Technical Memorandum

To: Jeff Uhlmeyer

From: Gonzalo Rada, Gary Elkins and Kevin Senn

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Date: September 6, 2019 (original)

Re. Forensic Desktop Study Report: LTPP Test Section 395003

The Long-Term Pavement Performance (LTPP) General Pavement Studies (GPS) test section 395003[1] was nominated for a desktop study under TPF-5(332) "LTPP Forensic Evaluations" because it is a continuously reinforced concrete pavement (CRCP) that was in service for 24 years, from 1988 until 2012, at the end of which it received a 3.4 in asphalt concrete (AC) overlay that does not appear to be performing well. The last measurements on this project were performed between 2014 and 2016. This document is intended to review the test section history, examine distress manifestations, and make recommendations on the need for forensic evaluation related work to explain the performance of the test section over time, for both the original CRCP and the CRCP with AC overlay.

SITE DESCRIPTION

LTPP test section 39_5003 is located on US 20 eastbound at milepost 11.1 in Lorain County, Ohio. US 20 is a rural principal arterial with two lanes in the direction of traffic. It is classified as being in a Wet Freeze climate zone with an average annual precipitation ranging between 26.1 inches (1991) and 61.2 inches (2011) and an annual average air freezing index ranging between 175 Deg-F degree-days (2012) and 1,004 Deg-F degree-days (2015) during the performance period in question (1988 to 2017). The coordinates of the test section are 41.30417, -82.14944. Photograph 1 shows the test section in 2014, while Map 1 shows the geographical location of the test section relative to the City of Cleveland within the State of Ohio.

[1] First two digits in test section number represent the State Code [39 = Ohio]. For LTPP GPS test sections, the final four digits are unique within each State/Province and they were assigned at the time the test section was accepted into the LTPP program. For LTPP Specific Pavement Studies (SPS) test sections, the second set of two numbers indicates the Project Code (e.g., 02 = SPS-2) and the final set of two numbers represents the test section number on that project (e.g., 13).

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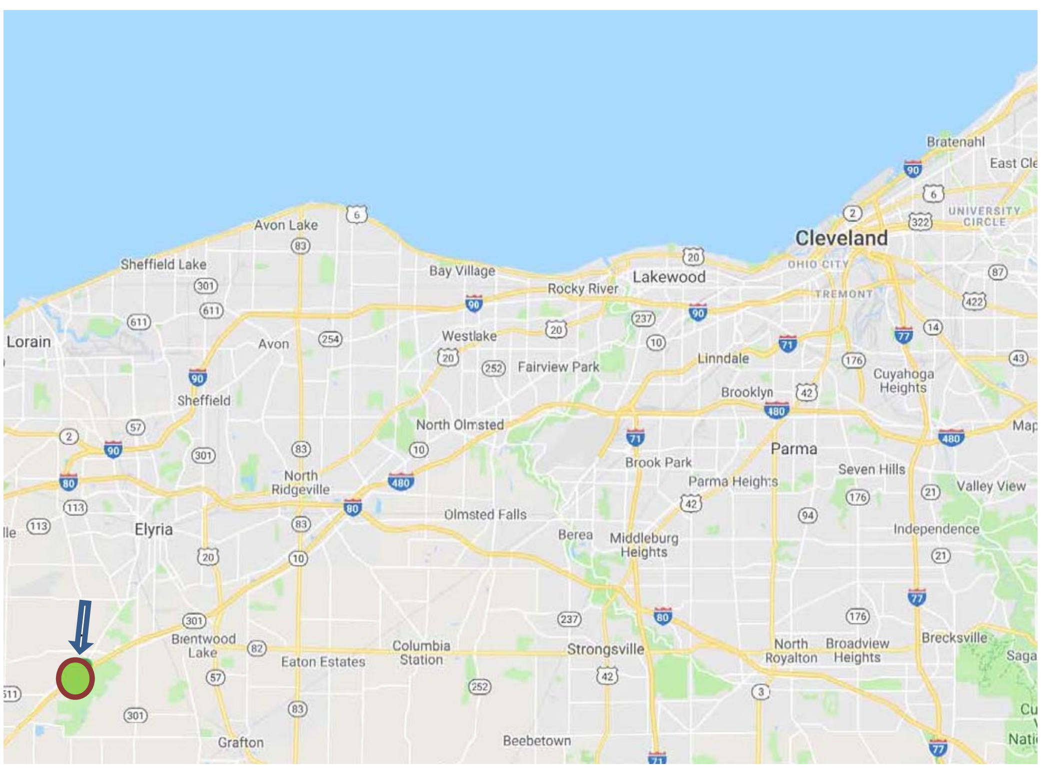
Photograph 1. Picture of test section 395003 in 2014 (from start of section looking east).



Map 1. Geographical location of test section relative to the City of Cleveland in Ohio.

BASE-LINE PAVEMENT HISTORY

The information included in this portion of the document presents the baseline data on history of pavement structure, climate, traffic and pavement distresses, roughness and deflection.

Pavement Structure and Construction history

The initial pavement structure was constructed in 1988, which is also the year when the test section was included in the LTPP program as part of the GPS-5 CRCP experiment. The original layer structure is detailed in Table 1. This corresponds to CONSRTUCTION_NO = 1 (CN = 1).

Table 1. Pavement structure from 1988 to 2012.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)		133-Fine-Grained Soil: Silty Clay with Sand
2	Unbound (granular) subbase	5.2	303-Crushed Stone
3	Bound (treated) base	4.8	319-Hot Mix Asphalt Concrete (HMAC)
4	Portland cement concrete layers	9.8	6-Portland Cement Concrete (CRCP). (Longitudinal steel bars are placed at depth of 4.0 inches. They are 0.88 inches in diameter and are spaced at 6.3 inches, which yields 0.6 percent longitudinal steel. Transverse steel bars are 0.5 inches in diameter and they are spaced at 30 inches.)

Partial depth patching of the CRCP was performed in 2008 and 2011. These correspond to CN = 2 and CN = 3, respectively. In June 2012, the test section was patched and overlaid with a 3.4-inch recycled AC, hot laid, central plant mix. This corresponds to CN = 4 and the test section was moved to the LTPP GPS-7C (AC overlay of existing concrete pavement) experiment. The resulting pavement structure is detailed in Table 2.

Table 2. Pavement Structure from 2012 to Date

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)		133-Fine-Grained Soil: Silty Clay with Sand
2	Unbound (granular) subbase	5.2	303-Crushed Stone
3	Bound (treated) base	4.8	319-Hot Mix Asphalt Concrete (HMAC)
4	Portland cement concrete layers	9.8	6-Portland Cement Concrete (CRCP)
5	AC layer	3.4	13-Recycled AC, Hot Laid, Central Plant Mix

Pavement Structural Properties

Figure 1 shows the time history average FWD deflection plot under the nominal 9,000 lb. load from the sensor position in the load plate. The deflection of the sensor located in the load plate is a general indication of the total “strength” or response of all layers in the pavement structure to a vertically applied load. This deflection can be influenced by pavement temperature at the time of testing, precipitation, and changes in pavement structure. As shown, deflections are not only very small but they have remained low (below 2.2 mils) over the entire life of the pavement test section. The 2012 AC overlay does not appear to have had much of an impact on the deflections, as they have remained at about the same level prior to the overlay. Overall the central sensor deflection time history magnitudes are judged to be very low, indicating a very "strong" pavement structure.

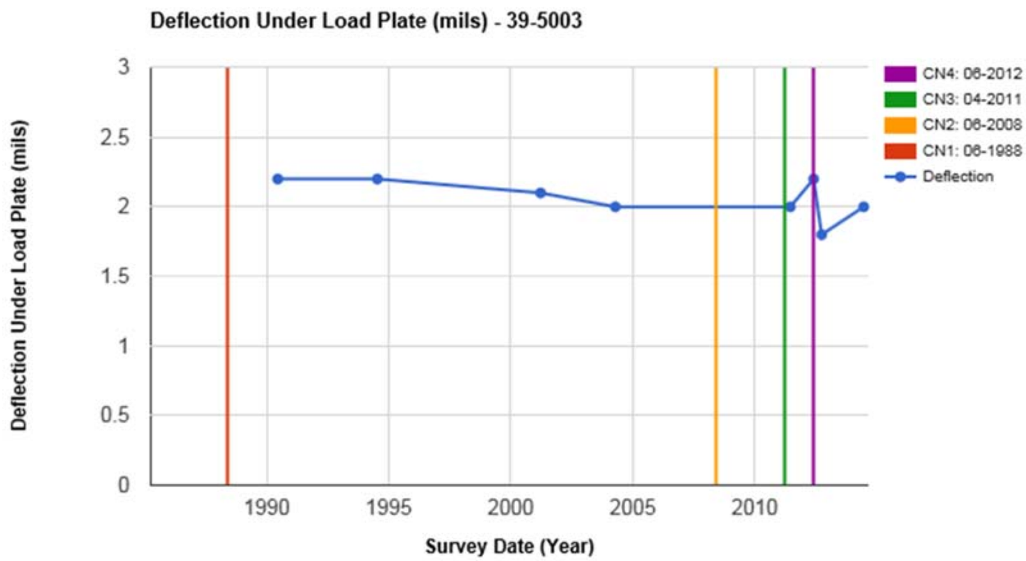


Figure 11. Time history of average deflection for the sensor located in the load plate normalized to 9,000 lb. drop load.

Table 3 shows the layer moduli backcalculated from the deflection data measured between June 1990 and May 2012; i.e., six rounds of FWD testing – four under CN = 1 and two under CN = 3. In all cases, the pavement structure was modeled as consisting of 9.7 inches of CRCP, 4.6 inches of AC treated base, 5.2 inches of unbound granular subbase, over subgrade. As shown in the table:

- The backcalculated modulus values for the CRCP layer vary over a narrow range (i.e., moisture and temperature changes do not appear to have a significant impact) and the values are typical of a well-constructed concrete layer.
- The backcalculated layer moduli for the AC treated base, unbound granular subbase and subgrade appear to be high.
  - In the case of the AC treated base, temperature appears to have an effect on the value – i.e., the lowest modulus values occur in the summer months and the highest ones in the non-summer months.
  - No clear trend for the changes in the untreated granular subbase can be observed, but it is hypothesized that the changes in moisture may be responsible for some of the variations.
  - The subgrade moduli are within a narrow range, indicating moisture and temperature changes are either relatively constant (which is not reflected in the unbound granular subbase) or they do not affect the subgrade modulus.

Table 3. Backcalculated layer moduli over time.

Layer Type	Thickness (inches)	Test Date	Modulus (ksi)
CRCP	9.7	06/13/1990	5,676
		07/13/1994	5,928
		03/22/2001	5,907
		04/15/2004	6,085
		06/16/2011	6,634
		05/30/2012	5,221
AC Treated Base	4.6	06/13/1990	1,353
		07/13/1994	510
		03/22/2001	1,621
		04/15/2004	1,380
		06/16/2011	841
		05/30/2012	1,563
Unbound Granular Base	5.2	06/13/1990	97
		07/13/1994	51
		03/22/2001	62
		04/15/2004	99
		06/16/2011	55
		05/30/2012	55
Subgrade		06/13/1990	34
		07/13/1994	33
		03/22/2001	23
		04/15/2004	25
		06/16/2011	23
		05/30/2012	26

Note: Information obtained from LTPP InfoPave™ indicates that the AC treated base is 4.8 inches thick, but it appears that a thickness of 4.6 inches was used in the backcalculations for the layer.

It is possible the untreated layers are stress dependent. In the case of the subgrade, which is a silty clay with sand, the material could be stress softening (i.e., strength increases as stresses decrease), which would explain the high moduli given the slab action and hence reduction in stresses. By the same token, however, the unbound granular subbase would likely be a stress hardening material (i.e., strength increases as stresses increase), which does not appear to be the case given the high moduli.

No other plausible explanation is offered beyond the nature of the backcalculation procedures – e.g., layer compensating effects, minimum or maximum allowable moduli values reached, localized solutions that are not the true solution, etc. Consequently, a more in-depth layer moduli backcalculation analysis is recommended as a follow-up investigation to this desktop study to either explain the reasons for the high moduli or to provide revised moduli values. It should also be noted that no deflection testing has been performed on the test section performed after placement of the AC overlay, and consequently the overlay does not have backcalculated moduli.

Climate History

The time history for annual average precipitation at the site since 1988 is shown in Figure 2. In 2011, the amount of precipitation appears to be a local high at 61.2 inches, while a low of 26.1 inches was recorded in 1991. Neither of these measurements are considered to drastically deviate from the mean at the site of 39.6 inches for the time period in question, nor do they appear to have resulted in drastic changes in pavement distresses or pavement response.

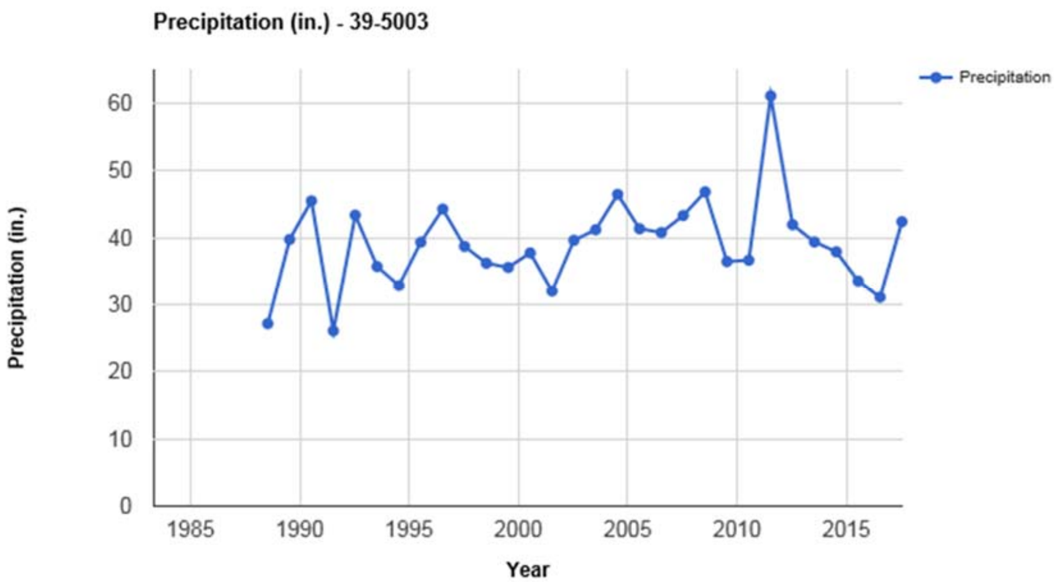


Figure 2. History of annual precipitation starting in 1973.

Figure 3 shows the time history of the annual freezing index over the history of this test section. The freezing index is the sum of the difference between 32 degrees F and when the average air temperature is less than freezing and 32 degrees F for each day, which is summed over a year's time. This index is an indicator of the harshness of the winter season relative to issues such as ground frost and low temperature cracking in pavements. The most significant spike in extreme low temperatures was observed in 2014 and 2015. This extreme in air freezing index was still below the threshold between non-frost and frost climate zones. The only performance measurement taken after those dates was an IRI survey in 2016, which does not show any significant impacts of the earlier low temperature event.

Truck Volume History

Figure 4 shows the annual truck volume data in the LTPP test lane by year. The red triangles are data provided by the Ohio DOT from historical records. The blue diamonds are truck counts based on monitoring data reported to LTPP by the Ohio DOT. While not perfect, there appears to be agreement between the estimated and monitored counts, except during the period of 2009 and 2013 where the counts appear to be outliers, especially the 2012 and 2013 values. The figure also shows that truck volumes have remained fairly constant (between 500 and 1,000 per year) on the LTPP lane, except for the earlier referenced period of 2009 to 2013.

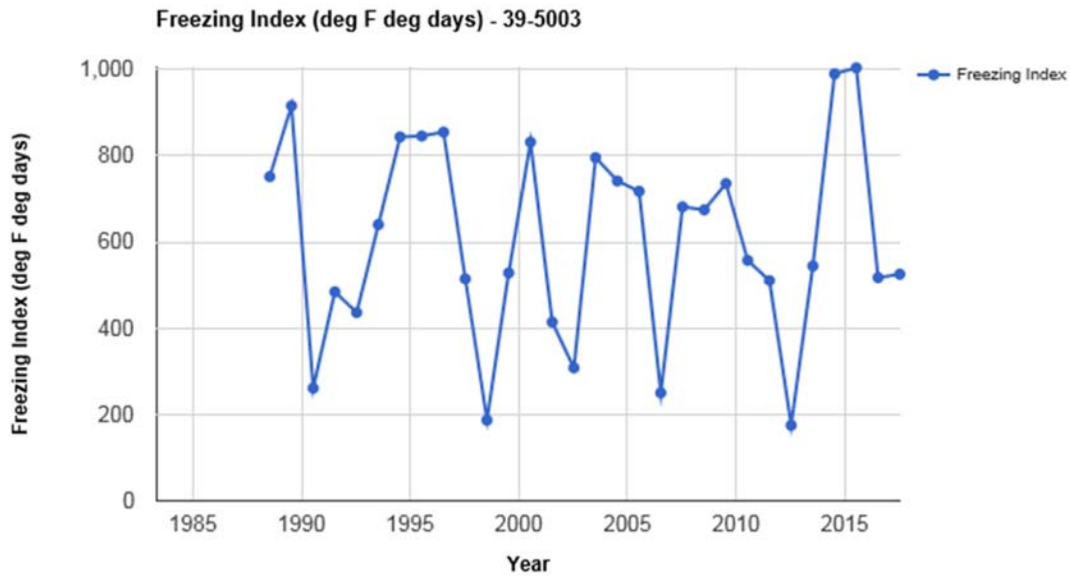


Figure 3. Time history of annual air temperature freezing index.

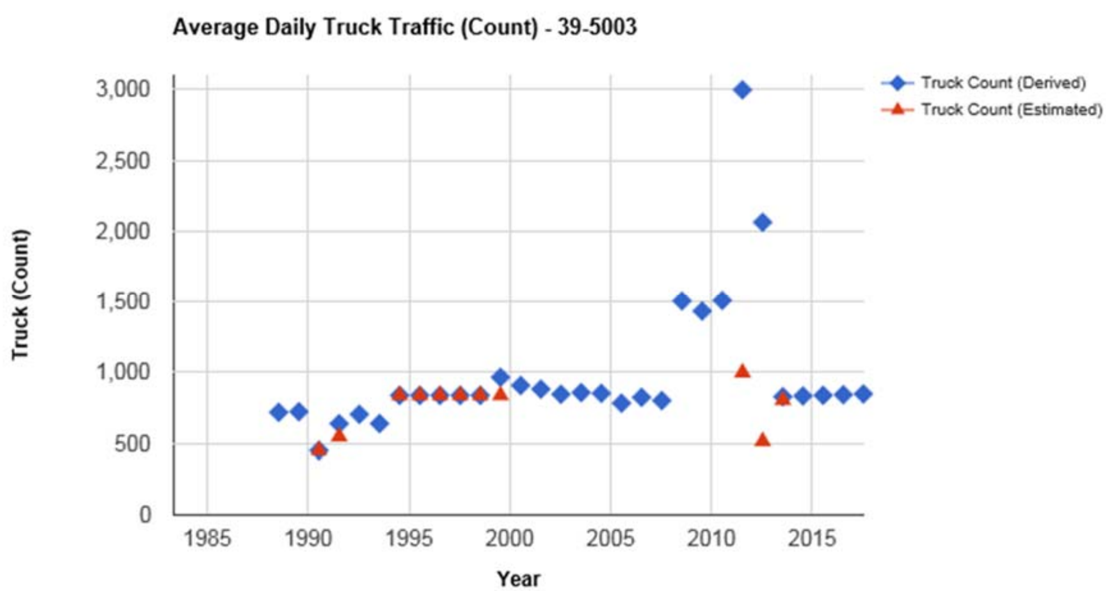


Figure 4. Average annual daily truck traffic on test section 395003 based on state supplied estimates and monitoring measurements.

Pavement Distress History

This section summarizes the distresses observed at the test section, first during the period of 1988 to 2012 when it was a CRCP pavement (CN =1, 2 and 3), and then during the period starting in 2012 to date when the CRCP pavement was covered by an AC overlay (CN = 4). Except for rutting and IRI, the distress data shown are from manual distress surveys.

<u>CRCP Pavement</u> (1988 to 2012)

Figure 5 shows the time history plot of longitudinal cracking. As shown, there has been limited longitudinal cracking throughout the life of the CRCP pavement. Except for a spike in 2004 of close to 50 feet (not a significant amount), longitudinal cracking remained at or below 12.5 ft (almost non-existent) through 2012 when it was overlaid with a thin AC layer. Attempts were made to review the distress maps, images and videos from the 2004 survey to explain the spike, but they were not readily accessible via LTPP InfoPave™, and consequently this information will need to be pursued as part of the follow-up investigations. In the interim, it is hypothesized that the 2014 spike is an outlier related to the interpretation of lane edge cracking.

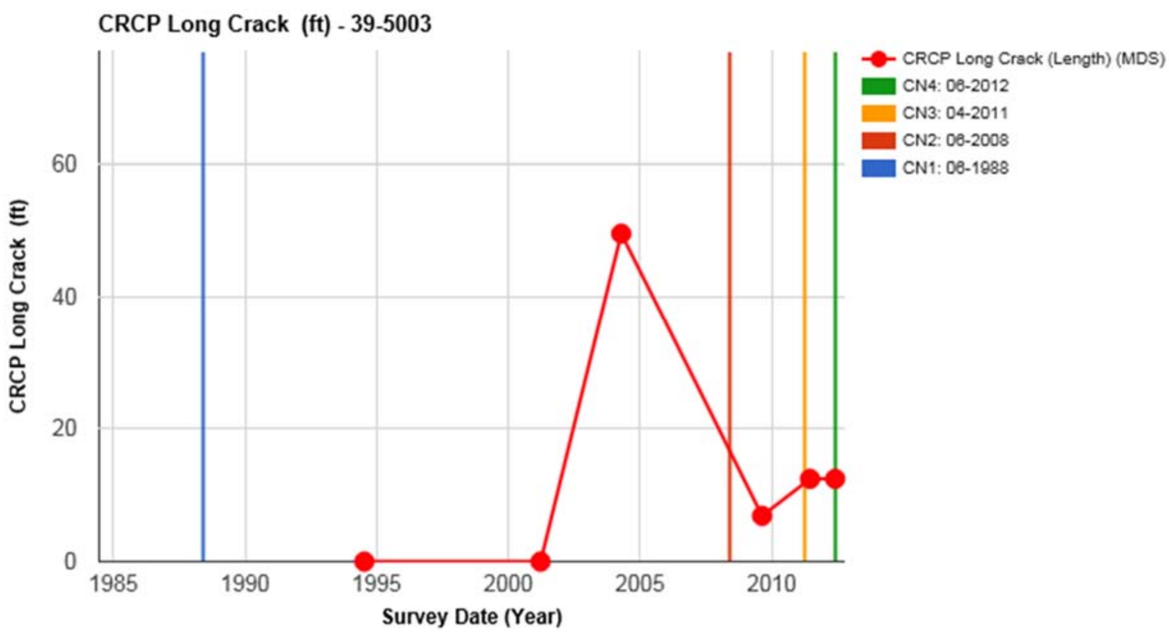


Figure 5. Time history of longitudinal cracking (CRCP).

Figures 6 and 7 show the time history of the number and length of transverse cracks, respectively, on the pavement. In this figure, the construction events are shown with vertical lines – the focus of this investigation is the period of 1988 (CN = 1) to 2012 (CN =2 and 3), which captures the performance of the CRCP pavement. As shown in these two figures, the number and length of transverse cracking remained at or close to zero from 1994 through 2001 (no manual surveys were performed prior to 1994, only photographic surveys), and then jumped to 160 to 180 cracks totaling 1,800 to 2,100 feet during the 1994 to 2012 period, which averages to about one transverse crack every three feet.

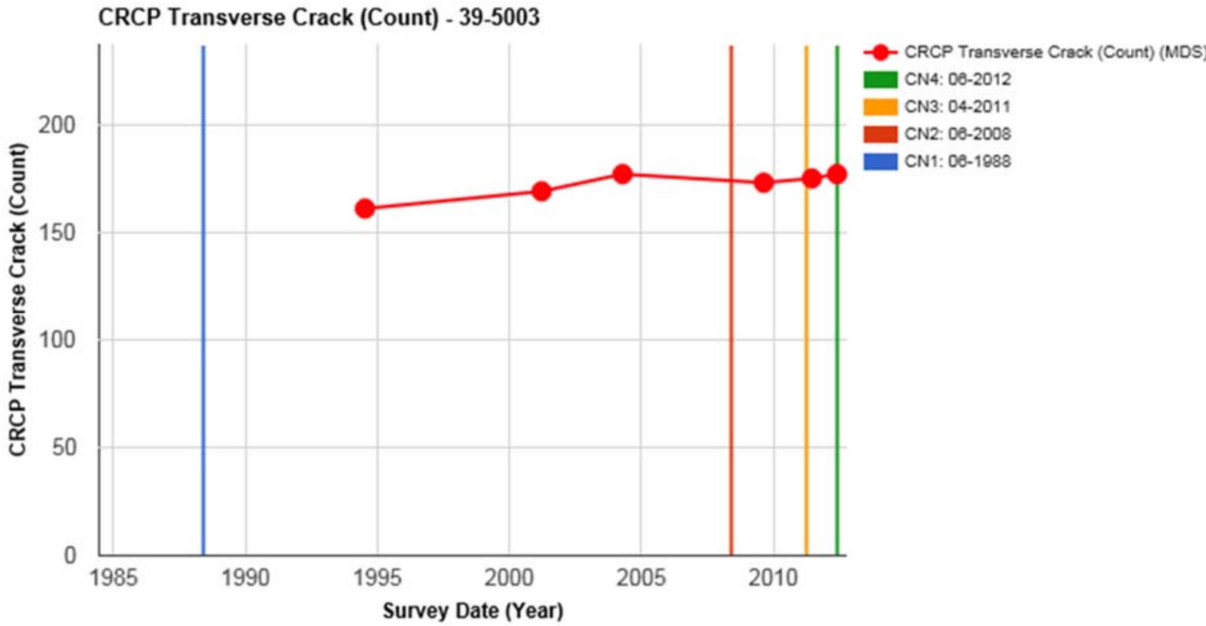


Figure 6. Time history of the number of transverse cracks (CRCP).

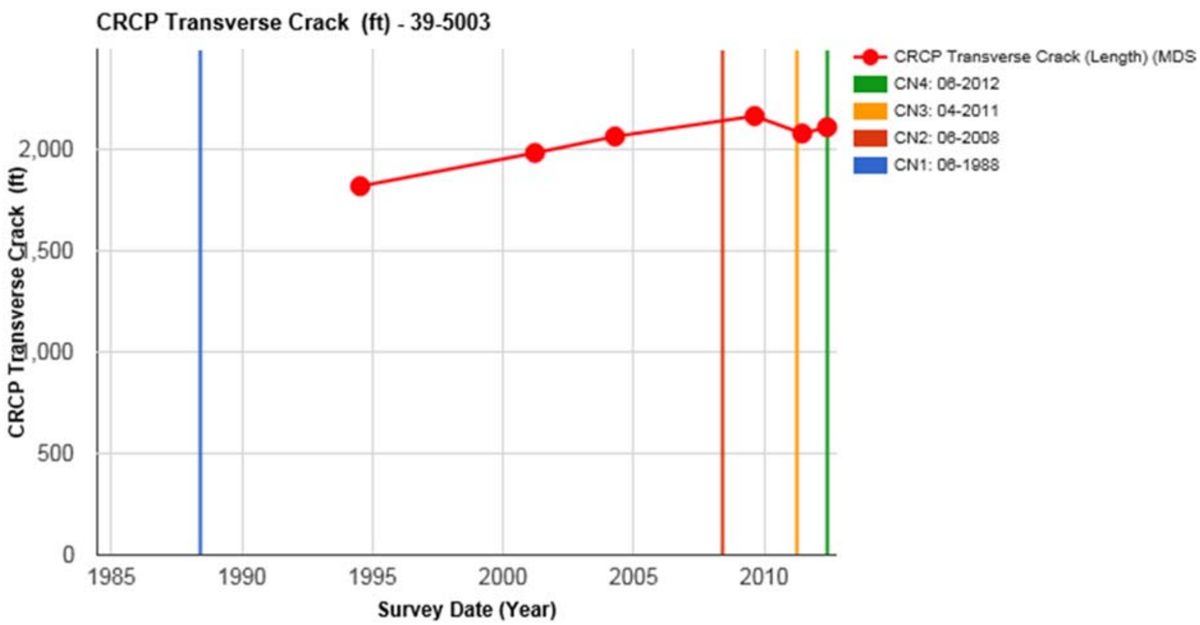


Figure 7. Time history of length of transverse cracks (CRCP).

Figure 8 shows the number of punchouts during the 1994 to 2012 period; no manual surveys were performed prior to 1994, only photographic surveys. As shown, there were no punchouts until 2004, when two of them were identified. Both of the punchouts appear to have been fixed my means of flexible patches in 2008 (CN = 2), but another punchout was identified in 2009 and this one appears to have been fixed in 2011 (CN = 3), which reduced the number of punchouts to zero. No further punchouts were identified after this time. As shown in Figures 9 and 10, the number flexible patches increased from zero in

2004 to eight in 2012, while the area of the patches increased from zero to 14 ft^2 during the same time period.

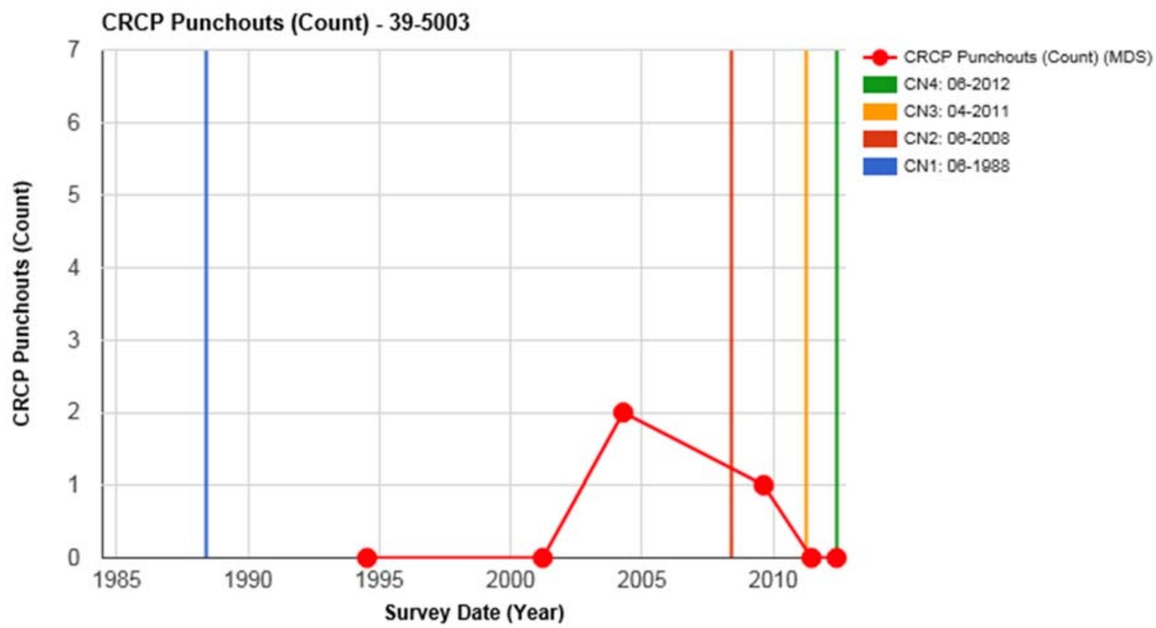


Figure 8. Time history of the number of punchouts (CRCP).

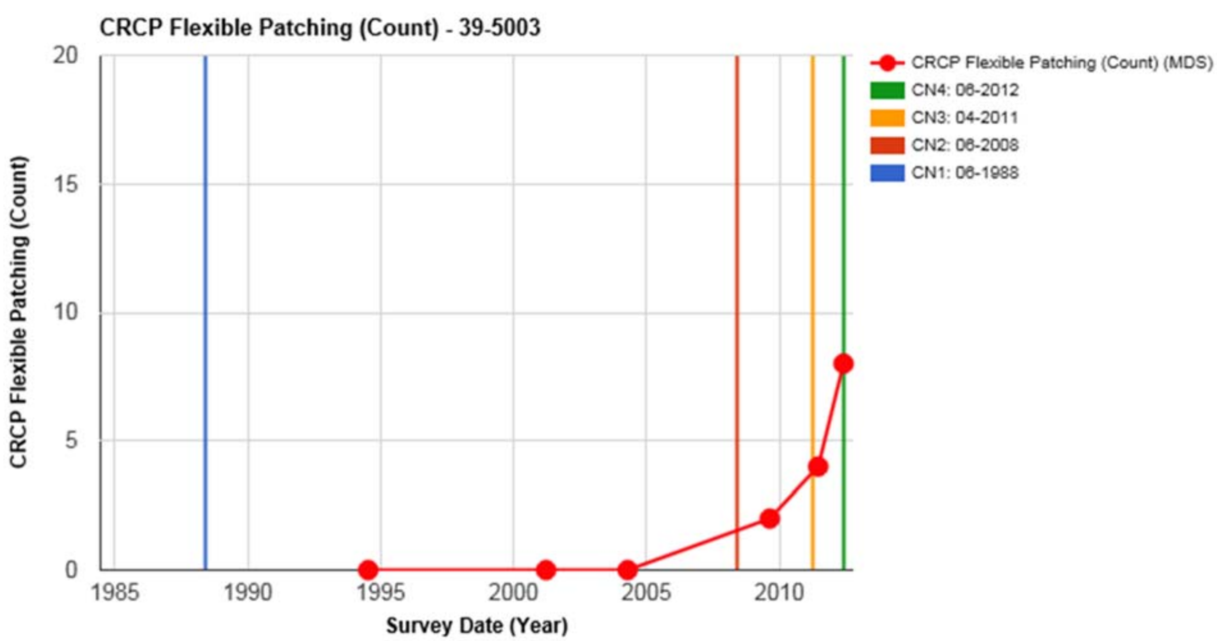


Figure 9. Time history of the number of flexible patches (CRCP).

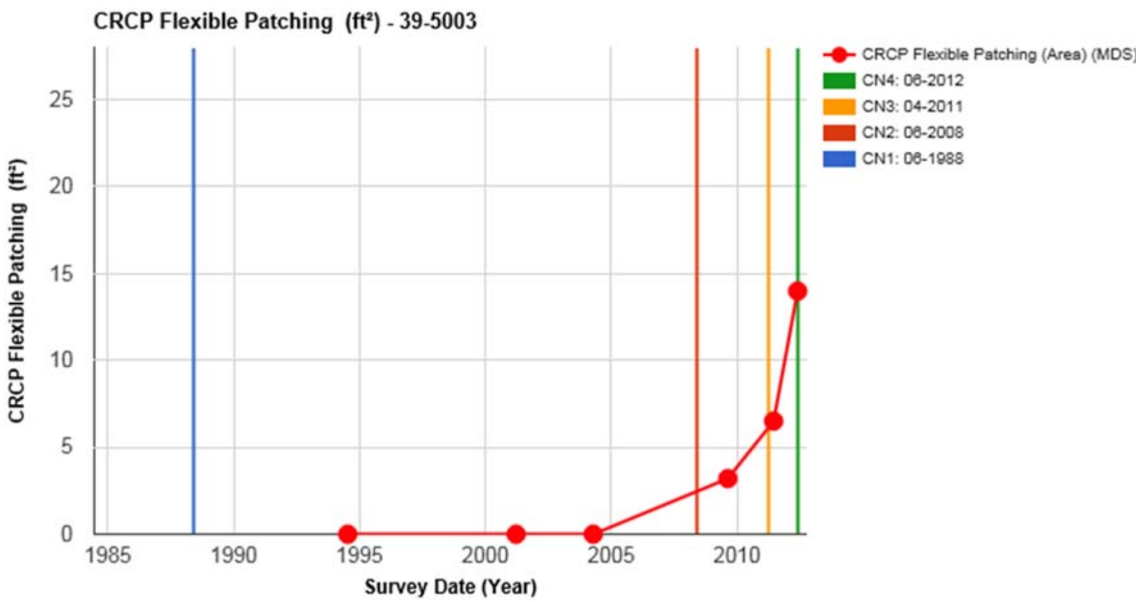


Figure 10. Time history of the area of flexible patches (CRCP).

<u>AC Overlay of CRCP Pavement</u> (2012 to latest measurements)

Figure 11 shows the time history plot of alligator cracking data on LTPP test section 395003. While the plot is labeled fatigue cracking, in the LTPP distress rating system, this is alligator cracking that is not limited to the wheel path. As shown, the amount of alligator cracking on this test section is high (248 ft^2) within two years after the AC overlay. Moreover, the presence of cracking that appears to look like alligator cracking is somewhat surprising given the underlying CRCP pavement; see Photograph 1 earlier in this technical memorandum. As such, further information, including a follow-up surface distress survey, is required to more clearly explain this cracking.

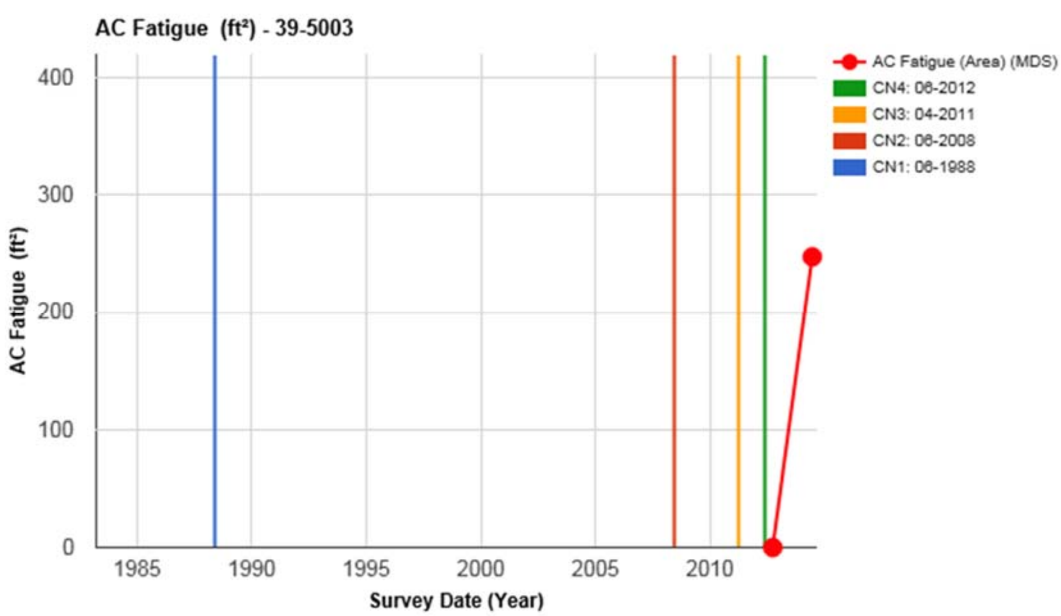


Figure 11. Time history of area of alligator cracking.

Figures 12 shows the time history plots of longitudinal cracking not in the wheel path (NWP). Like alligator cracking, the length of longitudinal cracking NWP is high (507 ft) within two years of application of the AC overlay.

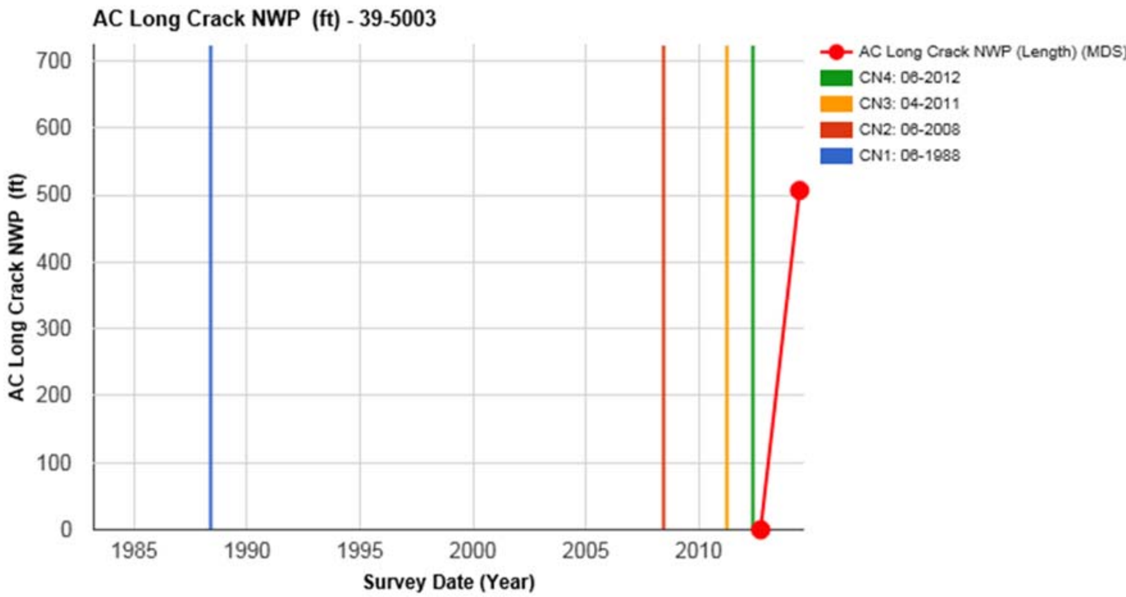


Figure 12. Time history of longitudinal cracking in the wheel path.

Figures 13 and 14 show the time history of the number and length of transverse cracks, respectively, on the overlaid pavement. As shown in these two figures, the number and length of transverse cracking is high – 90 and 490 feet, respectively. The number of cracks is approximately half the number of transverse cracks on the CRCP pavement prior to the AC overlay, which appears to imply that half of the transverse cracks are not acting as slabs. Moreover, the fact that the transverse cracks on the AC overlay have developed within two years of placement of the overlay appears to indicate that they are reflection cracks.

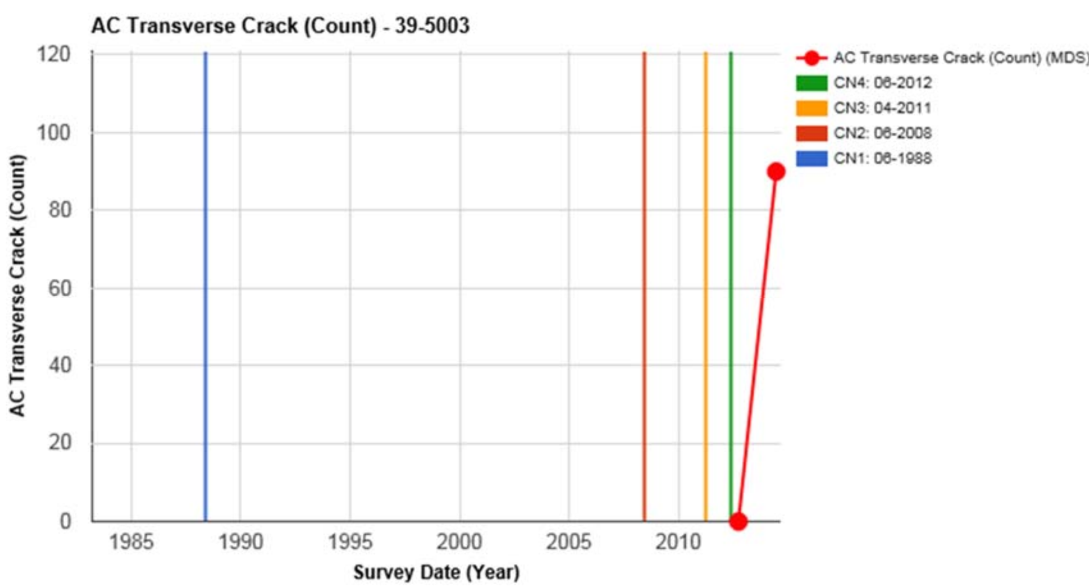


Figure 13. Time history of the number of transverse cracks for CN = 4.

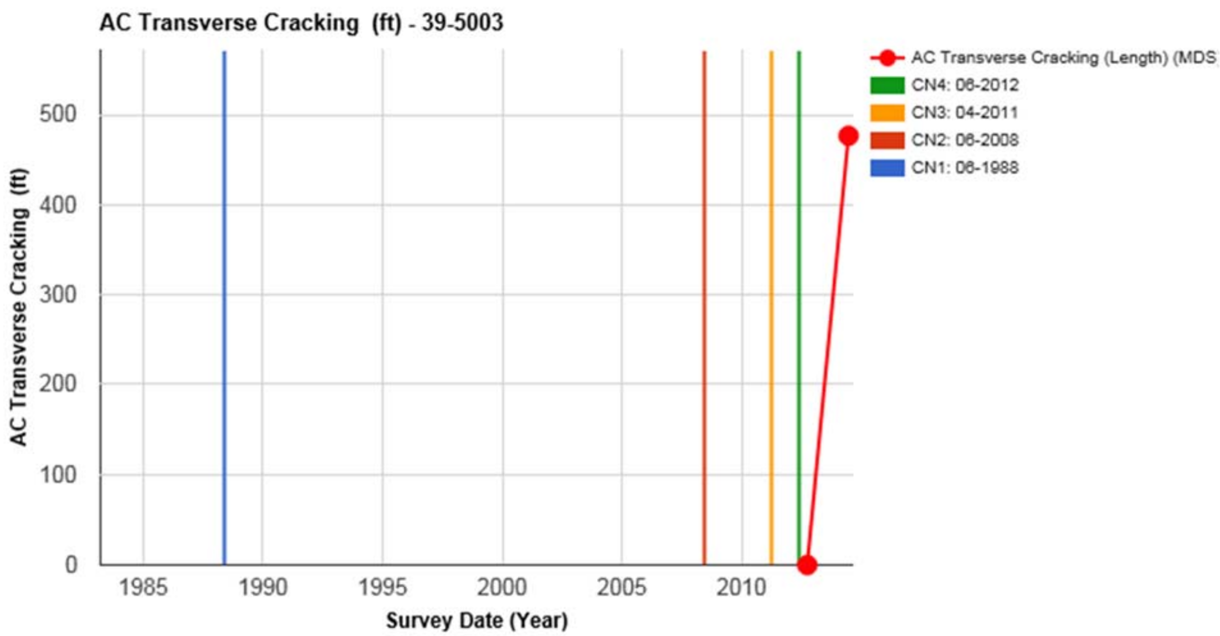


Figure 14. Time history of the length of transverse cracks for CN = 4.

<u>Other Distresses </u>(1988 to date)

The time history plot of rutting on the test section is shown in Figure 15. As shown, rutting of the pavement test sections has remained low (~0.2 inches) throughout the life of the pavement, and under 0.1 inches since the application of the 3.4 inch AC overlay in 2012.

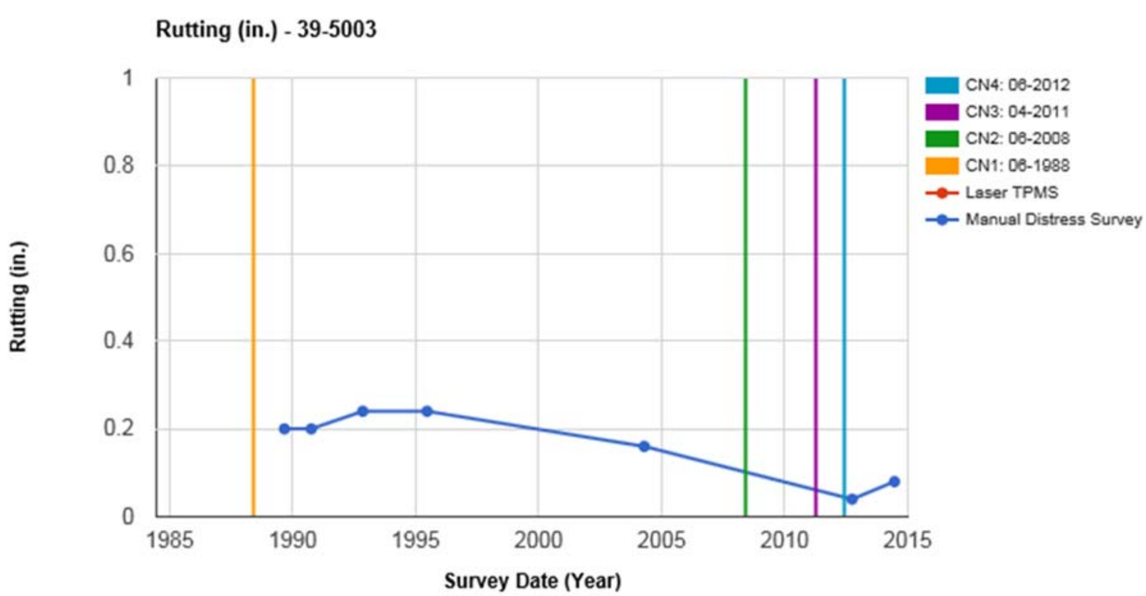


Figure 15. Time history plot of average rut depth computations.

Similarly, the time history of roughness measurements is shown in Figure 16. As shown, the IRI remained close to 70 inches/mile throughout the life of the CRCP pavement. After placement of the AC overlay in

2012, the IRI of the pavement test section dropped to around 39 inches/mile, an extremely smooth value, and it has remained at that level through 2016, which is when the last survey was performed.

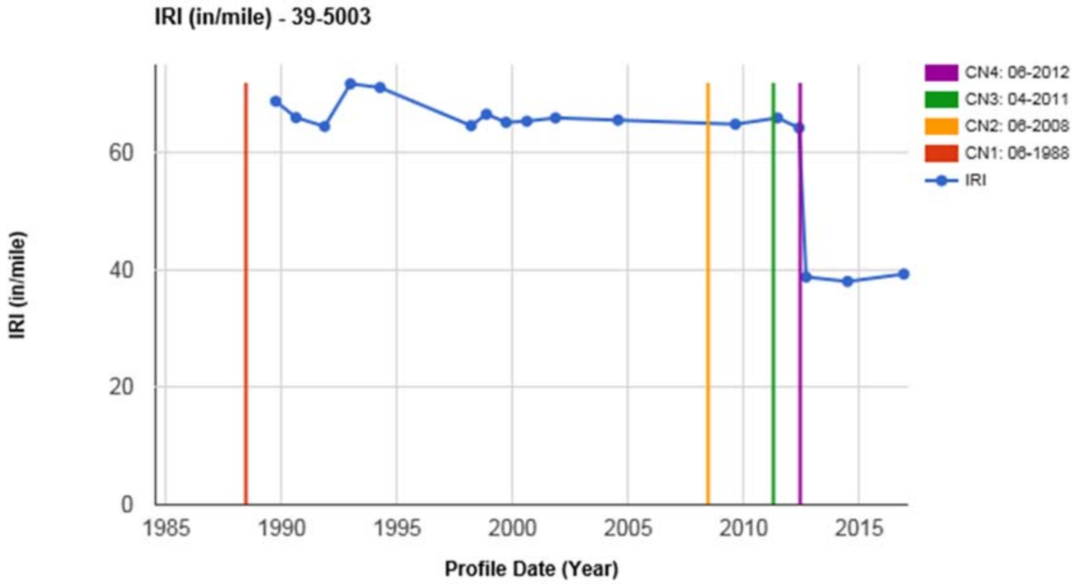


Figure 16. Time history plot of pavement roughness.

SUMMARY OF FINDINGS

In this review of information concerning the performance history of test section 395003 the following information was presented:

- The test section was originally constructed in 1988, consisting of 9.8 inches of continuously reinforced concrete on 4.8 inches of AC treated base, and 5.2 inches of unbound granular subbase over a silty clay with sand. The longitudinal steel bars in the CRCP layer are placed at a depth of 4.0 inches. They are 0.88 inches in diameter and are spaced at 6.3 inches, which yields 0.6 percent longitudinal steel. The transverse steel bars are 0.5 inches in diameter and they are spaced at 30 inches. The test section was included in the LTPP program that same year as part of the GPS-5 experiment. In 2012, after 24 years of service, the CRCP pavement test section received a 3.4 inch AC overlay and it was moved to the GPS-7C experiment.
- The CRCP pavement structure performed well over the 24 year period prior to application of the AC overlay in 2012. However, the same cannot be said about the performance of the pavement after the AC overlay, at least in terms of cracking. Two years after construction, the AC overlay was showing significant amounts of alligator, longitudinal (NWP) and transverse cracking, as summarized in Table 4. The other performance measures show better pavement condition – IRI improved by 25 (from 64 to 39) inches/miles, rutting by 0.1 inches, and the average normalized maximum deflection by 0.4 mils after the overlay, and those values have remained low during the first couple of years of the AC overlay life.
- Traffic at the test section has remained relatively constant throughout the life (1988 to present) of the test section, with counts in the 500 to 1,000 truck per day. However, the counts for the time period of 2000 through 2012 increased to 1,500 to 3,000 trucks per day. It is possible that the added loading on

the pavement indicated by the elevated truck counts may have contributed to the poor performance of the AC overlay.

Table 4. Pavement Test Section 395003 Condition History

Pavement Condition Metric	Condition Prior to AC Overlay	Condition After AC Overlay	Latest Condition
Longitudinal Cracking Wheel Path	50 ft	0 ft	507 ft in 2014
Transverse Crack Count & Length	177 / 2,100 ft	0 / 0 ft	90 / 490 ft in 2014
Patching	14 ft^2	0 ft^2	0 ft^2 in 2014
Rutting	0.2 inches	0.1 inches	0.1 inches in 2014
IRI	64 inches/mile	39 inches/mile	39 inches/mile in 2016
Normalized Maximum Deflection	2.2 mils	1.8 mils	2.0 mils in 2014

- The moduli values backcalculated from the FWD deflection data appear reasonable for the CRCP layer, but not so for the asphalt treated base, unbound granular base and subgrade – all appear to be unreasonably high. Similarly the effects of moisture and stress sensitivity on the moduli changes for the unbound granular subbase and subgrade layers is not clear.
- The observance of alligator cracking on the AC overlay appears odd given the presence of the relatively strong structure of the underlying CRCP pavement structure.
- It could be hypothesized that this alligator cracking is the result of separation between the AC overlay and CRCP layer, but the deflections values do not support this hypothesis – i.e., the referenced layers appear to be acting monolithically given the low deflections. It is also possible that the issue may be materials related, but no laboratory test data is available in the LTPP database for the overlay layer.

In summary, the original CRCP pavement test section appears to have performed well over 24 years, but not so after the application of the AC overlay; albeit this is based on limited information (i.e., just one round of measurements.)

FORENSIC EVALUATION RECOMMENDATIONS

While sufficient data are available to explain the performance of the Ohio 395003 test section from 1988 to 2012, while a CRC pavement, that is not the case for the performance of the pavement after application of the AC overlay. Moreover, there are a few items that require confirmation or clarification in order to provide a better understanding of the performance of the test section. Accordingly, it is recommended that the desktop study be extended as follows:

- Obtain design information from the Ohio DOT for the original pavement structure as well as for the AC overlay to confirm the performance of the test section. This should include traffic, material strengths, layer thicknesses and drainage information. As part of this information gathering effort, it is also recommended that interviews of Ohio DOT staff familiar with test section be conducted, if possible, to gather their thoughts as to why the test section performed so well prior to the overlay and not so well after the overlay.

- Explore via Ohio DOT staff or other means the reason for the high truck counts between the period of 2008 and 2012. Also, expand review of traffic data to include equivalent single axle loads (ESALs). Once completed, pursue more in-depth investigation into the effects of traffic on the performance of the AC overlay.
- Perform more in-depth layer moduli backcalculation analyses to either explain the reasons for the high asphalt treated, unbound granular subbase and subgrade layers or to provide revised moduli values for all layers. As part of the investigation, also pursue the following:
  - Information on moisture conditions at the time of deflection testing to assess the effects of moisture on the layer moduli for the unbound layers.
  - Laboratory resilient modulus data for the unbound layers stored in the LTPP database to assess the stress sensitivity of the referenced layers; results from two tests per layer are available.
  - Theoretical study to assess effects of bonding versus no bonding of AC overlay and CRC layer on deflections, and in turn to determine if lack of bonding may be a contributor to the presence of alligator cracking on the AC overlay.
- Perform another round of distress and IRI surveys to confirm the performance of the AC overlay over the 2012 through 2019 period. Additional FWD testing is also very important in order to confirm the current structural properties of the pavement, especially in light that there has been no FWD deflection testing since placement of the AC overlay.
- Perform limited coring to confirm (1) bonding conditions between the AC overlay and the CRCP layer and (2) whether transverse cracks observed on the AC overlay are reflection cracks.
- Given lack of materials characterization data for the AC overlay, it is suggested that MRL material samples for the test section be used to address current material data gaps – both 4 inch and 6 inch cores are available. The testing could be performed by the current FHWA LTPP laboratory testing contractor or via the pooled fund study. The resulting information could then be used to help explain the apparent presence of alligator cracking on the AC overlay, which is unusual given the presence of the underneath CRCP layer.