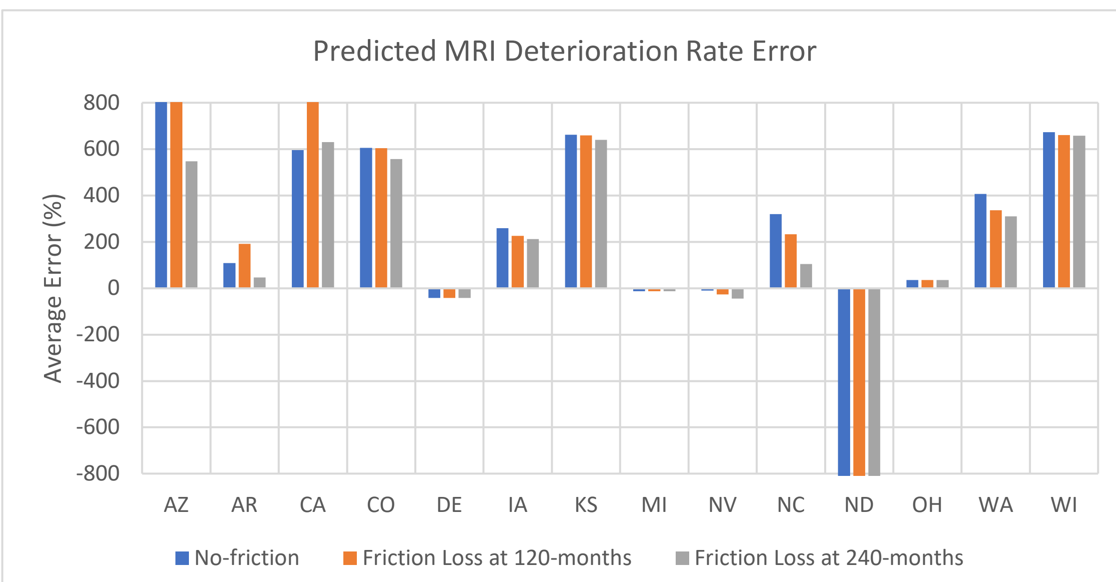


Figure B 1. Average Error (%) Between MRI Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

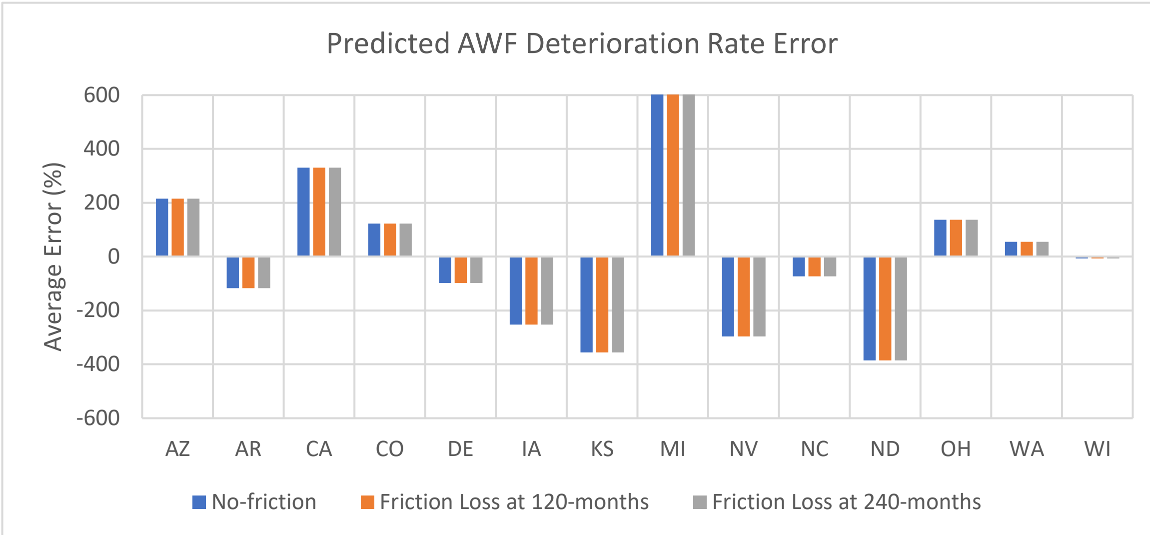


Figure B 2. Average Error (%) Between AWF Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

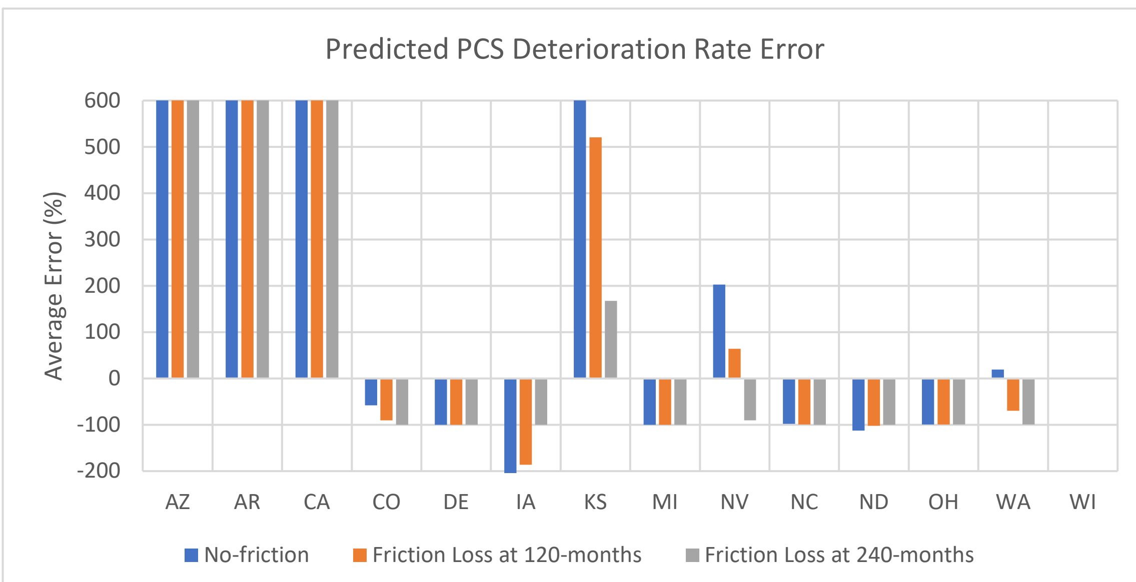


Figure B 3. Average Error (%) Between PCS Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

2. Thick Pavements

Table B 2. Average Change in Predicted Deterioration Rate (PDR) with a Change in the Friction-Loss Parameter.

State	Average of the PDR Difference between Bonded and Unbonded Condition (%) by State					
	[120 Months PDR] vs. [No-Friction PDR]			[240 Months PDR] vs. [No-Friction PDR]		
	MRI	AWF	PCS	MRI	AWF	PCS
AZ	2.5	0	-54.4	-18.9	0	-79.1
AR	135.4	0	-41.6	2.5	0	-54.8
CA	-13.7	0	-29.8	-45.3	0	-62.3
CO	-8.9	0	-58.3	-12.5	0	-78.8
DE	0	0	-85.7	0	0	-100
IA	-6.9	0	-63.1	-14.7	0	-88.5
KS	-5.8	0	-80	-5.8	0	-96.5
MI	0	0	N/A	0	0	N/A
NV	-8.1	0	-81.1	-10.1	0	-100
NC	-12.1	0	-69	-16.8	0	-82.4
ND	0	0	-59.7	0	0	-77.8
OH	0	0	-33.3	0	0	-66.7
WA	0	0	-85.7	0	0	-100
WI	0	0	-41.7	0	0	-100

N/A – PDR could not be predicted because there was no deterioration

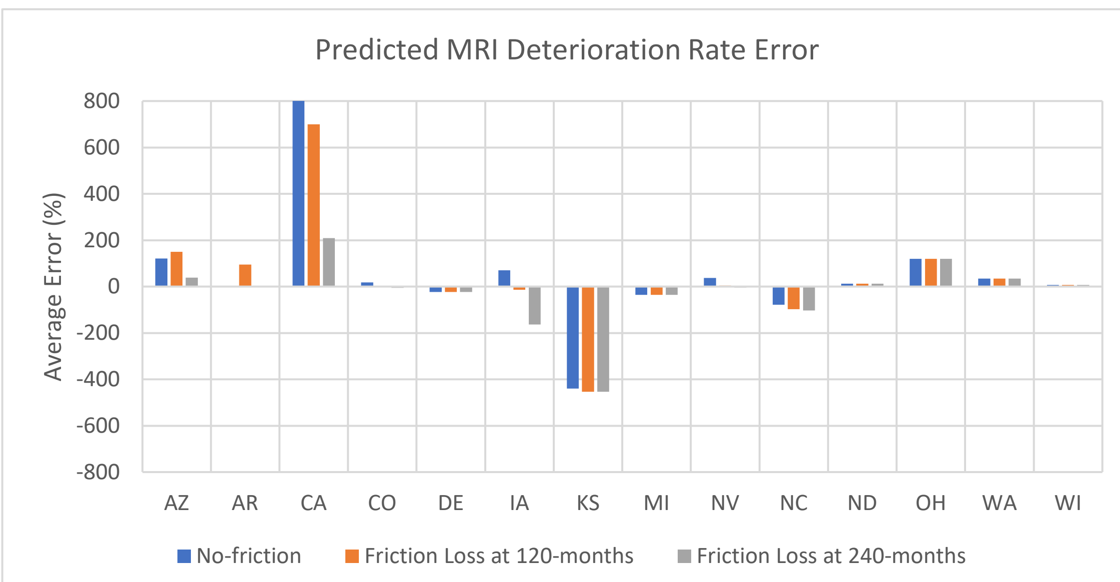


Figure B 4. Average Error (%) Between MRI Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

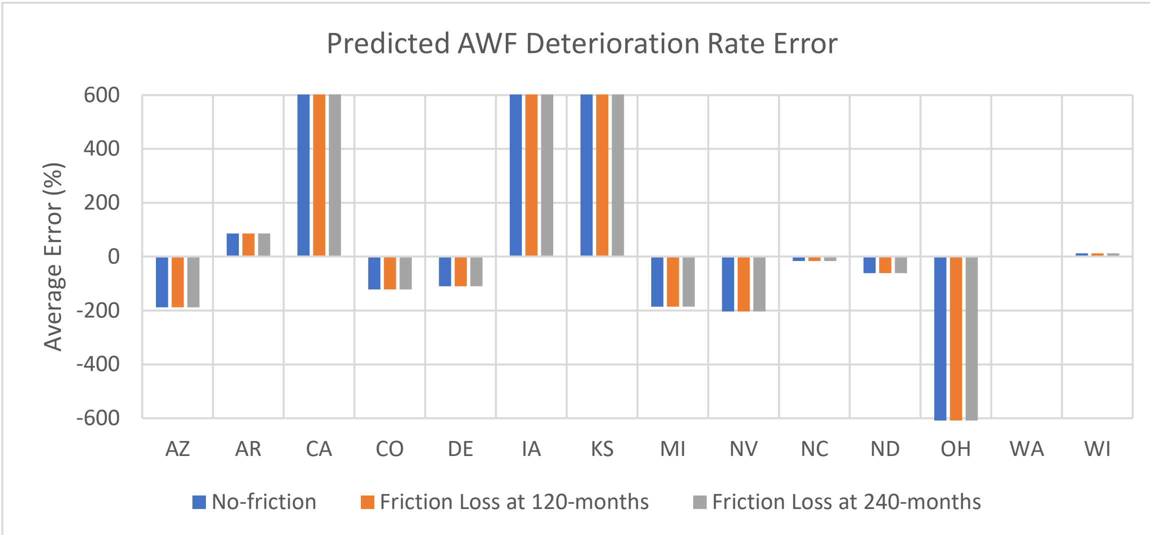


Figure B 5. Average Error (%) Between AWF Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

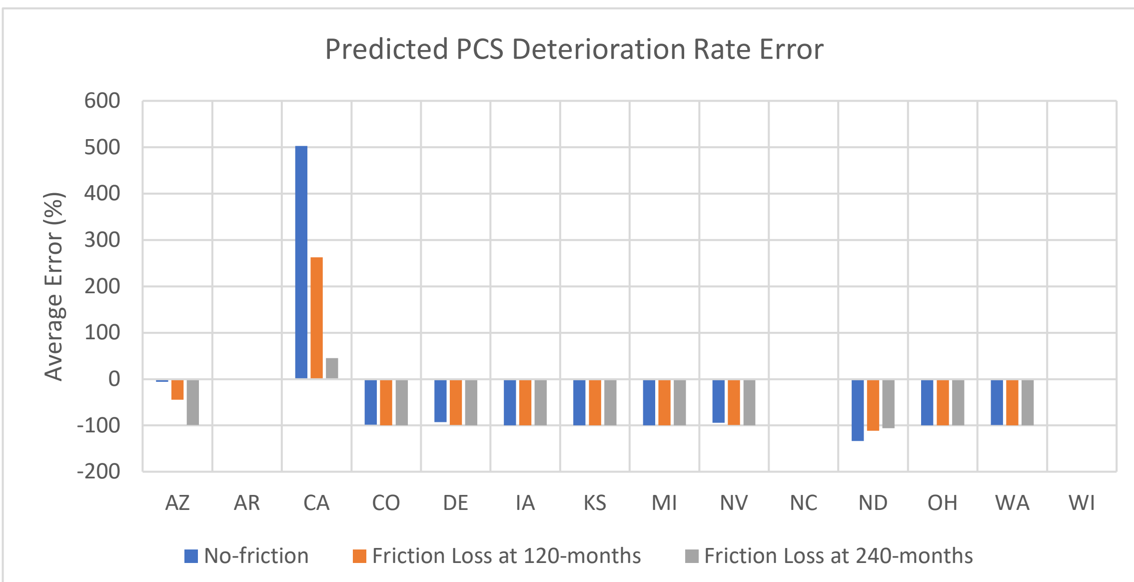


Figure B 6. Average Error (%) Between PCS Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

3. DGAB Base

Table B 3. Average Change in Predicted Deterioration Rate (PDR) with a Change in the Friction-Loss Parameter.

State	Average of the PDR Difference between Bonded and Unbonded Condition (%) by State					
	[120 Months PDR] vs. [No-Friction PDR]			[240 Months PDR] vs. [No-Friction PDR]		
	MRI	AWF	PCS	MRI	AWF	PCS
AZ	3.5	0	-75.8	0.8	0	-81.3
AR	52.6	0	-57.1	13.4	0	-64.9
CA	22.4	0	-39	13	0	-49.2
CO	-4.8	0	-29.5	-9.2	0	-45.6
DE	0	0	N/A	0	0	N/A
IA	-1.9	0	-24.8	-2.5	0	-37.6
KS	1.8	0	-72.2	-6.7	0	-92.6
MI	0	0	N/A	0	0	N/A
NV	0	0	-100	0	0	-100
NC	-7.2	0	-63.1	-22.8	0	-82.3
ND	0	0	-68.8	0	0	-75
OH	0	0	-24.2	0	0	-26.7
WA	-4.2	0	-76.6	-4.2	0	-97.9
WI	0	0	-43.8	0	0	-100

N/A – PDR could not be predicted because there was no deterioration

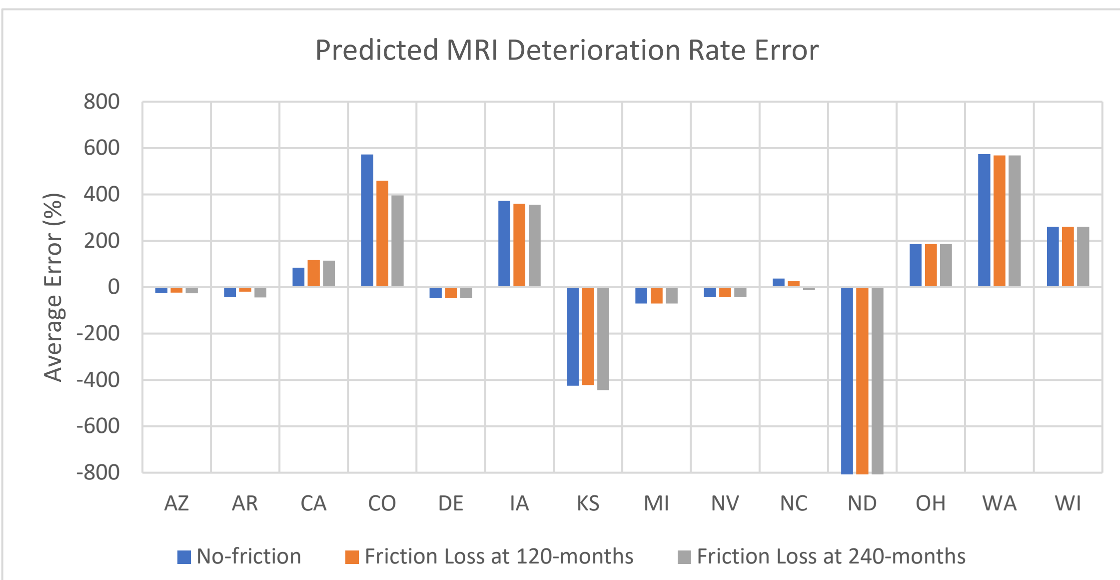


Figure B 7. Average Error (%) Between MRI Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

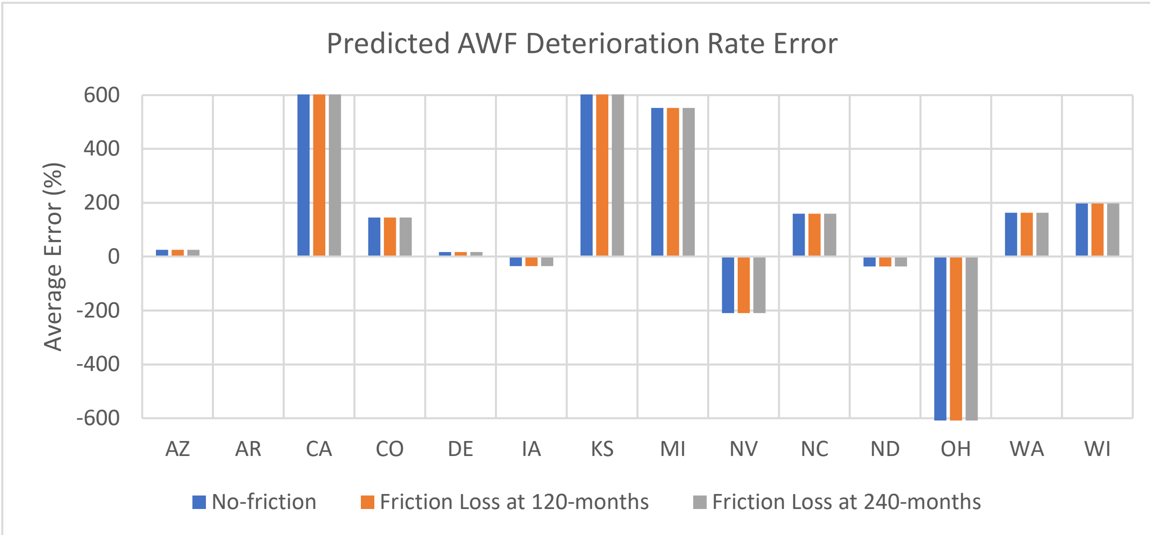


Figure B 8. Average Error (%) Between AWF Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

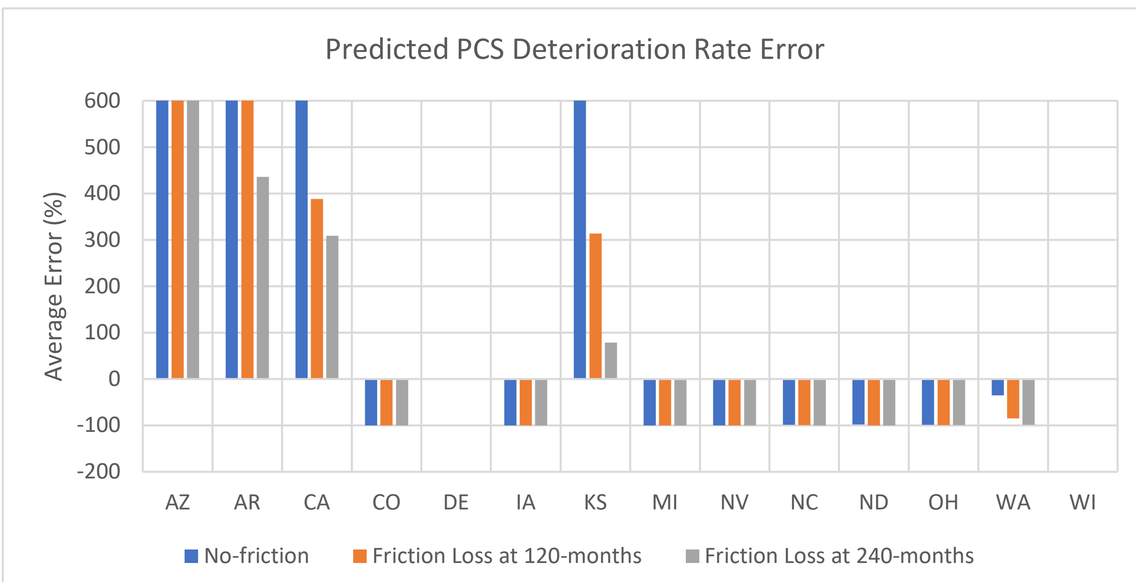


Figure B 9. Average Error (%) Between PCS Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

4. LCB Base

Table B 4. Average Change in Predicted Deterioration Rate (PDR) with a Change in the Friction-Loss Parameter.

State	Average of the PDR Difference between Bonded and Unbonded Condition (%) by State					
	[120 Months PDR] vs. [No-Friction PDR]			[240 Months PDR] vs. [No-Friction PDR]		
	MRI	AWF	PCS	MRI	AWF	PCS
AZ	3.4	0	-45.4	-42	0	-99.6
AR	277.4	0	-42.6	-17.4	0	-73.1
CA	110	0	-65.7	-60	0	-97.9
CO	-25.4	0	-77.6	-32.7	0	-100
DE	0	0	-85.7	0	0	-100
IA	-17.5	0	-73.1	-31.4	0	-98.9
KS	-15.2	0	-87.8	-17.6	0	-99.8
MI	0	0	N/A	0	0	N/A
NV	-12.1	0	-81.1	-15.2	0	-100
NC	-22.5	0	-75.9	-35	0	-100
ND	-1	0	-74.3	-1	0	-90.8
OH	0	0	-68.3	0	0	-95.7
WA	-14	0	-79.9	-19.1	0	-100
WI	-1	0	-84.8	-1	0	-100

N/A – PDR could not be predicted because there was no deterioration

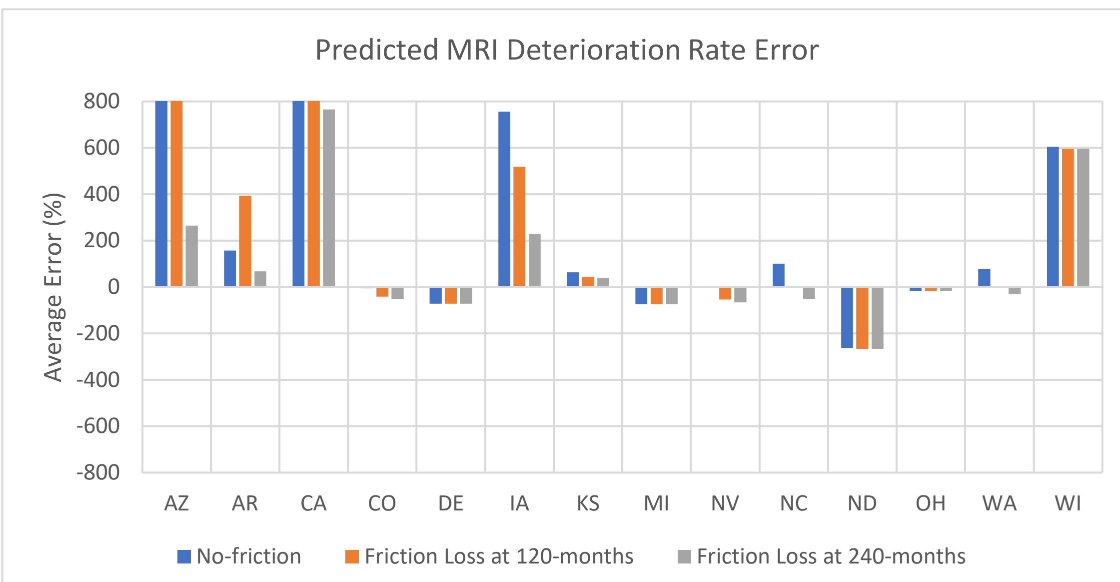


Figure B 10. Average Error (%) Between MRI Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

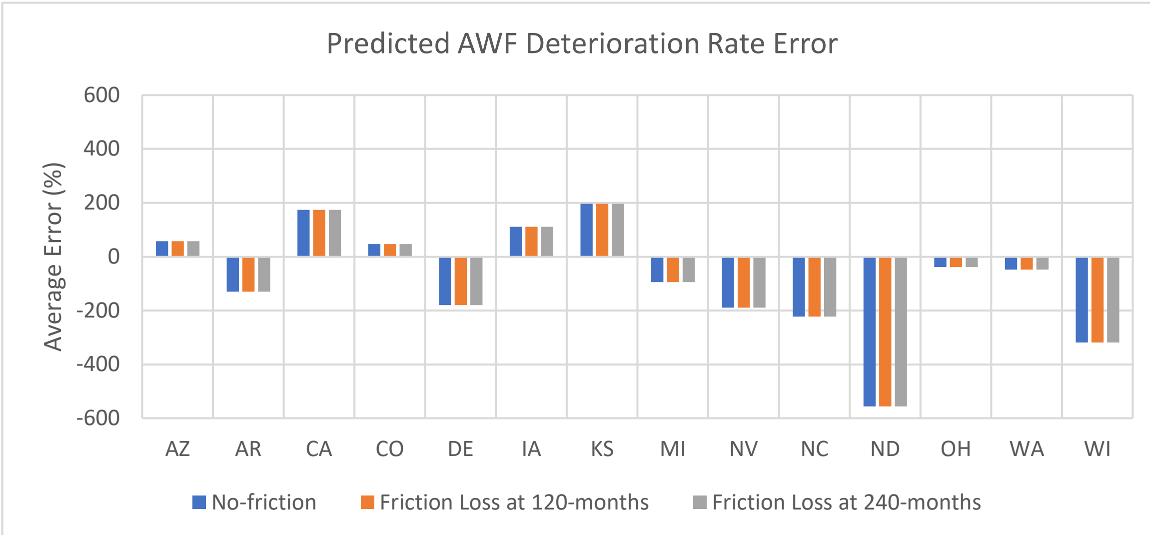


Figure B 11. Average Error (%) Between AWF Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

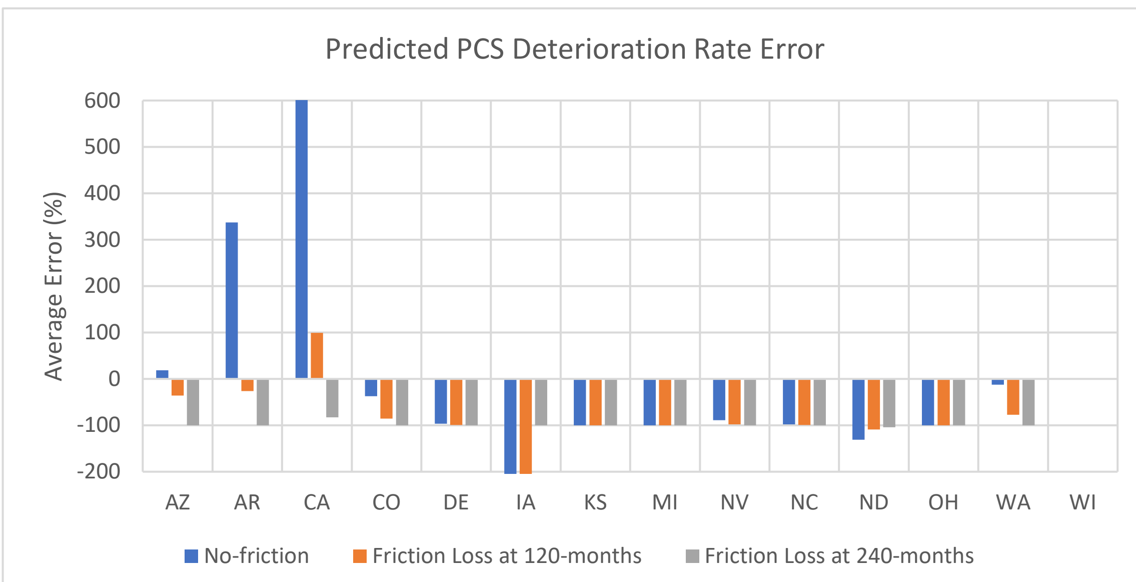


Figure B 12. Average Error (%) Between PCS Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

5. PATB Base

Table B 5. Average Change in Predicted Deterioration Rate (PDR) with a Change in the Friction-Loss Parameter.

State	Average of the PDR Difference between Bonded and Unbonded Condition (%) by State					
	[120 Months PDR] vs. [No-Friction PDR]			[240 Months PDR] vs. [No-Friction PDR]		
	MRI	AWF	PCS	MRI	AWF	PCS
AZ	18.1	0	-63.4	15.2	0	-74.1
AR	7.5	0	-56.2	2.1	0	-73
CA	32.6	0	-51.3	22.1	0	-64.4
CO	16.5	0	-57.6	15.7	0	-65.6
DE	0	0	N/A	0	0	N/A
IA	-3.6	0	-67.9	-6	0	-97.6
KS	4.1	0	-36.1	4.1	0	-76.5
MI	0	0	-50	0	0	-100
NV	-7.5	0	-45.7	-16.2	0	-96.9
NC	-18.7	0	-53.5	-31.9	0	-76.7
ND	-6.4	0	-74.5	-9	0	-98.9
OH	0	0	-28	0	0	-20.8
WA	-11	0	-65.5	-16	0	-94.2
WI	-2.8	0	-77.5	-3.7	0	-97

N/A – PDR could not be predicted because there was no deterioration

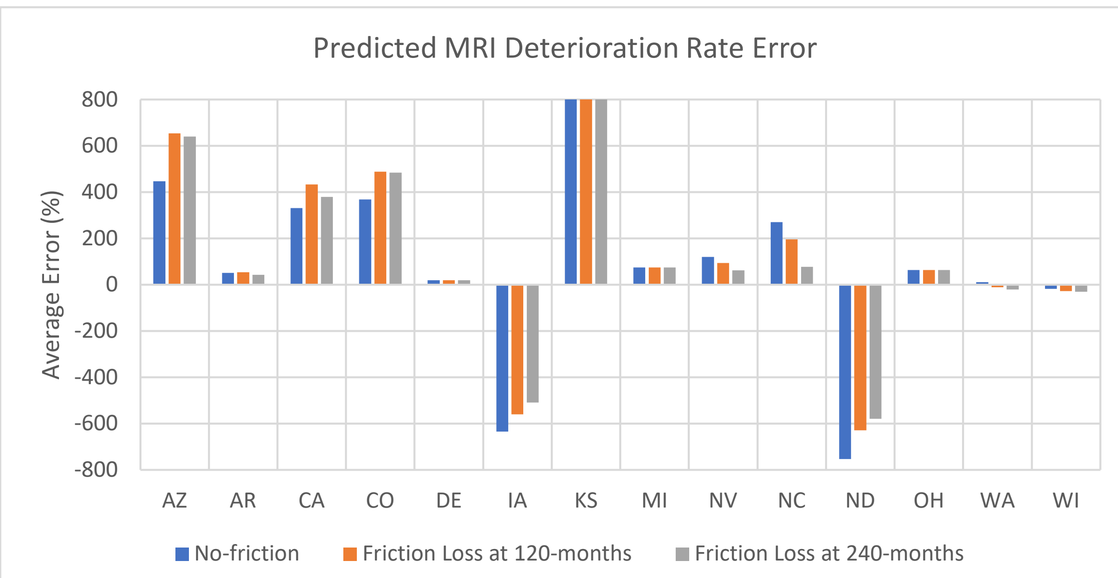


Figure B 13. Average Error (%) Between MRI Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

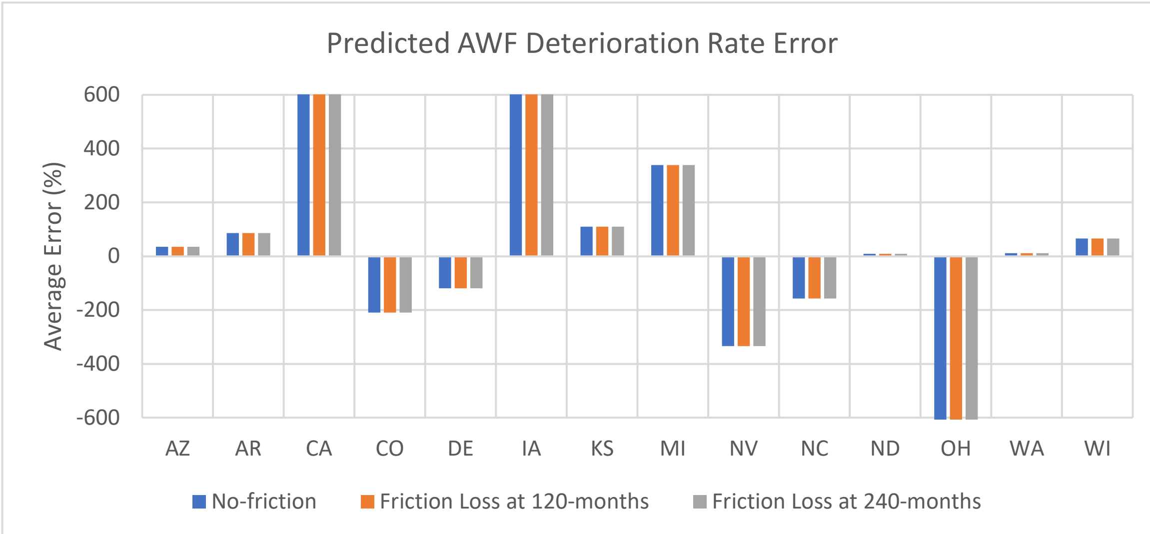


Figure B 14. Average Error (%) Between AWF Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

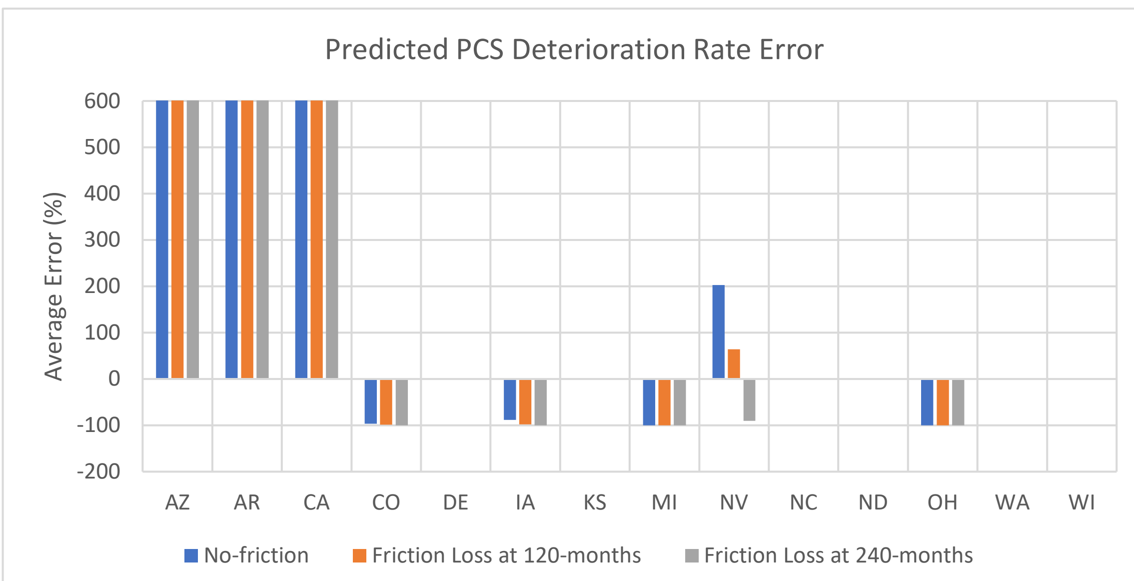


Figure B 15. Average Error (%) Between PCS Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

6. Low-Strength PCC

Table B 6. Average Change in Predicted Deterioration Rate (PDR) with a Change in the Friction-Loss Parameter.

State	Average of the PDR Difference between Bonded and Unbonded Condition (%) by State					
	[120 Months PDR] vs. [No-Friction PDR]			[240 Months PDR] vs. [No-Friction PDR]		
	MRI	AWF	PCS	MRI	AWF	PCS
AZ	16.7	0	-48.4	-17.4	0	-72.5
AR	212.2	0	-55.6	20.6	0	-56.4
CA	75.7	0	-57.5	-14.3	0	-77.3
CO	-11.1	0	-58.9	-19.4	0	-75.7
DE	0	0	-85.7	0	0	-100
IA	-15.3	0	-55	-26.6	0	-83.1
KS	-6.2	0	-67.7	-13.4	0	-84.4
MI	0	0	-50	0	0	-100
NV	-11.8	0	-75.6	-18.2	0	-99
NC	-8.1	0	-69.7	-10.5	0	-83.5
ND	-4.9	0	-72.5	-6.6	0	-88.3
OH	0	0	-33.5	0	0	-38.3
WA	-19.4	0	-75.5	-26.2	0	-98
WI	-2.5	0	-66.9	-3.1	0	-99.4

N/A – PDR could not be predicted because there was no deterioration

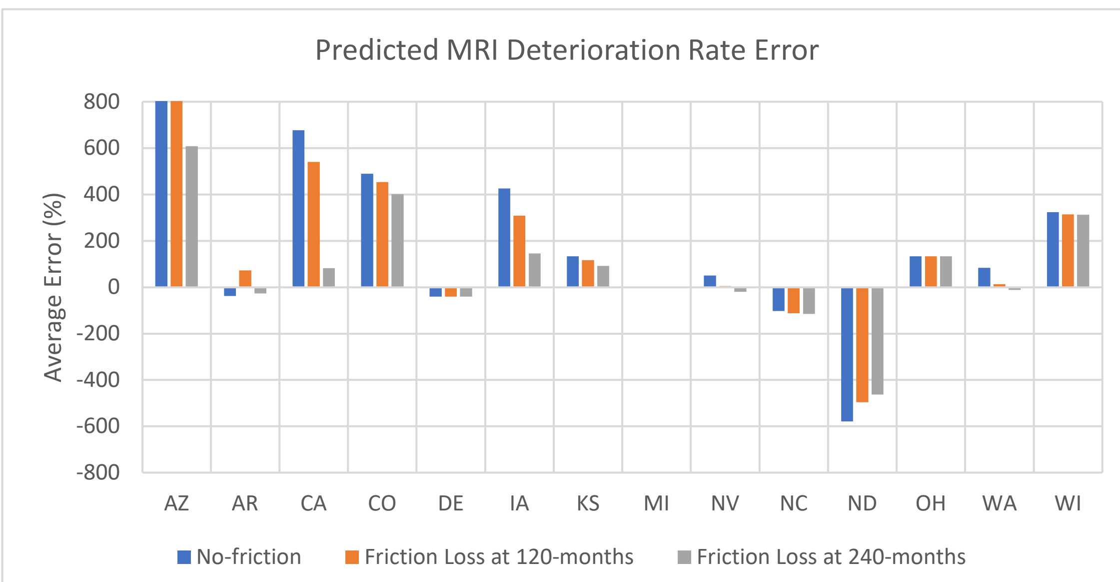


Figure B 16. Average Error (%) Between MRI Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

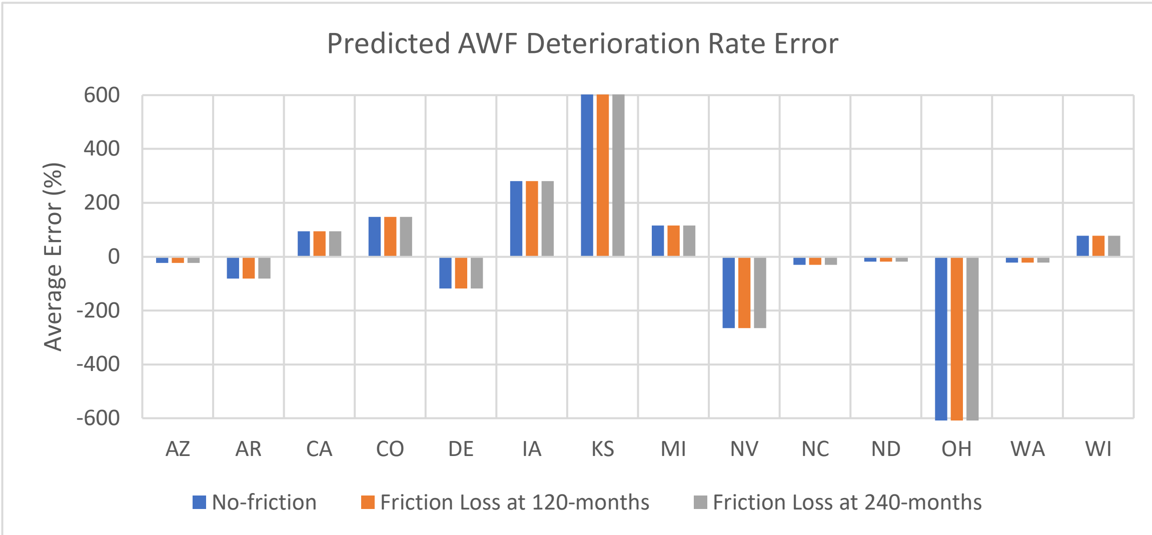


Figure B 17. Average Error (%) Between AWF Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

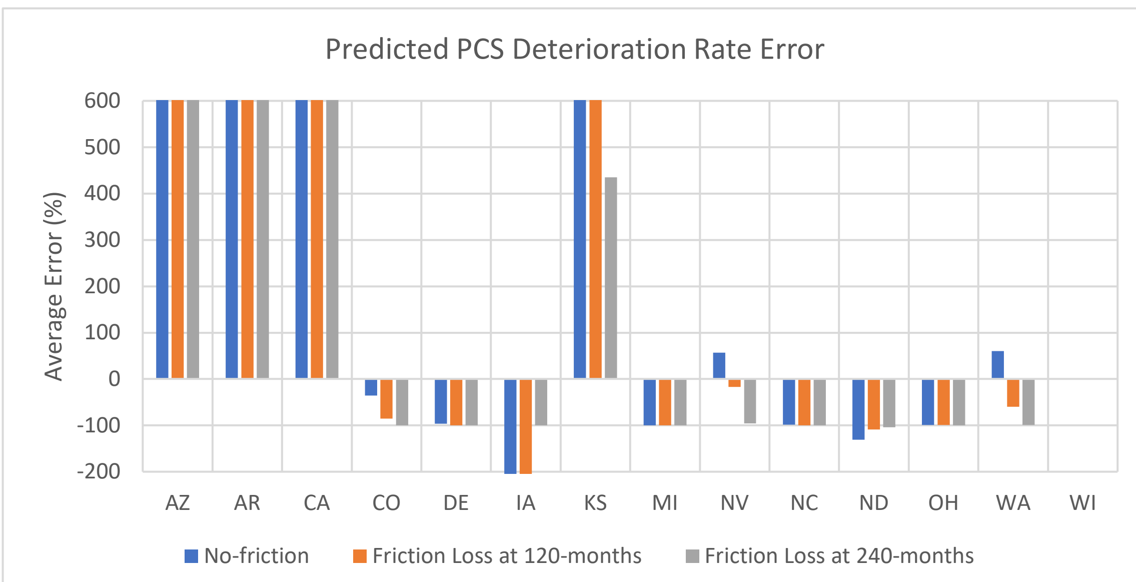


Figure B 18. Average Error (%) Between PCS Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

7. High-Strength PCC

Table B 7. Average Change in Predicted Deterioration Rate (PDR) with a Change in the Friction-Loss Parameter.

State	Average of the PDR Difference between Bonded and Unbonded Condition (%) by State					
	[120 Months PDR] vs. [No-Friction PDR]			[240 Months PDR] vs. [No-Friction PDR]		
	MRI	AWF	PCS	MRI	AWF	PCS
AZ	0	0	-89.3	0	0	-96.4
AR	12.7	0	-52.6	-21.9	0	-78.7
CA	34.3	0	-46.5	-2.4	0	-63.7
CO	1.9	0	-33.8	1.9	0	-33.8
DE	0	0	N/A	0	0	N/A
IA	0	0	-61.7	0	0	-80
KS	0	0	-60.6	0	0	-100
MI	0	0	N/A	0	0	N/A
NV	0	0	N/A	0	0	N/A
NC	-24.1	0	-57.6	-49.4	0	-86.4
ND	0	0	N/A	0	0	N/A
OH	0	0	-53.4	0	0	-66.5
WA	0	0	N/A	0	0	N/A
WI	0	0	N/A	0	0	N/A

N/A – PDR could not be predicted because there was no deterioration

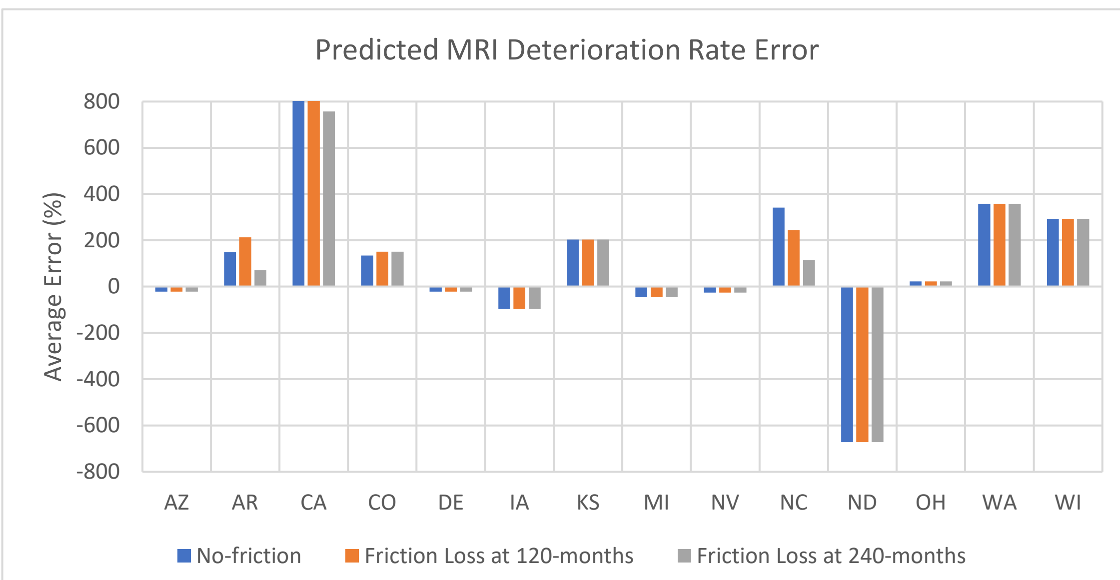


Figure B 19. Average Error (%) Between MRI Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

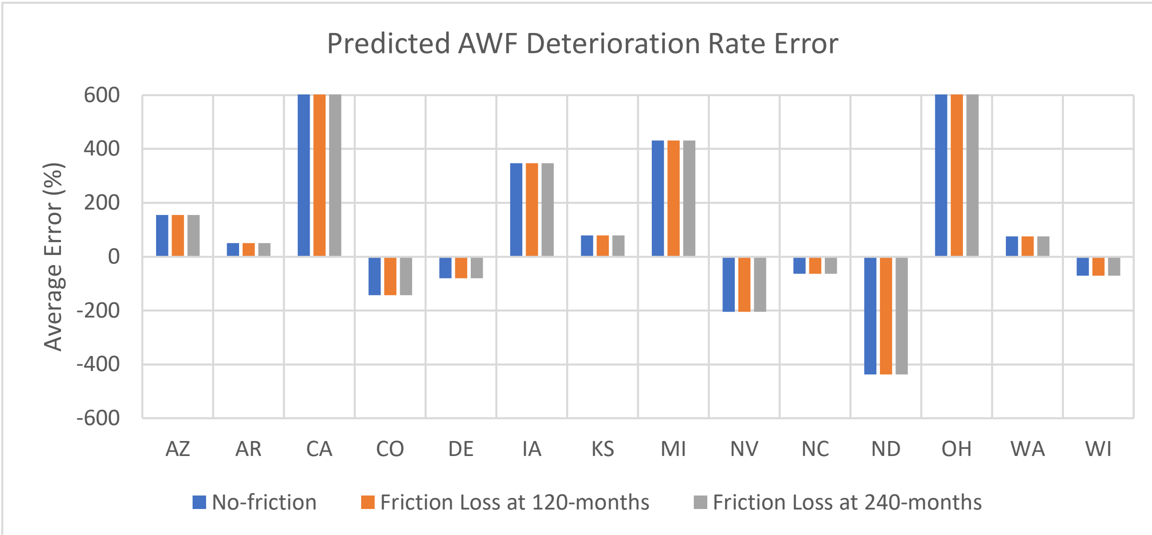


Figure B 20. Average Error (%) Between AWF Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

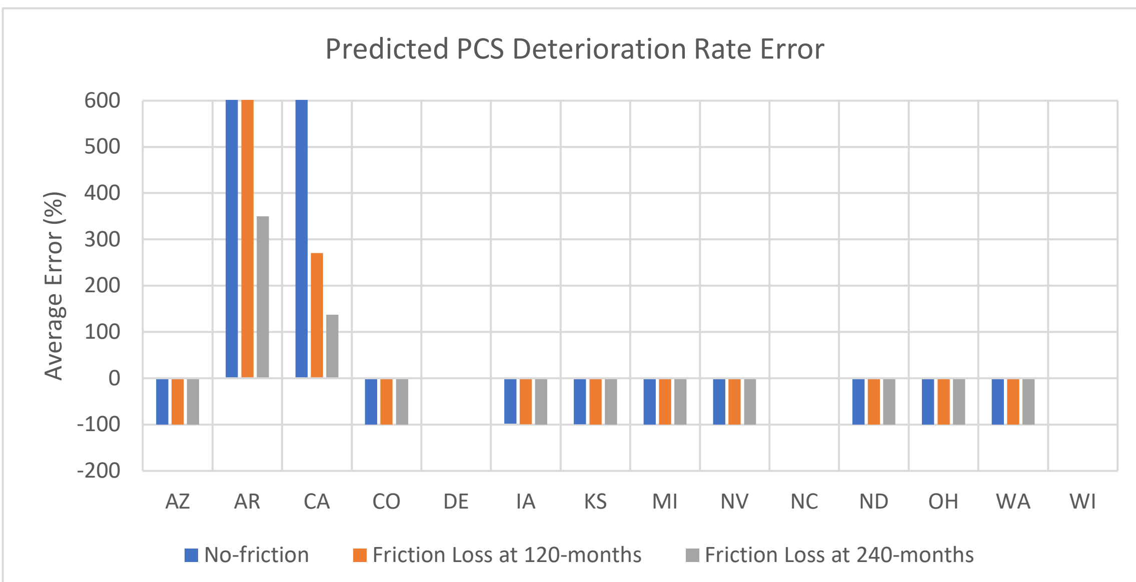


Figure B 21. Average Error (%) Between PCS Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

8. Standard Lane Width

Table B 8. Average Change in Predicted Deterioration Rate (PDR) with a Change in the Friction-Loss Parameter.

State	Average of the PDR Difference between Bonded and Unbonded Condition (%) by State					
	[120 Months PDR] vs. [No-Friction PDR]			[240 Months PDR] vs. [No-Friction PDR]		
	MRI	AWF	PCS	MRI	AWF	PCS
AZ	2.5	0	-63	-18.9	0	-81.9
AR	146	0	-50	-9.9	0	-68.1
CA	91.5	0	-46.5	-0.6	0	-64.3
CO	-7	0	-52.2	-10.6	0	-67.5
DE	0	0	N/A	0	0	N/A
IA	-2.4	0	-47	-4	0	-69.4
KS	-0.4	0	-55.5	-7.7	0	-72.4
MI	0	0	N/A	0	0	N/A
NV	-4.5	0	-72.9	-9.7	0	-98.5
NC	-20.2	0	-76.7	-27.2	0	-93.8
ND	0	0	-59.7	0	0	-77.8
OH	0	0	-33.6	0	0	-28.9
WA	-19.4	0	-72.1	-26.2	0	-97.4
WI	0	0	-41.7	0	0	-100

N/A – PDR could not be predicted because there was no deterioration

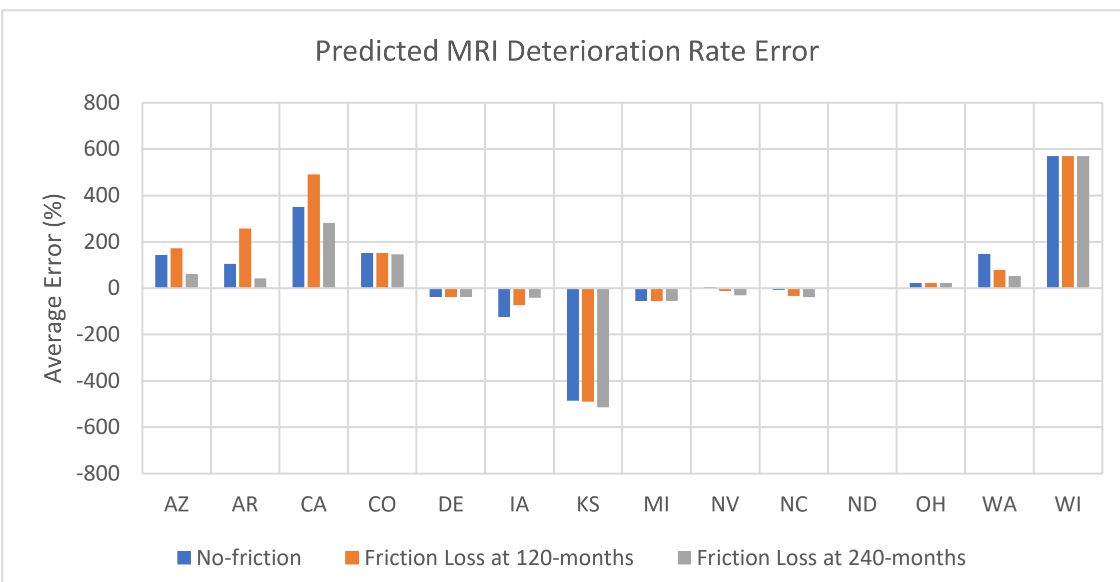


Figure B 22. Average Error (%) Between MRI Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

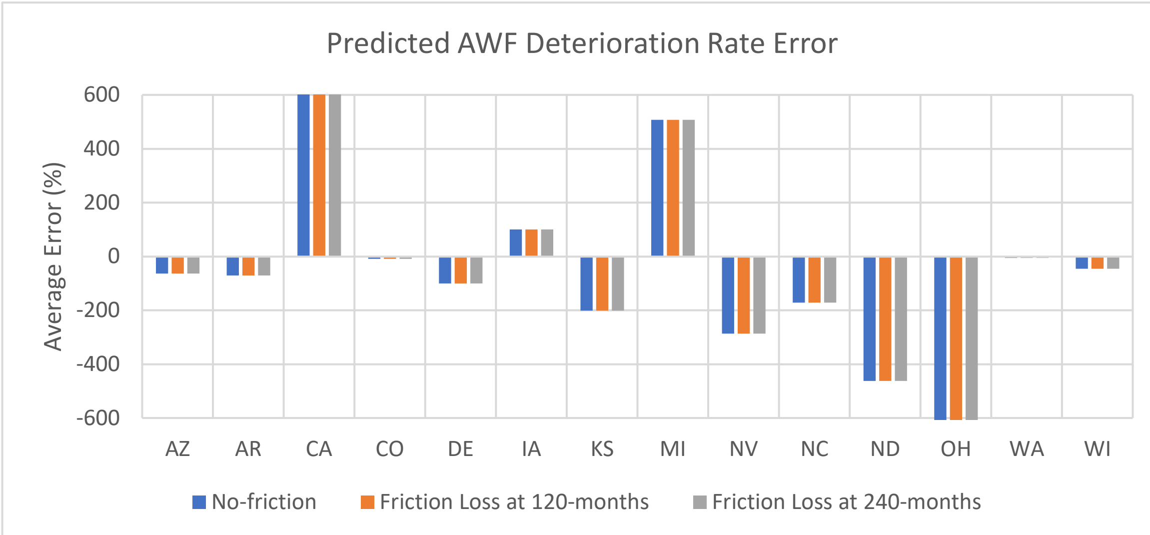


Figure B 23. Average Error (%) Between AWF Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

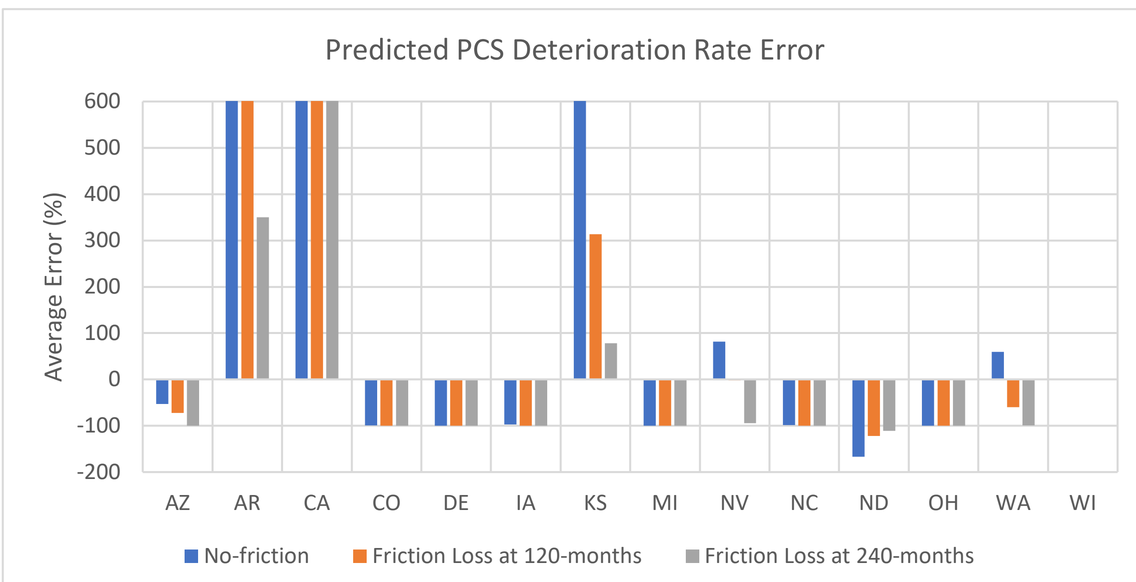


Figure B 24. Average Error (%) Between PCS Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

9. Widened Lane Width

Table B 9. Average Change in Predicted Deterioration Rate (PDR) with a Change in the Friction-Loss Parameter.

State	Average of the PDR Difference between Bonded and Unbonded Condition (%) by State					
	[120 Months PDR] vs. [No-Friction PDR]			[240 Months PDR] vs. [No-Friction PDR]		
	MRI	AWF	PCS	MRI	AWF	PCS
AZ	14.2	0	-66.5	1.5	0	-82.2
AR	79	0	-57.6	8.7	0	-71.4
CA	18.5	0	-57.5	-16.1	0	-76.7
CO	-2.2	0	-59.5	-6.9	0	-72.7
DE	0	0	-85.7	0	0	-100
IA	-12.9	0	-67.3	-22.6	0	-92
KS	-5.8	0	-70.3	-5.8	0	-98.2
MI	0	0	-50	0	0	-100
NV	-8.1	0	-81.1	-10.1	0	-100
NC	-12	0	-46.7	-32.6	0	-74.6
ND	-4.9	0	-85.3	-6.6	0	-98.7
OH	0	0	-46.7	0	0	-66.5
WA	0	0	-85.7	0	0	-100
WI	-2.5	0	-83.8	-3.1	0	-99

N/A – PDR could not be predicted because there was no deterioration

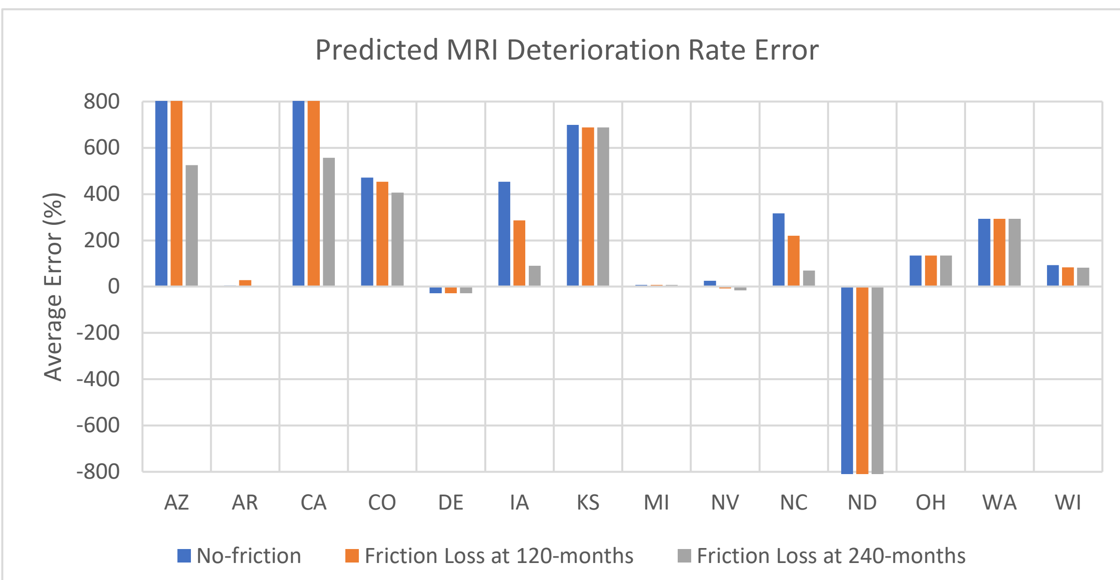


Figure B 25. Average Error (%) Between MRI Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

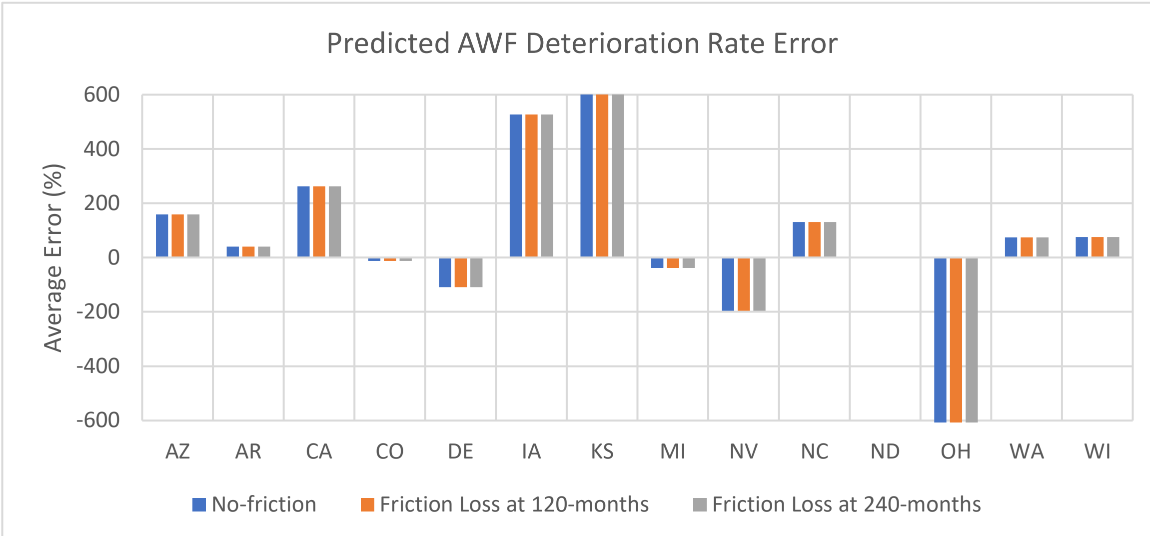


Figure B 26. Average Error (%) Between AWF Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

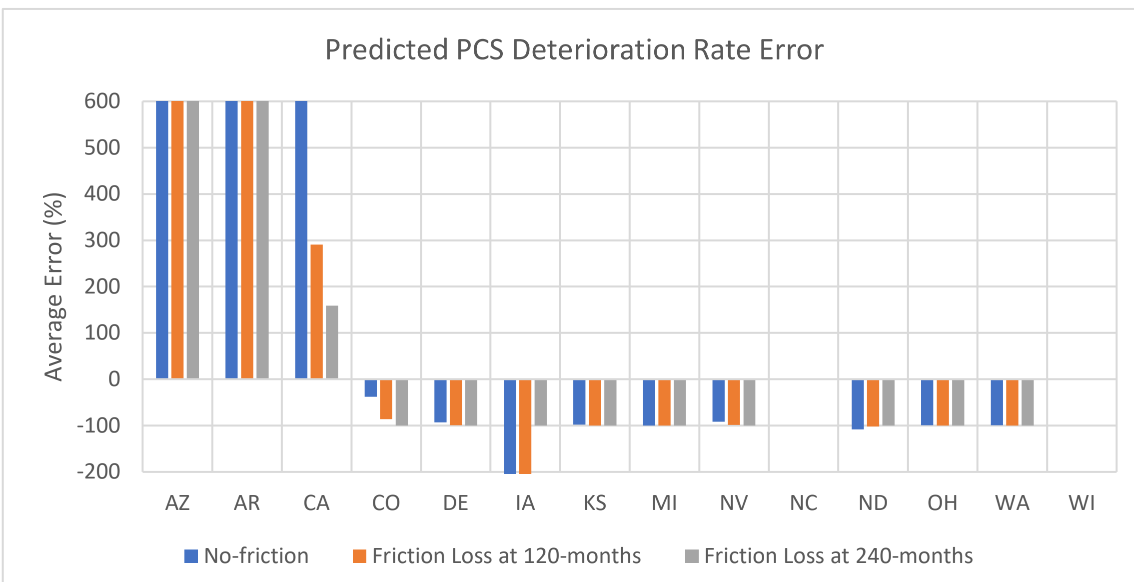


Figure B 27. Average Error (%) Between PCS Deterioration Rates When Comparing the Predicted Values to the LTPP Measured Values.

Appendix C

Updated Layer Modulus Inputs

Table C 1. Update Layer Modulus Inputs for PMED Version 2.6

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
4	0213	3	Subgrade	24603
4	0213	2	NonStabilized	51967
4	0213	1	PCC	5937073
4	0214	3	Subgrade	12267
4	0214	2	NonStabilized	46989
4	0214	1	PCC	4850933
4	0215	3	Subgrade	23475
4	0215	2	NonStabilized	42369
4	0215	1	PCC	5675449
4	0216	3	Subgrade	28770
4	0216	2	NonStabilized	32710
4	0216	1	PCC	6027460
4	0217	4	Subgrade	54196
4	0217	3	NonStabilized	54196
4	0217	2	Cement_Base	1065767
4	0217	1	PCC	4753321
4	0218	4	Subgrade	23986
4	0218	3	NonStabilized	23986
4	0218	2	Cement_Base	914293
4	0218	1	PCC	4598750
4	0219	4	Subgrade	42150
4	0219	3	NonStabilized	42150
4	0219	2	Cement_Base	923780
4	0219	1	PCC	6156030
4	0220	4	Subgrade	30038
4	0220	3	NonStabilized	30038
4	0220	2	Cement_Base	1263850
4	0220	1	PCC	5421831
4	0221	4	Subgrade	21380
4	0221	3	NonStabilized	58920
4	0221	2	Flexible	N/A
4	0221	1	PCC	6239453
4	0222	4	Subgrade	19509
4	0222	3	NonStabilized	37973
4	0222	2	Flexible	N/A
4	0222	1	PCC	6222427
4	0223	4	Subgrade	29438
4	0223	3	NonStabilized	43877

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
4	0223	2	Flexible	N/A
4	0223	1	PCC	6208131
4	0224	4	Subgrade	25157
4	0224	3	NonStabilized	35500
4	0224	2	Flexible	N/A
4	0224	1	PCC	6697614
4	0262	3	Subgrade	50125
4	0262	2	NonStabilized	83450
4	0262	1	PCC	5017250
4	0263	4	Subgrade	25133
4	0263	3	NonStabilized	34767
4	0263	2	Flexible	N/A
4	0263	1	PCC	5753300
4	0264	4	Subgrade	34600
4	0264	3	NonStabilized	60600
4	0264	2	Flexible	N/A
4	0264	1	PCC	5892267
4	0265	3	Subgrade	18114
4	0265	2	NonStabilized	28929
4	0265	1	PCC	6134743
4	0266	4	Subgrade	32908
4	0266	3	NonStabilized	32908
4	0266	2	Flexible	N/A
4	0266	1	PCC	6479133
4	0267	4	Subgrade	33279
4	0267	3	NonStabilized	33279
4	0267	2	Flexible	N/A
4	0267	1	PCC	5860879
4	0268	4	Subgrade	28260
4	0268	3	NonStabilized	28260
4	0268	2	Flexible	N/A
4	0268	1	PCC	6434340
5	0213	4	Bedrock	N/A
5	0213	3	Subgrade	25823
5	0213	2	NonStabilized	91373
5	0213	1	PCC	N/A
5	0214	3	Subgrade	50200
5	0214	2	NonStabilized	67550
5	0214	1	PCC	5181817

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
5	0215	3	Subgrade	36540
5	0215	2	NonStabilized	34200
5	0215	1	PCC	5758920
5	0216	3	Subgrade	13200
5	0216	2	NonStabilized	41850
5	0216	1	PCC	3848150
5	0217	4	Subgrade	44425
5	0217	3	NonStabilized	85125
5	0217	2	Cement_Base	2909100
5	0217	1	PCC	6178200
5	0218	4	Subgrade	51175
5	0218	3	NonStabilized	56050
5	0218	2	Cement_Base	1050650
5	0218	1	PCC	3705200
5	0219	4	Subgrade	39800
5	0219	3	NonStabilized	48800
5	0219	2	Cement_Base	2423450
5	0219	1	PCC	5212750
5	0220	4	Subgrade	22500
5	0220	3	NonStabilized	40750
5	0220	2	Cement_Base	173950
5	0220	1	PCC	6541550
5	0221	4	Subgrade	32135
5	0221	3	NonStabilized	70524
5	0221	2	Flexible	N/A
5	0221	1	PCC	5621592
5	0222	4	Subgrade	28138
5	0222	3	NonStabilized	104353
5	0222	2	Flexible	N/A
5	0222	1	PCC	N/A
5	0223	4	Subgrade	36225
5	0223	3	NonStabilized	51350
5	0223	2	Flexible	N/A
5	0223	1	PCC	5850875
5	0224	4	Subgrade	50562
5	0224	3	NonStabilized	66318
5	0224	2	Flexible	N/A
5	0224	1	PCC	N/A
6	0201	3	Subgrade	20725

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
6	0201	2	NonStabilized	49750
6	0201	1	PCC	4913200
6	0202	3	Subgrade	23013
6	0202	2	NonStabilized	77925
6	0202	1	PCC	6043950
6	0203	3	Subgrade	31213
6	0203	2	NonStabilized	41475
6	0203	1	PCC	5815100
6	0204	3	Subgrade	20600
6	0204	2	NonStabilized	17800
6	0204	1	PCC	5734400
6	0205	4	Subgrade	15982
6	0205	3	NonStabilized	15982
6	0205	2	Cement_Base	1407636
6	0205	1	PCC	6246536
6	0206	4	Subgrade	24686
6	0206	3	NonStabilized	24686
6	0206	2	Cement_Base	505400
6	0206	1	PCC	4856664
6	0207	4	Subgrade	27243
6	0207	3	NonStabilized	27243
6	0207	2	Cement_Base	1225157
6	0207	1	PCC	6307743
6	0208	4	Subgrade	18700
6	0208	3	NonStabilized	18700
6	0208	2	Cement_Base	1968100
6	0208	1	PCC	6882400
6	0209	4	Subgrade	14540
6	0209	3	NonStabilized	87540
6	0209	2	Flexible	N/A
6	0209	1	PCC	4989680
6	0210	4	Subgrade	19800
6	0210	3	NonStabilized	76600
6	0210	2	Flexible	N/A
6	0210	1	PCC	6085400
6	0211	4	Subgrade	18600
6	0211	3	NonStabilized	22600
6	0211	2	Flexible	N/A
6	0211	1	PCC	5554500

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
6	0212	4	Subgrade	20200
6	0212	3	NonStabilized	53900
6	0212	2	Flexible	N/A
6	0212	1	PCC	6260300
8	0213	3	Subgrade	29183
8	0213	2	NonStabilized	53775
8	0213	1	PCC	5147133
8	0214	3	Subgrade	23967
8	0214	2	NonStabilized	24733
8	0214	1	PCC	5960033
8	0215	3	Subgrade	31732
8	0215	2	NonStabilized	24329
8	0215	1	PCC	5033259
8	0216	3	Subgrade	21050
8	0216	2	NonStabilized	10200
8	0216	1	PCC	6416300
8	0217	4	Subgrade	15763
8	0217	3	NonStabilized	15763
8	0217	2	Cement_Base	879056
8	0217	1	PCC	4517126
8	0218	4	Subgrade	10971
8	0218	3	NonStabilized	10971
8	0218	2	Cement_Base	1023007
8	0218	1	PCC	4404657
8	0219	4	Subgrade	22914
8	0219	3	NonStabilized	22914
8	0219	2	Cement_Base	1510143
8	0219	1	PCC	6328986
8	0220	4	Subgrade	27695
8	0220	3	NonStabilized	27695
8	0220	2	Cement_Base	508530
8	0220	1	PCC	4759000
8	0221	4	Subgrade	9614
8	0221	3	NonStabilized	35907
8	0221	2	Flexible	N/A
8	0221	1	PCC	4388864
8	0222	4	Subgrade	13744
8	0222	3	NonStabilized	48944
8	0222	2	Flexible	N/A

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
8	0222	1	PCC	6180433
8	0223	4	Subgrade	23409
8	0223	3	NonStabilized	22827
8	0223	2	Flexible	N/A
8	0223	1	PCC	4200882
8	0224	4	Subgrade	21817
8	0224	3	NonStabilized	28156
8	0224	2	Flexible	N/A
8	0224	1	PCC	4930211
8	0259	3	Subgrade	28496
8	0259	2	NonStabilized	28496
8	0259	1	PCC	4822021
10	0201	4	Subgrade	22933
10	0201	3	NonStabilized	10896
10	0201	2	NonStabilized	39071
10	0201	1	PCC	N/A
10	0202	4	Subgrade	11533
10	0202	3	NonStabilized	25833
10	0202	2	NonStabilized	37133
10	0202	1	PCC	6397367
10	0203	4	Subgrade	26563
10	0203	3	NonStabilized	32288
10	0203	2	NonStabilized	34925
10	0203	1	PCC	5981013
10	0204	4	Subgrade	16822
10	0204	3	NonStabilized	50267
10	0204	2	NonStabilized	47956
10	0204	1	PCC	6073056
10	0205	4	Subgrade	31548
10	0205	3	NonStabilized	24938
10	0205	2	Cement_Base	526526
10	0205	1	PCC	N/A
10	0206	4	Subgrade	39356
10	0206	3	NonStabilized	9867
10	0206	2	Cement_Base	2497694
10	0206	1	PCC	4995400
10	0207	4	Subgrade	25223
10	0207	3	NonStabilized	29585
10	0207	2	Cement_Base	596277

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
10	0207	1	PCC	5429731
10	0208	4	Subgrade	20675
10	0208	3	NonStabilized	20775
10	0208	2	Cement_Base	456775
10	0208	1	PCC	4263700
10	0209	5	Subgrade	25479
10	0209	4	NonStabilized	12979
10	0209	3	NonStabilized	12979
10	0209	2	Flexible	N/A
10	0209	1	PCC	N/A
10	0210	5	Subgrade	31871
10	0210	4	NonStabilized	19186
10	0210	3	NonStabilized	19186
10	0210	2	Flexible	N/A
10	0210	1	PCC	N/A
10	0211	5	Subgrade	36193
10	0211	4	NonStabilized	27736
10	0211	3	NonStabilized	27736
10	0211	2	Flexible	N/A
10	0211	1	PCC	6399886
10	0212	5	Subgrade	57369
10	0212	4	NonStabilized	16715
10	0212	3	NonStabilized	27531
10	0212	2	Flexible	N/A
10	0212	1	PCC	5336931
10	0259	4	Subgrade	51000
10	0259	3	NonStabilized	26181
10	0259	2	NonStabilized	41479
10	0259	1	PCC	6219570
10	0260	4	Subgrade	36067
10	0260	3	NonStabilized	10267
10	0260	2	NonStabilized	23300
10	0260	1	PCC	5804933
19	0213	4	Subgrade	15033
19	0213	3	NonStabilized	10678
19	0213	2	NonStabilized	25233
19	0213	1	PCC	4908133
19	0214	4	Subgrade	19433
19	0214	3	NonStabilized	10167

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
19	0214	2	NonStabilized	23000
19	0214	1	PCC	5031167
19	0215	4	Subgrade	19653
19	0215	3	NonStabilized	5753
19	0215	2	NonStabilized	32661
19	0215	1	PCC	4900397
19	0216	4	Subgrade	17017
19	0216	3	NonStabilized	30717
19	0216	2	NonStabilized	20950
19	0216	1	PCC	6077767
19	0217	4	Subgrade	13471
19	0217	3	NonStabilized	13871
19	0217	2	Cement_Base	912057
19	0217	1	PCC	4835200
19	0218	4	Subgrade	16522
19	0218	3	NonStabilized	46078
19	0218	2	Cement_Base	838889
19	0218	1	PCC	5635244
19	0219	4	Subgrade	27400
19	0219	3	NonStabilized	40233
19	0219	2	Cement_Base	959800
19	0219	1	PCC	6420767
19	0220	4	Subgrade	32927
19	0220	3	NonStabilized	18809
19	0220	2	Cement_Base	720291
19	0220	1	PCC	6130645
19	0221	5	Subgrade	24133
19	0221	4	NonStabilized	11167
19	0221	3	NonStabilized	11167
19	0221	2	Flexible	N/A
19	0221	1	PCC	3454900
19	0222	5	Subgrade	10850
19	0222	4	NonStabilized	18550
19	0222	3	NonStabilized	18550
19	0222	2	Flexible	N/A
19	0222	1	PCC	4905300
19	0223	5	Subgrade	31575
19	0223	4	NonStabilized	16350
19	0223	3	NonStabilized	16350

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
19	0223	2	Flexible	N/A
19	0223	1	PCC	5062300
19	0224	5	Subgrade	24600
19	0224	4	NonStabilized	15500
19	0224	3	NonStabilized	15500
19	0224	2	Flexible	N/A
19	0224	1	PCC	6947200
19	0259	4	Subgrade	20621
19	0259	3	NonStabilized	31679
19	0259	2	NonStabilized	58879
19	0259	1	PCC	N/A
20	0201	5	Subgrade	11340
20	0201	4	NonStabilized	11340
20	0201	3	Cement_Base	523760
20	0201	2	Sandwich/Fractured	523760
20	0201	1	PCC	5662227
20	0202	5	Subgrade	19717
20	0202	4	NonStabilized	19717
20	0202	3	Cement_Base	531300
20	0202	2	Sandwich/Fractured	531300
20	0202	1	PCC	6072333
20	0203	5	Subgrade	17064
20	0203	4	NonStabilized	17064
20	0203	3	Cement_Base	492600
20	0203	2	Sandwich/Fractured	492600
20	0203	1	PCC	5941591
20	0204	5	Subgrade	15760
20	0204	4	NonStabilized	15760
20	0204	3	Cement_Base	1122100
20	0204	2	Sandwich/Fractured	1122100
20	0204	1	PCC	5154880
20	0205	5	Subgrade	12900
20	0205	4	NonStabilized	12900
20	0205	3	Cement_Base	630150
20	0205	2	Cement_Base	630150
20	0205	1	PCC	5001950
20	0206	5	Subgrade	16200
20	0206	4	NonStabilized	16200
20	0206	3	Cement_Base	831600

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
20	0206	2	Cement_Base	831600
20	0206	1	PCC	5884750
20	0207	5	Subgrade	23680
20	0207	4	NonStabilized	23680
20	0207	3	Cement_Base	789580
20	0207	2	Cement_Base	789580
20	0207	1	PCC	6087200
20	0208	5	Subgrade	29100
20	0208	4	NonStabilized	29100
20	0208	3	Cement_Base	3809900
20	0208	2	Cement_Base	3809900
20	0208	1	PCC	6817500
20	0209	6	Subgrade	18081
20	0209	5	NonStabilized	18081
20	0209	4	Cement_Base	581011
20	0209	3	Sandwich/Fractured	581011
20	0209	2	Flexible	N/A
20	0209	1	PCC	6527094
20	0210	6	Subgrade	19233
20	0210	5	NonStabilized	19233
20	0210	4	Cement_Base	581011
20	0210	3	Sandwich/Fractured	581011
20	0210	2	Flexible	N/A
20	0210	1	PCC	5299400
20	0211	6	Subgrade	22744
20	0211	5	NonStabilized	22744
20	0211	4	Cement_Base	581011
20	0211	3	Sandwich/Fractured	581011
20	0211	2	Flexible	N/A
20	0211	1	PCC	6068088
20	0212	6	Subgrade	24623
20	0212	5	NonStabilized	24623
20	0212	4	Cement_Base	581011
20	0212	3	Sandwich/Fractured	581011
20	0212	2	Flexible	N/A
20	0212	1	PCC	5698497
20	0259	5	Subgrade	29300
20	0259	4	NonStabilized	29300
20	0259	3	Cement_Base	754700

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
20	0259	2	Cement_Base	754700
20	0259	1	PCC	5671950
26	0213	4	Subgrade	22450
26	0213	3	NonStabilized	12300
26	0213	2	NonStabilized	52875
26	0213	1	PCC	6383850
26	0214	4	Subgrade	12700
26	0214	3	NonStabilized	16533
26	0214	2	NonStabilized	22167
26	0214	1	PCC	4936400
26	0215	4	Subgrade	33000
26	0215	3	NonStabilized	14529
26	0215	2	NonStabilized	32514
26	0215	1	PCC	6191043
26	0216	4	Subgrade	19750
26	0216	3	NonStabilized	18375
26	0216	2	NonStabilized	18975
26	0216	1	PCC	6352700
26	0217	4	Subgrade	36242
26	0217	3	NonStabilized	16425
26	0217	2	Cement_Base	2349738
26	0217	1	PCC	4699492
26	0218	4	Subgrade	24083
26	0218	3	NonStabilized	29483
26	0218	2	Cement_Base	570683
26	0218	1	PCC	5759450
26	0219	4	Subgrade	31318
26	0219	3	NonStabilized	34327
26	0219	2	Cement_Base	437600
26	0219	1	PCC	5269173
26	0220	4	Subgrade	35483
26	0220	3	NonStabilized	26742
26	0220	2	Cement_Base	589004
26	0220	1	PCC	6005875
26	0221	5	Subgrade	21427
26	0221	4	NonStabilized	12791
26	0221	3	NonStabilized	12791
26	0221	2	Flexible	N/A
26	0221	1	PCC	6346127

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
26	0222	5	Subgrade	20230
26	0222	4	NonStabilized	26310
26	0222	3	NonStabilized	26310
26	0222	2	Flexible	N/A
26	0222	1	PCC	6387810
26	0223	5	Subgrade	29541
26	0223	4	NonStabilized	33941
26	0223	3	NonStabilized	33941
26	0223	2	Flexible	N/A
26	0223	1	PCC	6066147
26	0224	5	Subgrade	26325
26	0224	4	NonStabilized	16942
26	0224	3	NonStabilized	16942
26	0224	2	Flexible	N/A
26	0224	1	PCC	6419542
26	0259	5	Subgrade	39239
26	0259	4	NonStabilized	37528
26	0259	3	NonStabilized	37528
26	0259	2	Flexible	N/A
26	0259	1	PCC	5785517
32	0201	6	Subgrade	15446
32	0201	5	NonStabilized	15446
32	0201	4	Cement_Base	1263438
32	0201	3	Sandwich/Fractured	1263438
32	0201	2	Sandwich/Fractured	1263438
32	0201	1	PCC	3073654
32	0202	6	Subgrade	9617
32	0202	5	NonStabilized	9617
32	0202	4	Cement_Base	2893056
32	0202	3	Sandwich/Fractured	2893056
32	0202	2	Sandwich/Fractured	2893056
32	0202	1	PCC	4793634
32	0203	6	Subgrade	29408
32	0203	5	NonStabilized	29408
32	0203	4	Cement_Base	2893056
32	0203	3	Sandwich/Fractured	2893056
32	0203	2	Sandwich/Fractured	2893056
32	0203	1	PCC	2650000
32	0204	6	Subgrade	36368

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
32	0204	5	NonStabilized	36368
32	0204	4	Cement_Base	2893056
32	0204	3	Sandwich/Fractured	2893056
32	0204	2	Sandwich/Fractured	2893056
32	0204	1	PCC	3000000
32	0205	6	Subgrade	26461
32	0205	5	NonStabilized	26461
32	0205	4	Cement_Base	2893056
32	0205	3	Sandwich/Fractured	2893056
32	0205	2	Cement_Base	2893056
32	0205	1	PCC	2650000
32	0206	6	Subgrade	173333
32	0206	5	NonStabilized	173333
32	0206	4	Cement_Base	2893056
32	0206	3	Sandwich/Fractured	2893056
32	0206	2	Cement_Base	1373663
32	0206	1	PCC	2747313
32	0207	6	Subgrade	24875
32	0207	5	NonStabilized	24875
32	0207	4	Cement_Base	2893056
32	0207	3	Sandwich/Fractured	2893056
32	0207	2	Cement_Base	2338484
32	0207	1	PCC	4676975
32	0208	6	Subgrade	23458
32	0208	5	NonStabilized	23458
32	0208	4	Cement_Base	2893056
32	0208	3	Sandwich/Fractured	2893056
32	0208	2	Cement_Base	2893056
32	0208	1	PCC	3233333
32	0209	7	Subgrade	18664
32	0209	6	NonStabilized	18664
32	0209	5	Cement_Base	2893056
32	0209	4	Sandwich/Fractured	2893056
32	0209	3	Sandwich/Fractured	2893056
32	0209	2	Flexible	N/A
32	0209	1	PCC	4466297
32	0210	7	Subgrade	23472
32	0210	6	NonStabilized	23472
32	0210	5	Cement_Base	2893056

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
32	0210	4	Sandwich/Fractured	2893056
32	0210	3	Sandwich/Fractured	2893056
32	0210	2	Flexible	N/A
32	0210	1	PCC	3793303
32	0211	7	Subgrade	21133
32	0211	6	NonStabilized	21133
32	0211	5	Cement_Base	2893056
32	0211	4	Sandwich/Fractured	2893056
32	0211	3	Sandwich/Fractured	2893056
32	0211	2	Flexible	N/A
32	0211	1	PCC	2450000
32	0259	6	Subgrade	33175
32	0259	5	NonStabilized	33175
32	0259	4	Cement_Base	2893056
32	0259	3	Sandwich/Fractured	2893056
32	0259	2	Flexible	N/A
32	0259	1	PCC	2650000
37	0201	5	Subgrade	16136
37	0201	4	NonStabilized	16136
37	0201	3	Cement_Base	665479
37	0201	2	Sandwich/Fractured	665479
37	0201	1	PCC	5212292
37	0202	5	Subgrade	17227
37	0202	4	NonStabilized	17227
37	0202	3	Cement_Base	665479
37	0202	2	Sandwich/Fractured	665479
37	0202	1	PCC	6650517
37	0203	4	Subgrade	20267
37	0203	3	NonStabilized	17233
37	0203	2	NonStabilized	53600
37	0203	1	PCC	6554433
37	0204	5	Subgrade	16664
37	0204	4	NonStabilized	16664
37	0204	3	Cement_Base	665479
37	0204	2	Sandwich/Fractured	665479
37	0204	1	PCC	6896000
37	0205	5	Subgrade	13563
37	0205	4	NonStabilized	13563
37	0205	3	Cement_Base	584150

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
37	0205	2	Cement_Base	1582713
37	0205	1	PCC	5052213
37	0206	5	Subgrade	18600
37	0206	4	NonStabilized	18600
37	0206	3	Cement_Base	448017
37	0206	2	Cement_Base	1906717
37	0206	1	PCC	5527267
37	0207	4	Subgrade	23950
37	0207	3	NonStabilized	38686
37	0207	2	Cement_Base	1292657
37	0207	1	PCC	5910900
37	0208	5	Subgrade	17520
37	0208	4	NonStabilized	17520
37	0208	3	Cement_Base	961800
37	0208	2	Cement_Base	1607250
37	0208	1	PCC	5752960
37	0209	6	Subgrade	25742
37	0209	5	NonStabilized	25742
37	0209	4	Cement_Base	665067.333
37	0209	3	Sandwich/Fractured	665067.333
37	0209	2	Flexible	N/A
37	0209	1	PCC	6210688
37	0210	6	Subgrade	19113
37	0210	5	NonStabilized	19113
37	0210	4	Cement_Base	665067.333
37	0210	3	Sandwich/Fractured	665067.333
37	0210	2	Flexible	N/A
37	0210	1	PCC	6398332
37	0211	6	Subgrade	18339
37	0211	5	NonStabilized	18339
37	0211	4	Cement_Base	665067.333
37	0211	3	Sandwich/Fractured	665067.333
37	0211	2	Flexible	N/A
37	0211	1	PCC	6656452
37	0212	6	Subgrade	23700
37	0212	5	NonStabilized	23700
37	0212	4	Cement_Base	665067.333
37	0212	3	Sandwich/Fractured	665067.333
37	0212	2	Flexible	N/A

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
37	0212	1	PCC	6516686
37	0259	5	Subgrade	21062
37	0259	4	Subgrade	21062
37	0259	3	Cement_Base	245700
37	0259	2	Flexible	N/A
37	0259	1	PCC	6486733
37	0260	4	Subgrade	22073
37	0260	3	NonStabilized	22073
37	0260	2	Flexible	N/A
37	0260	1	PCC	4287000
38	0213	4	Subgrade	12775
38	0213	3	NonStabilized	8628
38	0213	2	NonStabilized	32361
38	0213	1	PCC	4500000
38	0214	4	Subgrade	9567
38	0214	3	NonStabilized	20233
38	0214	2	NonStabilized	37433
38	0214	1	PCC	6818233
38	0215	4	Subgrade	18600
38	0215	3	NonStabilized	18675
38	0215	2	NonStabilized	25275
38	0215	1	PCC	6376325
38	0216	4	Subgrade	15333
38	0216	3	NonStabilized	12400
38	0216	2	NonStabilized	29000
38	0216	1	PCC	5595900
38	0217	4	Subgrade	12867
38	0217	3	NonStabilized	12600
38	0217	2	Cement_Base	423133
38	0217	1	PCC	5462300
38	0218	4	Subgrade	16072
38	0218	3	NonStabilized	12233
38	0218	2	Cement_Base	2337728
38	0218	1	PCC	4675489
38	0219	4	Subgrade	18300
38	0219	3	NonStabilized	10200
38	0219	2	Cement_Base	189300
38	0219	1	PCC	6251200
38	0220	4	Subgrade	18625

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
38	0220	3	NonStabilized	45350
38	0220	2	Cement_Base	963300
38	0220	1	PCC	5527900
38	0221	5	Subgrade	13500
38	0221	4	NonStabilized	21456
38	0221	3	NonStabilized	21456
38	0221	2	Flexible	N/A
38	0221	1	PCC	5755656
38	0222	5	Subgrade	16483
38	0222	4	NonStabilized	7700
38	0222	3	NonStabilized	7700
38	0222	2	Flexible	N/A
38	0222	1	PCC	6589000
38	0223	5	Subgrade	19833
38	0223	4	NonStabilized	29433
38	0223	3	NonStabilized	29433
38	0223	2	Flexible	N/A
38	0223	1	PCC	6471567
38	0224	5	Subgrade	21520
38	0224	4	NonStabilized	18700
38	0224	3	NonStabilized	18700
38	0224	2	Flexible	N/A
38	0224	1	PCC	5631960
38	0259	5	Subgrade	22164
38	0259	4	NonStabilized	22682
38	0259	3	NonStabilized	22682
38	0259	2	Flexible	N/A
38	0259	1	PCC	5731145
38	0260	4	Subgrade	15440
38	0260	3	NonStabilized	7253
38	0260	2	NonStabilized	24240
38	0260	1	PCC	4640000
38	0261	4	Subgrade	15300
38	0261	3	NonStabilized	42163
38	0261	2	NonStabilized	34938
38	0261	1	PCC	6375700
38	0262	4	Subgrade	21300
38	0262	3	NonStabilized	22633
38	0262	2	Cement_Base	818267

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
38	0262	1	PCC	6784300
38	0263	5	Subgrade	19925
38	0263	4	NonStabilized	33542
38	0263	3	NonStabilized	33542
38	0263	2	Flexible	N/A
38	0263	1	PCC	6150067
38	0264	5	Subgrade	17525
38	0264	4	NonStabilized	29325
38	0264	3	NonStabilized	29325
38	0264	2	Flexible	N/A
38	0264	1	PCC	6742650
39	0201	3	Subgrade	16588
39	0201	2	NonStabilized	35363
39	0201	1	PCC	6662463
39	0202	3	Subgrade	15333
39	0202	2	NonStabilized	40242
39	0202	1	PCC	5609292
39	0203	3	Subgrade	19343
39	0203	2	NonStabilized	43743
39	0203	1	PCC	5811764
39	0204	4	Subgrade	36008
39	0204	3	NonStabilized	29581
39	0204	2	NonStabilized	32396
39	0204	1	PCC	6084923
39	0205	4	Subgrade	21412
39	0205	3	NonStabilized	21412
39	0205	2	Cement_Base	513447
39	0205	1	PCC	4877588
39	0206	4	Subgrade	15760
39	0206	3	NonStabilized	15760
39	0206	2	Cement_Base	488495
39	0206	1	PCC	5335550
39	0207	4	Subgrade	24623
39	0207	3	NonStabilized	24623
39	0207	2	Cement_Base	694392
39	0207	1	PCC	5933723
39	0208	4	Subgrade	25990
39	0208	3	NonStabilized	25990
39	0208	2	Cement_Base	652730

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
39	0208	1	PCC	5238810
39	0209	4	Subgrade	16550
39	0209	3	NonStabilized	38008
39	0209	2	Flexible	N/A
39	0209	1	PCC	5601950
39	0210	4	Subgrade	15258
39	0210	3	NonStabilized	23092
39	0210	2	Flexible	N/A
39	0210	1	PCC	6183192
39	0211	4	Subgrade	19900
39	0211	3	NonStabilized	19575
39	0211	2	Flexible	N/A
39	0211	1	PCC	6712650
39	0212	5	Subgrade	27600
39	0212	4	NonStabilized	26150
39	0212	3	NonStabilized	26150
39	0212	2	Flexible	N/A
39	0212	1	PCC	6171413
39	0259	4	Subgrade	25975
39	0259	3	NonStabilized	23967
39	0259	2	NonStabilized	22600
39	0259	1	PCC	5870892
39	0260	5	Subgrade	33564
39	0260	4	NonStabilized	19771
39	0260	3	NonStabilized	19771
39	0260	2	Flexible	N/A
39	0260	1	PCC	5104193
39	0261	4	Subgrade	30804
39	0261	3	NonStabilized	41319
39	0261	2	Cement_Base	1345829
39	0261	1	PCC	6729214
39	0262	4	Subgrade	28567
39	0262	3	NonStabilized	45667
39	0262	2	Cement_Base	3126300
39	0262	1	PCC	5841633
39	0263	3	Subgrade	24477
39	0263	2	NonStabilized	30946
39	0263	1	PCC	6211531
39	0264	4	Subgrade	24150

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
39	0264	3	NonStabilized	12700
39	0264	2	Cement_Base	401750
39	0264	1	PCC	4314650
39	0265	5	Subgrade	33840
39	0265	4	NonStabilized	13473
39	0265	3	NonStabilized	13473
39	0265	2	Flexible	N/A
39	0265	1	PCC	5550920
53	0201	5	Subgrade	19008
53	0201	4	NonStabilized	34267
53	0201	3	NonStabilized	34267
53	0201	2	NonStabilized	60450
53	0201	1	PCC	4318442
53	0202	5	Bedrock	N/A
53	0202	4	Subgrade	23353
53	0202	3	NonStabilized	33980
53	0202	2	NonStabilized	45300
53	0202	1	PCC	5001300
53	0203	4	Bedrock	N/A
53	0203	3	Subgrade	16920
53	0203	2	NonStabilized	43930
53	0203	1	PCC	3963980
53	0204	5	Subgrade	49621
53	0204	4	NonStabilized	20314
53	0204	3	NonStabilized	20314
53	0204	2	NonStabilized	34907
53	0204	1	PCC	5760264
53	0205	5	Subgrade	38055
53	0205	4	NonStabilized	32545
53	0205	3	NonStabilized	32545
53	0205	2	Cement_Base	915730
53	0205	1	PCC	4009625
53	0206	5	Subgrade	32167
53	0206	4	NonStabilized	39942
53	0206	3	NonStabilized	39942
53	0206	2	Cement_Base	535925
53	0206	1	PCC	4504758
53	0207	4	Subgrade	33283
53	0207	3	NonStabilized	33283

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
53	0207	2	Cement_Base	1103156
53	0207	1	PCC	4954400
53	0208	5	Subgrade	57691
53	0208	4	NonStabilized	37618
53	0208	3	NonStabilized	37618
53	0208	2	Cement_Base	524764
53	0208	1	PCC	4876745
53	0209	6	Subgrade	12711
53	0209	5	NonStabilized	27356
53	0209	4	NonStabilized	27356
53	0209	3	NonStabilized	27356
53	0209	2	Flexible	N/A
53	0209	1	PCC	5257294
53	0210	5	Subgrade	26988
53	0210	4	NonStabilized	20941
53	0210	3	NonStabilized	20941
53	0210	2	Flexible	N/A
53	0210	1	PCC	5257294
53	0211	7	Bedrock	N/A
53	0211	6	Subgrade	48715
53	0211	5	NonStabilized	22008
53	0211	4	NonStabilized	22008
53	0211	3	NonStabilized	22008
53	0211	2	Flexible	N/A
53	0211	1	PCC	3840246
53	0212	6	Subgrade	62029
53	0212	5	NonStabilized	22286
53	0212	4	NonStabilized	22286
53	0212	3	NonStabilized	22286
53	0212	2	Flexible	N/A
53	0212	1	PCC	5287029
53	0259	4	Subgrade	31279
53	0259	3	NonStabilized	42886
53	0259	2	Flexible	N/A
53	0259	1	PCC	4338257
55	0213	4	Subgrade	13543
55	0213	3	NonStabilized	51129
55	0213	2	NonStabilized	67486
55	0213	1	PCC	4732729

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
55	0214	5	Subgrade	19811
55	0214	4	NonStabilized	51544
55	0214	3	NonStabilized	46400
55	0214	2	NonStabilized	46400
55	0214	1	PCC	6058244
55	0215	4	Subgrade	31150
55	0215	3	NonStabilized	20000
55	0215	2	NonStabilized	31900
55	0215	1	PCC	4964350
55	0216	4	Subgrade	28433
55	0216	3	NonStabilized	23550
55	0216	2	NonStabilized	38750
55	0216	1	PCC	5734475
55	0217	4	Subgrade	29250
55	0217	3	NonStabilized	30533
55	0217	2	Cement_Base	2703890
55	0217	1	PCC	5407750
55	0218	5	Subgrade	29250
55	0218	4	NonStabilized	31313
55	0218	3	NonStabilized	42620
55	0218	2	Cement_Base	2800210
55	0218	1	PCC	5600410
55	0219	4	Subgrade	29250
55	0219	3	NonStabilized	45717
55	0219	2	Cement_Base	892417
55	0219	1	PCC	6017533
55	0220	4	Subgrade	29250
55	0220	3	NonStabilized	28977
55	0220	2	Cement_Base	2582575
55	0220	1	PCC	5165113
55	0221	5	Subgrade	16317
55	0221	4	NonStabilized	21433
55	0221	3	NonStabilized	21433
55	0221	2	Flexible	N/A
55	0221	1	PCC	5555050
55	0222	5	Subgrade	33667
55	0222	4	NonStabilized	36133
55	0222	3	NonStabilized	36133
55	0222	2	Flexible	N/A

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
55	0222	1	PCC	5807000
55	0223	5	Subgrade	29911
55	0223	4	NonStabilized	22840
55	0223	3	NonStabilized	5213
55	0223	2	Flexible	N/A
55	0223	1	PCC	5879734
55	0224	4	Subgrade	39750
55	0224	3	NonStabilized	36583
55	0224	2	Flexible	N/A
55	0224	1	PCC	6107442
55	0259	4	Subgrade	25500
55	0259	3	NonStabilized	94350
55	0259	2	NonStabilized	87450
55	0259	1	PCC	6173750
55	0260	4	Subgrade	23860
55	0260	3	NonStabilized	49460
55	0260	2	NonStabilized	46700
55	0260	1	PCC	6615980
55	0261	5	Subgrade	28750
55	0261	4	NonStabilized	26000
55	0261	3	NonStabilized	26000
55	0261	2	Cement_Base	956800
55	0261	1	PCC	6566600
55	0262	5	Subgrade	15500
55	0262	4	NonStabilized	51600
55	0262	3	NonStabilized	39900
55	0262	2	NonStabilized	39900
55	0262	1	PCC	6528100
55	0263	4	Subgrade	25633
55	0263	3	NonStabilized	10733
55	0263	2	NonStabilized	21700
55	0263	1	PCC	5590633
55	0264	4	Subgrade	30733
55	0264	3	NonStabilized	75833
55	0264	2	NonStabilized	91400
55	0264	1	PCC	6058067
55	0265	4	Subgrade	43133
55	0265	3	NonStabilized	35967
55	0265	2	NonStabilized	58300

State Code	SHRP ID	Layer No	Layer Type	Layer Modulus
55	0265	1	PCC	6610967
55	0266	4	Subgrade	27587
55	0266	3	NonStabilized	33383
55	0266	2	NonStabilized	40213
55	0266	1	PCC	6034450