



ANALYSIS AND MODELING OF NEW YORK AND CALIFORNIA SECTIONS IN LTPP DATA

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Abstract: This paper analyzed four Long-Term Pavement Performance (LTPP) sections located in California and New York. Two selected sections are located within 1 mile on I-5 in northern California and two sections located within 1 mile on US-4 in northern New York. Sections located in the same state were subjected to identical traffic spectrum but exhibited variation in structural capacity. Two levels of analysis were performed in this study: a) in-state analysis and b) cross state analysis. The in-state analysis focused on comparing the two sections located in each state. Sections located in California exhibited insignificant variation in thermal crack resistance regardless of the presence of additional 1.5" Asphalt Concrete (AC) layer in one section. On the other hand, the additional 1.5" AC layer resulted in significant reduction of rutting depth. The in-state analysis of sections located in New York concluded that chip seal layers has significantly low resistance to thermal cracking and rutting. The cross state analysis examined two sections of comparable structural capacity. The two structurally weak sections (sections 06-0606 in California and 36-A350 in New York) proved that chip seal layers exhibit significantly high rutting depth even under high traffic loads in freezing climate compared to low traffic sections with regular HMA in warmer climate. The analysis of strong sections in California and New York concluded that properly designed and constructed HMA in freeze climate exhibits equal thermal cracking resistance as sections in no-freeze zones. Furthermore, the paper presents pavement deterioration models for LTPP sections using linear regression.

1 Introduction

This paper investigates the deterioration of selective Long-Term Pavement Performance (LTPP) test sections. The selected test sections are located in New York and California. The selected sections were characterized by similarities in traffic spectrum and pavement layer's thickness. This paper investigated the deterioration rates of these sections to evaluate the impact of climate and pavement maintenance on the pavement functional and structural performance.

Two selected LTPP sections from California were part of the Specific Pavement Studies-6 (SPS-6). These sections were utilized to study the rehabilitation of Jointed Portland Cement Concrete (PCC) Pavement. The two LTPP sections selected from New York State were part of General Pavement Studies-6B (GPS-6B) and SPS-3. The two studies are designed to evaluate Asphalt Concrete (AC) on bound base and AC overlay on AC pavement, respectively. Further details about the four LTPP test sections are stated in subsequent segments of this paper.

The pavement functional and structural condition of the pavement sections were well-documented through frequent in-situ testing. The authors focused on transverse cracking and rutting as indicators of

the pavement deterioration within pavement's service life. The analysis concluded that application of chip sealing significantly reduces the pavement's resistance to thermal cracking and has low rutting resistance compared to thin HMA overlay. In addition, the authors developed deterioration models for transverse cracking and rutting in four LTPP sections using multiple linear regression.

2 Background

The Federal Highway Administration (FHWA) manages the LTPP program since 1992. The program was initiated through the Strategic Highway Research Program (NCHRP) in 1986 (FHWA 2009). The program included several experiments on flexible and rigid pavements. The background section of this paper focuses on the SPS-6, SPS-3 and GPS-6B experiments as the analyzed sections were included in these studies.

2.1 SPS-6

The SPS-6 experiment was designed to study rehabilitation methods of Jointed PCC pavements. The test sections were spread to include two climatic regions (wet-freeze and wet no-freeze), pavement types (plain and reinforced concrete) and traffic loads. The rehabilitation techniques included Asphalt Concrete (AC) overlays using 4" and 8" layers. Limited slab preparation or full slab restoration were applied prior to AC overlays (FHWA 1992).

The experiment identified the most effective rehabilitation techniques to restore IRI, rutting and cracking. The treatments (ranked from the most effective to least effective) are (Hall 2002):

1. 8" AC overlay on cracked/broken and seated pavement
2. 4" AC overlay of either intact or cracked/broken and seated pavement with or without sawing and sealing of transverse joints and with minimal or intensive preoverlay repair.
3. concrete pavement restoration with diamond grinding, full-depth repair, and joint and crack sealing
4. concrete pavement restoration without diamond grinding but with full-depth repair and joint and crack sealing.

2.2 SPS-3

The SPS-3 experiment evaluates the effectiveness of preventive maintenance of flexible pavements. The experiment was designed to study several parameters including climatic zones, subgrade type (fine or coarse), traffic loading (greater or less than 85,000 ESALs/year), initial condition (good, fair, or poor), and structural adequacy (high or low). The preventive maintenance treatments included slurry seal, chip seal, crack seal and thin overlay (FHWA 2011).

The experiment concluded that chip seal and thin overlay are the most effective treatments for fatigue cracking. This overlay was noted as the most effective preventive maintenance for pavement rutting and delaying the roughness progression (FHWA 2011). The structural adequacy of pavement sections had no significant impact on the performance of maintenance treatments (Morian 1998).

2.3 GPS-6B

The GPS-6B experiment studied sections originally included in GPS-1 and GPS-2 experiments. The test section studied in this paper originally belonged to GPS-2. The GPS-2 examined dense-graded HMAC surface layer with or without other HMAC layers, placed over a bound base layer. The test sections included bituminous and nonbituminous bound base layers. Bituminous bases included asphalt cements, cutbacks, emulsions, and road tars. Nonbituminous bases included all hydraulic cements, lime, fly ashes, and natural pozzolans, or combinations thereof. The test sections were constructed to examine variations

among climatic zones, subgrade types, traffic spectrum, and surface and base thicknesses (Elkins 2012). The GPS-6B sections received 1" overlay on the original pavement sections (Hall 2002).

The GPS-6B experiment concluded that about 0.24" of rutting are developed on the first year following AC overlay on top of AC pavement. This could be resulting from traffic compaction of new AC layer. The initial rutting is independent of the overlay thickness, mixture type, pre-overlay preparation, and preoverlay rutting level (Hall 2002).

3 Test Sections

3.1 Location

Two LTPP sections from California were studied and analyzed. Sections 06-0603 and 06-0606 located on Interstate 5 in Siskiyou County belonged to SPS-6 experiment. The test sections are located in Northern California climatic region which is wet, non-freeze. The two test sections are located in close proximity on I-5. The sections are located 60 miles north of City of Redding.

The two LTPP sections from New York State are sections 36-1643 and 36-A350. The two sections are located on US-4 highway within Washington county. The two sections from New York State are 1 mile apart and located in 66 miles north of Albany, NY. The two sections are located in a wet, freeze climatic zone.

3.2 Structural Cross-Section

3.2.1 California Sections

The pavement cross-section on LTPP 06-0603 was determined as 4.8" of AC on top of 8.2" of Jointed PCC and 4.4" cement-treated aggregate base. LTPP section 06-0606 was formed through 3.3" of AC and 8.4" of Jointed PCC and 4.7" cement-treated granular base layers. The subgrade in both LTPP sections is poorly graded gravel with sand (Program n.d.). The main difference between the two sections is the thickness of the asphalt concrete layer. The two sections are located within close proximity on I-5. Therefore, limited variation is noted in the traffic loads applied on both sections. Variation in pavement distresses are driven by the 1.5" difference in AC layer's thickness. Figures 1-A and 1-B present the pavement cross-sections in LTPP sections 06-0603 and 06-0606 respectively.

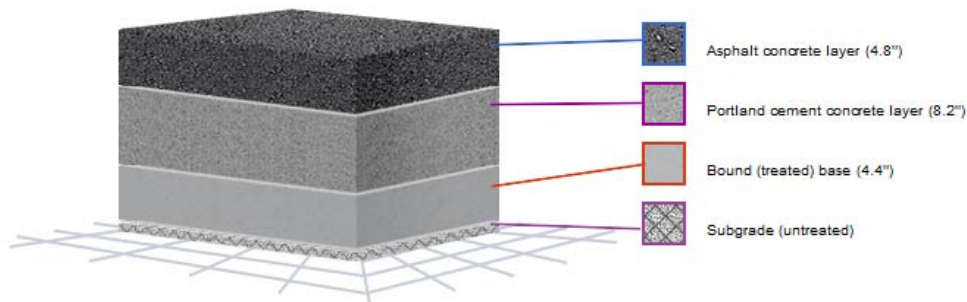


Figure 1-A: Pavement Cross-Section on LTPP section 06-0603 (LTPP 2017)

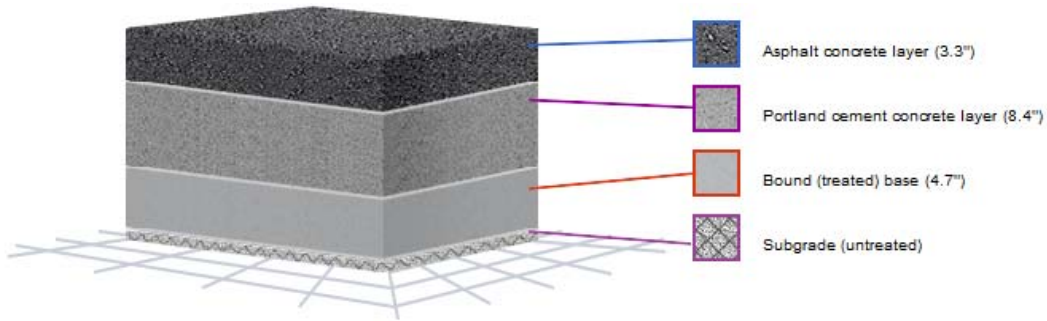


Figure 1-B: Pavement Cross-Section on LTPP section 06-0606 (LTPP 2017)

3.2.2 New York Sections

The pavement cross-section on LTPP 36-1643 is constructed through 5.1" of dense-graded AC layers followed by 8.2" Hot Mix Asphalt (HMA) Base and 7.2" unbound granular subbase. Section 36-A350 consists of 0.8" of chip sealing, 2.6" of dense-graded AC, 8" HMA base and 7.2" unbound granular subbase. The subgrade in both test sections is well graded sand with silt and gravel. Figures 2-A and 2-B present the pavement cross-sections of 36-1643 and 36-A350 respectively.

The sections selected from New York State and California are structurally comparable. Section 06-0603 (California) and section 36-1643 (New York) consist of 4.8" and 5.1" of AC layers respectively. The base layers in both sections are 8.2" jointed PCC and 8.2" HMA base.

Sections 06-0606 (California) and 36-A350 (New York) consist of 3.3" AC and 3.4" AC layers respectively. The base layers in both sections are 8.4" jointed PCC and 8" HMA base.

The authors analyzed multiple alternatives and the presented sections were the best alternatives to perform the comparison between pavement performance assuming structurally equivalent pavement sections.

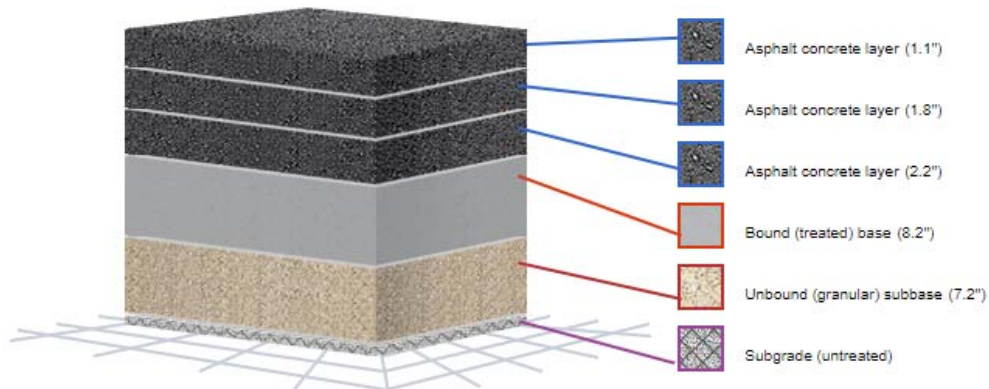


Figure 2-A: Pavement Cross-Section on LTPP section 36-1643 (LTPP 2017)

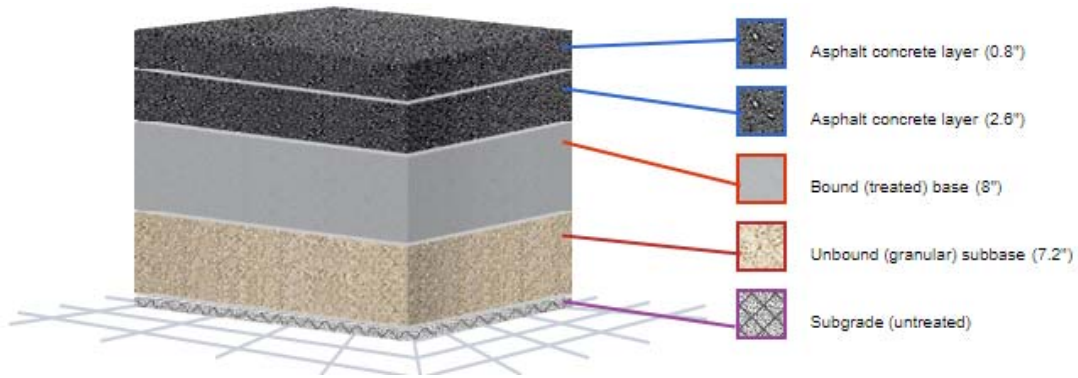


Figure 2-B: Pavement Cross-Section on LTPP section 36-A350 (LTPP 2017)

3.3 Traffic

In general, the Average Annual Daily Truck Traffic (AADTT) in both test sections located in California falls within the range of 2,000 to 3,000. The two sections are characterized by identical traffic spectrum due to their close proximity on the Interstate-5 freeway. Figure 3 presents the AADTT on sections 06-0603 and 06-0606 between 1976 and 2015. The selected sections located in New York State are located on US-4 within 1 mile stretch. The traffic loading on both sections is identical and the AADTT ranges between 600 and 1,000. Figure 4 presents the AADTT on sections 36-1643 and 36-A350 between 1980 and 2006.

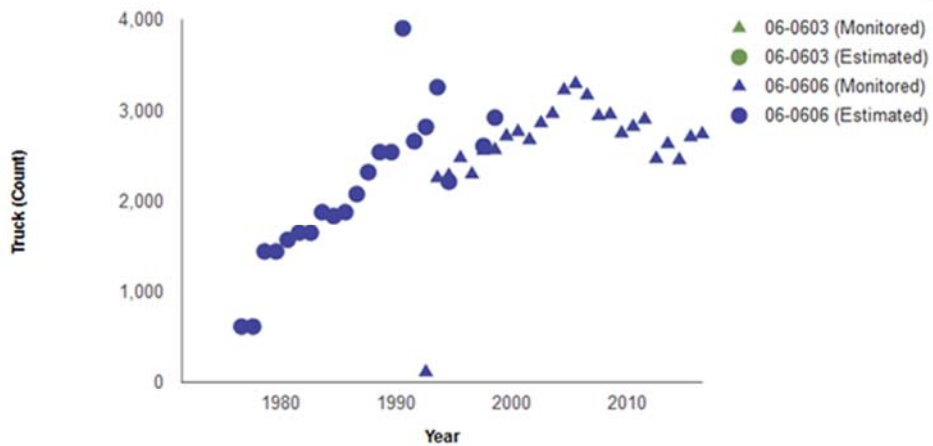


Figure 3: AADTT in Sections 06-0603 and 06-0606

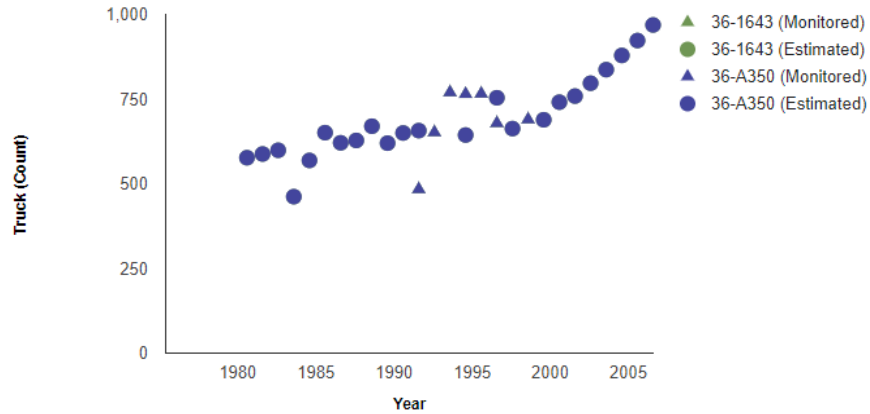


Figure 4: AADTT in Sections 36-1643 and 36-A350

3.4 Maintenance History

The LTPP sections located in California received a full depth patch and shoulder restoration in 1992. The authors identified a 7-year analysis period for this study between 1992 and 1999. Crack sealing was performed on the AC pavement surface in 1999 which impacted the distress records thereafter. Therefore, the authors performed the presented analysis based on data collected from 1992 to 1999 from sections 06-0603 and 06-0606. The sections located in New York State received patching and shoulder restoration in 1995. The following patching was recorded in 2002. The authors used the distress data between 1995 to 2002 (7 years) to perform the analysis presented herein.

4 In-State Analysis

This section presents findings by comparing the performance of the adjacent sections located on the same highway with variation in pavement thickness. The in-state analysis evaluates the impact of variation in structural strength of pavement section.

4.1 California Sections

Limited variation is noted in the transverse cracking count by comparing the performance of sections 06-0603 and 06-0606. The two sections are characterized by identical climate impact, traffic load and subgrade type. Performance variation between these two sections results from variation in AC layer's thickness. Section 06-0603 is characterized by additional 1.5" of AC on the surface pavement layer compared to section 06-0606. However, the additional pavement thickness had insignificant impact on the transverse (thermal) crack count. Figure 5 presents the progression of transverse crack counts over the analysis period for both pavement sections.

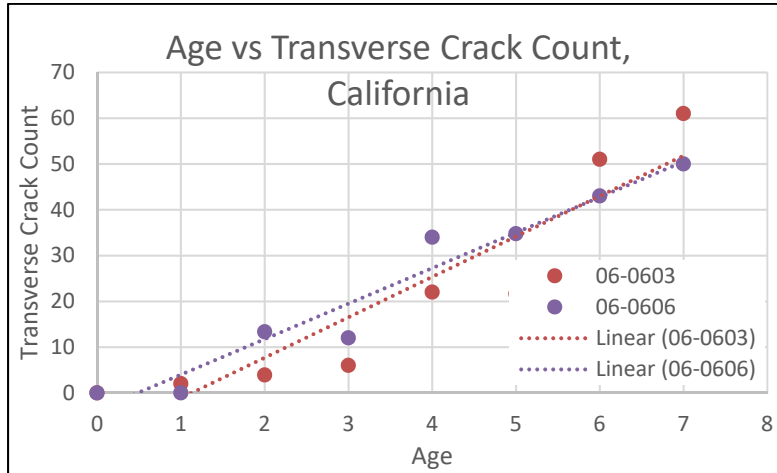


Figure 5: Transverse Crack Counts on Sections Located in California

The variation in AC thickness among sections 06-0603 and 06-0606 had significant impact on the pavement rutting. Performing a statistical T-test, the P-value comparing mean rutting in both sections resulted in a P-value of 0.01. Therefore, significant improvement (at 95% confidence level) is noted in rutting through the additional 1.5" AC constructed on section 06-0603. Figure 6 presents the rutting progression of both sections throughout the analysis period.

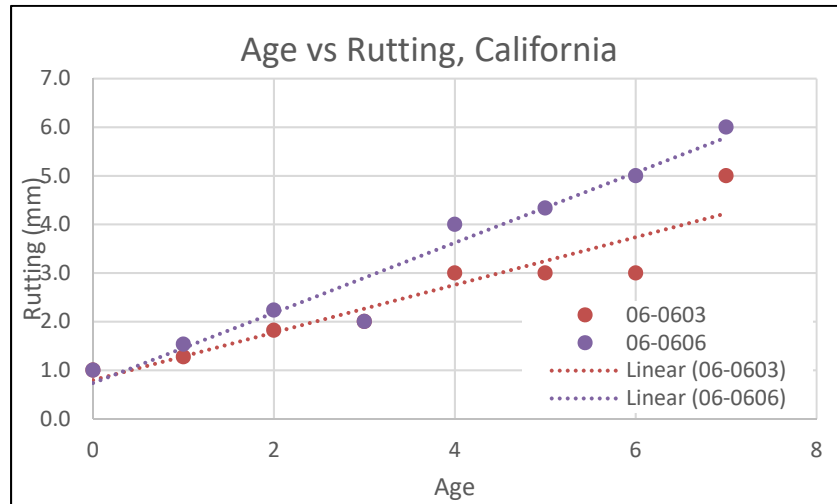


Figure 6: Rutting Progression on Sections Located in California

4.2 New York Sections

Significant variation in the performance of sections 36-1643 and 36-A350 is noted by analyzing the count of transverse cracks and rutting. The principal difference between the two sections located in New York State is the AC surface material and thickness. Section 36-A350 is characterized by 0.8" Chip sealing layer followed by thin 2.6" AC surface layer. Section 36-1643 includes 5.1" AC layers. The material properties of Chip sealing or the relatively thin layer resulted in a significant increase in thermal cracks on section 36-A350. Performing statistical T-test, the count of transverse cracks in section 36-A350 is significantly more than those on section 36-1643. The P-value for that test is 0.002. Figure 7 presents the progression of transverse crack counts on sections located in New York State.

Rutting depth in section 36-A350 is significantly higher than that in section 36-1643. The P-value determined from the T-test is 0.002. It should be noted that section 36-1643 was treated by thin overlay at

year 0 (1995) and exhibited 0.07" rutting on the 1st year. This behavior matches the conclusion determined by NCHRP Project 20-50(3/4) (Hall 2002).

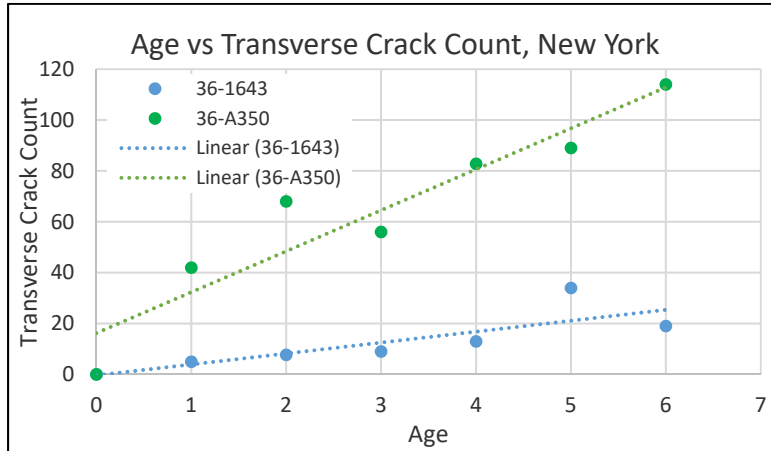


Figure 7: Transverse Crack Counts on Sections Located in New York State

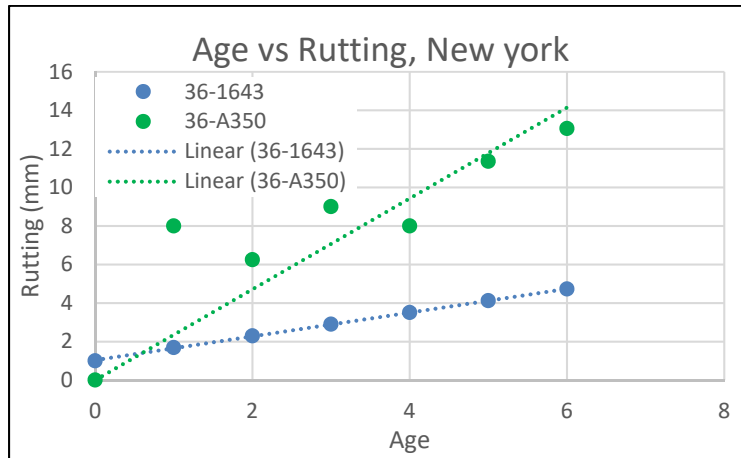


Figure 8: Rutting Progression on Sections Located in New York State

5 Cross-State Analysis

The analysis of pavement performance in the California sections and the New York State sections would be influenced by several parameters. Variations between the test sections would include traffic spectrum, structural strength and climate zones. However, that level of analysis is essential to develop a comprehensive investigation of pavement performance. The cross-state level of analysis compares the performance of structurally weak sections from both states. The structurally weak sections are 06-0606 (California) and 36-A350 (New York). Section 06-0606 consist of 3.3" AC layers and 8.4" jointed PCC base. On the other hand, section 36-A350 is formed through 3.4" AC layers (0.8" chip sealing and 2.6" AC layer) followed by 8" HMA base. The structurally strong sections in both states are compared in this level of analysis. The strong sections are 06-0603 (California) and 36-1643 (New York). Section 06-0603 consist of 4.8" AC and 8.2" jointed PCC base. Section 36-1643 includes 5.1" of AC layers and 8.2" HMA base.

The AADTT on California sections ranges from 2,000 to 3,000 while that on New York State sections ranges from 600 to 1,000. It should be noted as well that the California sections are located in a wet, no-freeze zone while the New York State sections are located in a wet, freeze zone.

5.1 Weak Sections

The transverse crack counts in New York's weak section (36-A350) is significantly higher than the count in California's section 06-0606. The P-value for this T-test is 0.002. This result is expected as New York section is located in a wet, freeze climate zone while the climate zone in California is wet, no-freeze. However, this comparison proves that traffic loads and AADTT would have no impact on the transverse crack progression. The AADTT in section 36-A350 is much lower than that in 06-0606. However, the thermal cracks show rapid deterioration even when subjected to low AADTT. Figure 9 presents the transverse crack count on both weak sections.

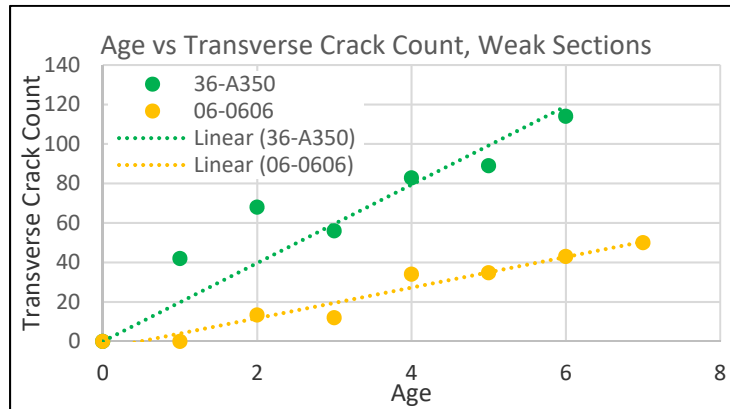


Figure 9: Transverse Crack Count on Weak Sections

The comparison between rutting in sections located in California and New York State illustrates significantly high rutting depth in New York's section 36-A350 compared to section 06-0606 in California. The P-value for this T-test is 0.003. The authors should note that AADTT on section 36-A350 is almost 67% lower than that on section 06-0606. In addition, the presence of section 36-A350 in a wet-freeze climate zone would offer it a relative advantage compared to section 06-0606 as it is located in a wet, no-freeze zone. Therefore, pavement temperature is relatively lower in the New York's test section location. The presence of rutting is facilitated through high pavement surface temperature (Kandhal 2003). The authors believe the significantly high rutting occurring on section 36-A350 is resulting from the 0.8" chip seal layer. This layer showed weak performance in rutting and thermal cracking. Figure 10 shows progressions of rutting on weak sections.

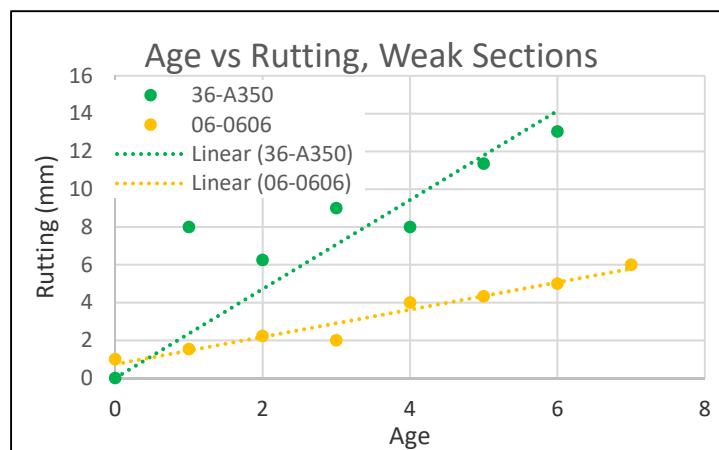


Figure 10: Rutting Progression on Weak Sections

5.2 Strong Sections

The transverse crack count in strong sections indicated weak statistical evidence the section in New York (36-1643) has slight advantage compared to California's section (06-0603). The P-value for this T-test is 0.048 (slightly lower than the 0.05 threshold). The thermal cracking count was pretty close during the first 5 years. The authors wish to note that the transverse cracking count at year 6 in New York's section (36-1643) could be an outlier resulting from operator's error. Thermal crack counts would not decrease unless maintenance treatment was performed but not documented on the LTPP database. As well, the thermal crack count at year 7 was not documented in the New York's section. Therefore, the authors would consider the two sections to have comparable performance in transverse cracking. This result as well confirms the traffic load (AADTT) has no significant influence on transverse cracking. Figure 11 presents the transverse crack count on the strong pavement sections.

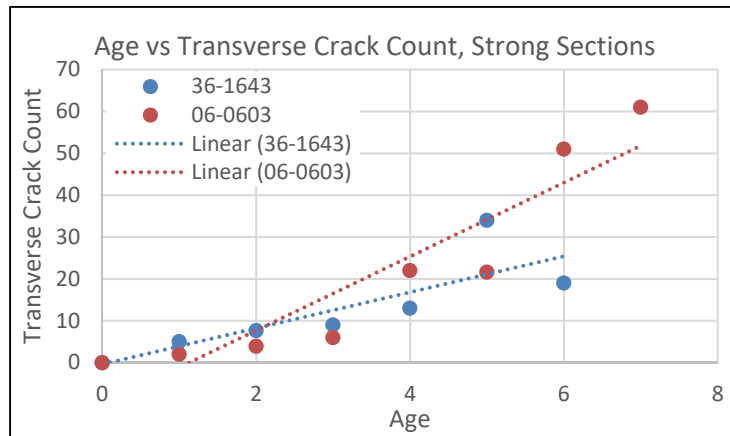


Figure 11: Transverse Crack Count on Strong Sections

The analysis of rutting depth in both sections showed no statistical difference among rutting depth. The P-value for this T-test is 0.22. This result gives slight advantage to the California's section (06-0603) as it performed slightly better even though it is subjected to high AADTT compared to the New York Section (36-1643) and it is located in a warmer climate zone.

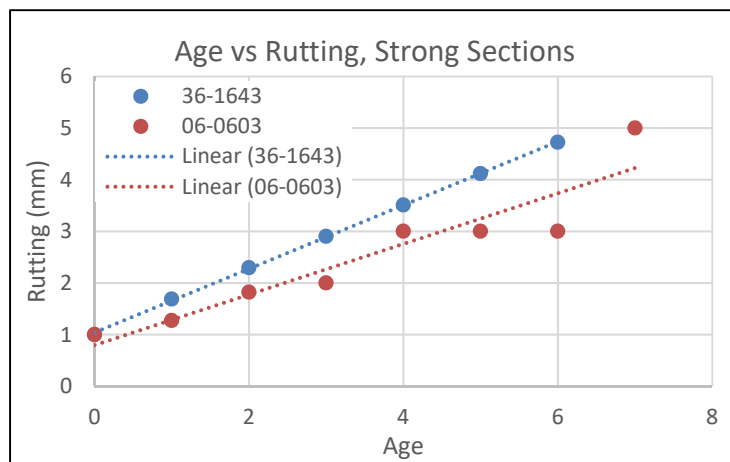


Figure 12: Rutting Progression on Strong Sections

6 Modeling And Deterioration Rates

The authors performed multiple regression analysis to develop deterioration rates for the four test sections. The regression models were developed using pavement service life (age), Traffic load (AADTT)

and climate impact (Freezing Index) as independent variables. The historical climate data used to calculate the freezing index was downloaded from www.weatherunderground.com. The Freezing Index (FI) was calculated using the Formula 1 (PavementInteractive 2017) (Rutherford 1985).

$$[1] FI = \sum(\bar{T} - 32^{\circ}F)$$

Where \bar{T} is the mean daily temperature.

The regression analysis is reported in this paper along with the models' R-squared values. The authors acceptable R-squared values between 0.8 to 1.0 as an indication of the development of a representable and reliable model. Rutting models were developed using two independent variables (Pavement Age and AADTT). The transverse cracking models were developed using three independent variables (Pavement Age, AADTT and Freezing Index). Table 1 presents deterioration models developed using linear regression.

Table 1: Regression Analysis for Deterioration Modeling

State	Section	Distress	Developed Model	R-Squared
CA	06-0603	Rutting	$y = .397*age + .000124*AADTT - 1.98$	0.89
CA	06-0606	Rutting	$y = 0.411*age + 0.0014*AADTT - 8.57$	0.92
CA	06-0603	Transverse Crack Count	$y = 4.606*age + .0511*AADTT + 40.09*FI - 140.11$	0.82
CA	06-0606	Transverse Crack Count	$y = 4.38*age + 0.046*AADTT - 24.67*FI - 102.681$	0.93
NY	36-1643	Rutting	$y = 0.623*age - 0.0000742*AADTT + 1.439$	0.93
NY	36-A350	Rutting	$y = -1.041*age + 0.00349*AADTT - 7.562$	0.84
NY	36-1643	Transverse Crack Count	$y = 2.894*age - 0.00995*AADTT + 0.406*FI + 50.5632$	0.82
NY	36-A350	Transverse Crack Count	$y = 20.8*age + 0.0055*AADTT - 0.9066*FI - 8.362$	0.91

7 Conclusion

This paper presented a comprehensive evaluation of four LTPP test sections located in California and New York State. Two sections were selected from each State. The sections selection was performed to create a controlled comparison between sections with identical traffic spectrum and others with comparable structural capacity. The analysis in this paper was performed on two levels: a) In-State analysis and b) Cross State analysis. The comparison of the two test sections located in California (06-0603 and 06-0606) concluded that structural strength has limited impact on transverse cracking. However, the reduction of 1.5" of AC layer's thickness resulted in a significant increase in rutting depth and an accelerated rutting progression in section 06-0606.

The in-state analysis performed on sections located in New York State concluded that 0.8" chip seal layer installed on section 36-A350 had the worst resistance to transverse cracking and rutting compared to the thin overlay applied on section 36-1643. The section treated by thin overlay was subjected to 0.7" rutting on the 1st in-service year. However, the deterioration rate of the thin HMA overlay is lower than the deterioration of the chip seal layer installed on 36-A350.

The cross-state analysis was performed by analyzing the sections with comparable structural capacity and located in two different states. The weak pavement sections in California and New York State were 06-0606 and 36-A350 respectively. The strong pavement sections in California and New York State were 06-0603 and 36-1643 respectively. The analysis of weak sections concluded that chip seal layer had low resistance to thermal cracking even if subjected to low traffic loads. The ability of chip seal layer to resist rutting is limited even in wet, freeze climate zone. Section 06-0603 located in California lower rutting depth although it is located in warmer climate than section 36-1643. The analysis of strong pavement sections concluded that sections in California and New York exhibited comparable rate of transverse

crack counts. The transverse cracks in California were slightly lower than that in New York. This result was concluded even though the traffic on the section in California is subjected to 150% additional truck loads (AADTT) compared to the section in New York. The rutting resistance of both sections was comparable and insignificant difference was concluded using T-test.

The authors developed deterioration models for transverse cracking and rutting for all four LTPP sections. The deterioration models were developed using multiple regression analysis. The independent variable included pavement age, AADTT and Freezing Index.

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