Technical Memorandum

To: Jeff Uhlmeyer

From: Gonzalo Rada, Gary Elkins and Kevin Senn

cc: Mustafa Mohamedali

Date: October 10, 2019 (original)

Re. Forensic Desktop Study Report: Mississippi LTPP Test Section 28_5025

The Long-Term Pavement Performance (LTPP) General Pavement Studies (GPS) test section 28_5025[1] was nominated for a desktop study under TPF-5(332) "LTPP Forensic Evaluations" to investigate the influence of short transverse crack spacing on the performance of this continuously reinforced concrete pavement (CRCP) structure. The test section is still active after 41 years (1978 to date), and it appears to have performed well when viewed in terms of IRI, rutting and deflections, but not so in terms of transverse cracking – there were 178 transverse cracks observed during the last manual distress survey in 2014. The focus of the proposed investigation is on the factors affecting transverse cracking, including the amount of reinforcement used and the influence of climatic conditions.

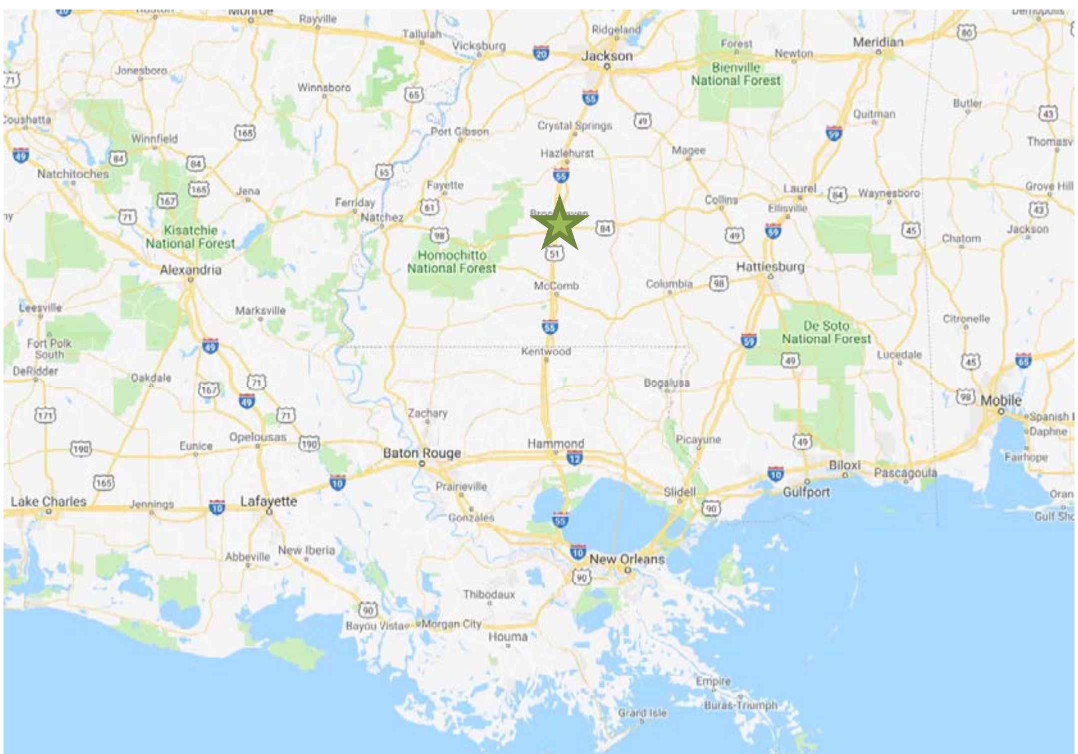
SITE DESCRIPTION

LTPP test section 28_5025 is located on US Route 84, westbound, in Lincoln County, Mississippi. US Route 84 is a rural principal arterial with two lanes in the direction of traffic. It is classified as being in a Wet—No Freeze climate zone with an average annual precipitation ranging between 43.6 inches (2000) and 78.9 inches (2012) and an annual average air freezing index ranging between 0 Deg-F degree-days (multiple years) and 85 Deg-F degree-days (1989 and 1996) during the performance period in question (1978 to 2017). The coordinates of the test section are 3 31.54636, -90.44317. Photograph 1 shows the test section at Station 3+50 looking westbound in 2014 (last distress survey), while Map 1 shows the geographical location of the test section relative to Jackson, Mississippi and to Baton Rouge and New Orleans, Louisiana.

[1] First two digits in test section number represent the State Code [28 = Mississippi]. 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).

Wood Environment & Infrastructure Solutions, Inc.
12000 Indian Creek Ct, Suite F
Beltsville, MD 20705
+1 301-210-5105
www.woodplc.com

Photograph 1. Picture of test section 28_5025 in 2014 (Station 3+50 looking westbound).



Map 1. Geographical location of test section relative to Jackson, Mississippi.

BASE-LINE PAVEMENT HISTORY

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

Pavement Structure and Construction history

The initial pavement structure was constructed in 1978, and it was incorporated into the LTPP program in 1987 as part of the GPS-5 Continuously Reinforced Concrete Pavement (CRCP) experiment. The original layer structure is detailed in Table 1. This corresponds to CONSRTUCTION_NO = 1 (CN = 1). The layer structure has remained as is (i.e., no maintenance or rehabilitation applied) since its construction in 1978 to date, and consequently there are no additional CN events beyond CN = 1.

The CRCP structure conforms to the Mississippi standard design as noted in the paper by T. C. Paul Teng included in Appendix A. The longitudinal reinforcement consisted of number 5 (5/8 inch) deformed bars with a 6.5 inch spacing in the nominal 8 inch thick PCC layer. This represents 0.6% longitudinal steel reinforcement. The transverse reinforcement consists of number 4 (0.5 inch) bars spaced 36 inches apart.

The average coefficient of thermal expansion (CTE) for the portland cement concrete at the test section is $6.05x10^{-6}$ /°F, which is a typical average value – i.e., not an extreme CTE value.

Table 1. Pavement structure.

Layer Number	Layer Type	Thickness (in.)	Material Code Description
1	Subgrade (untreated)		214-Coarse-Grained Soil: Silty Sand
2	Unbound (granular) subbase	6.8	308-Soil-Aggregate Mixture (Predominantly Coarse-Grained)
3	Bound (treated) base	4.3	319-HMAC
4	Portland cement concrete layer	8.2	6-Portland Cement Concrete (CRCP)

Pavement Structural Properties

Figure 1 shows the time history average FWD deflection plot under the nominal 9,000 lb. load from the sensor positioned 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, the original pavement structure had maximum deflections less than 3 mils in 1990, which increased over time to between 3 and 4 mils between 1995 and 2005 and then to more than 4 mils in 2012, which is when deflection testing was last performed on the test section. These deflections appear reasonable for a CRCP pavement structure with a treated base. They also clearly show that the pavement structure is steadily deteriorating with time under the influence of traffic and local climatic conditions.

Table 2 shows the layer moduli backcalculated (using EVERCALC 5.0 software) from the deflection data measured between November 1989 and May 2003 (four rounds of FWD testing; there is no backcalculation information from the fifth deflection data set). The pavement structure was modeled as consisting of an 8.2 inch CRCP layer over 4.3 inches of asphalt treated base, 24.0 inches of combined unbound granular subbase and subgrade, and a semi-infinite subgrade.

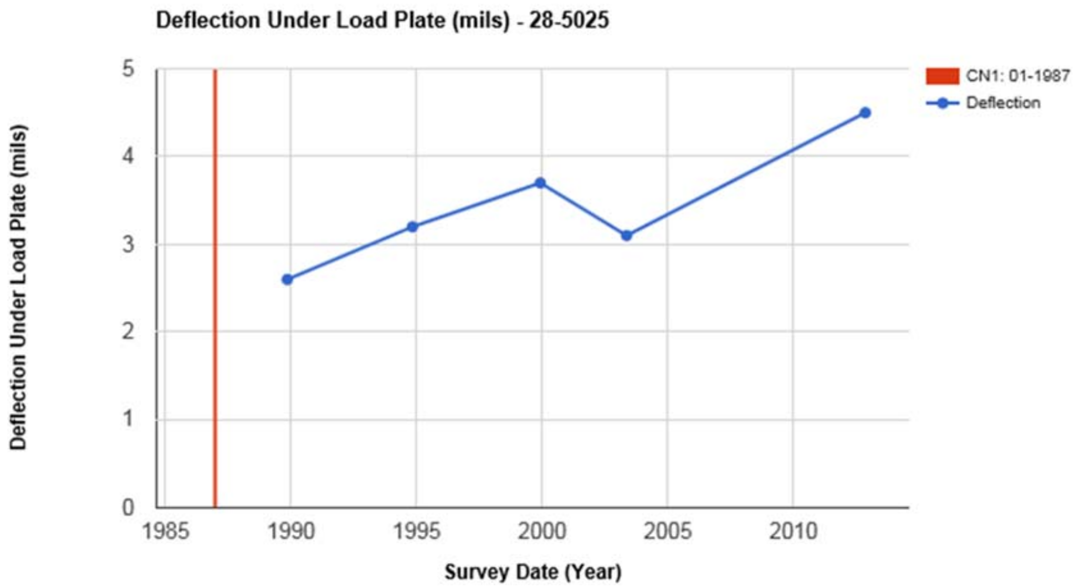


Figure 1. Time history of average deflection for the sensor located in the load plate normalized to 9,000 lb. drop load.

Table 2. Backcalculated layer moduli over time.

Layer Type	Thickness (inches)	Test Date	Modulus (ksi)
CRCP	8.2	11/06/1989	7.028
		10/31/1994	5,682
		12/02/1999	5,675
		05/09/2003	4,803
AC Treated base	4.3	11/06/1989	429
		10/31/1994	269
		12/02/1999	166
		05/09/2003	719
Subgrade and Unbound Granular Subbase	24.0 (6.8 inches of granular subbase and 17.2 inches of subgrade)	11/06/1989	20
		10/31/1994	23
		12/02/1999	10
		05/09/2003	15
Subgrade	Semi-infinite	11/06/1989	52
		10/31/1994	48
		12/02/1999	53
		05/09/2003	53

As shown in Table 2:

- The backcalculated modulus values for the CRCP layer appear to be reasonable and they also appear to confirm the steady deterioration of the pavement structure noted earlier. These layer moduli also go hand in hand with the distress survey results presented later in this memorandum, which show a steady increase in the number and length of transverse cracks over time.

- The backcalculated modulus values for the asphalt treated based also appear reasonable and they too appear to confirm the steady deterioration of the pavement structure. The only exception is the modulus backcalculated from the deflection data collected during the 2003 (last visit for which backcalculation information is available), which shows an unusually high modulus. It is hypothesized that this may be due to compensating layer effects during the backcalculation process, especially when viewed in light of the decrease in the modulus value of the combined granular subbase and subgrade layer in 2003.
- The backcalculated layer moduli for the two unbound granular layers appear to be reasonable. It is somewhat surprising, however, that the moduli values for the semi-infinite subgrade layer remain so stable – between 48 and 53 ksi – over the 14 year period (1989 to 2003) for which backcalculation information is available, despite pavement deterioration and changing climatic conditions. Further investigation into the stability of these moduli is warranted and it should consider the effects of climatic condition and stress sensitivity.

Climate History

The time history for annual average precipitation since 1978 is shown in Figure 2. In 2012, the amount of precipitation appears to be a local high (78.9 inches) at the site, while the low (43.6 inches) was recorded in 2000. These measurements as well as the remaining measurements do not deviate significantly from the mean at the site (61.1 inches for the time period in Figure 2), and hence there are no specific precipitation events that would have affected the performance of the pavement, whether accelerating or decelerating deterioration rates.

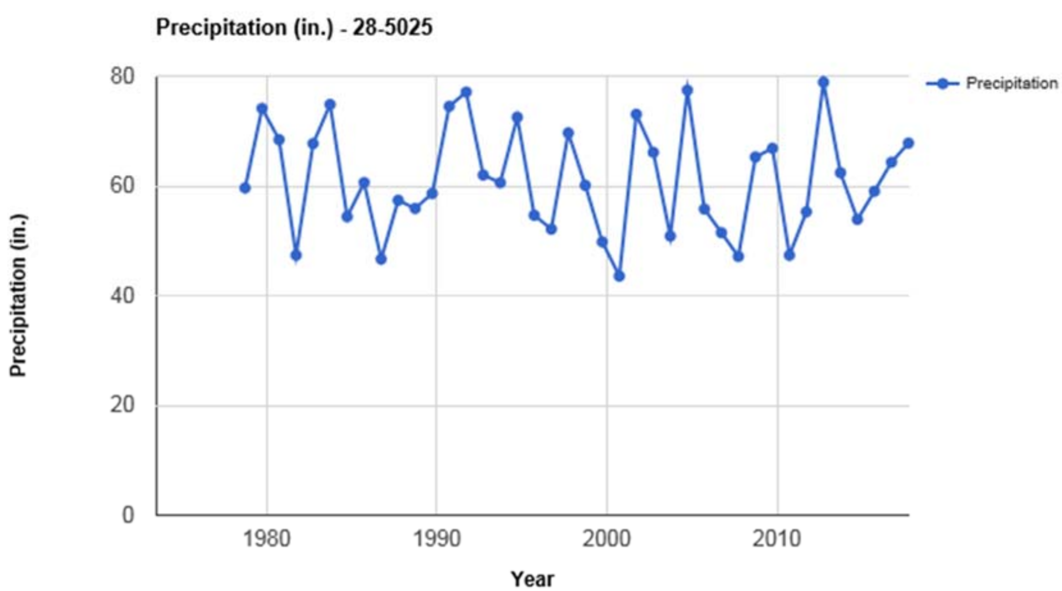


Figure 2. Time history of annual precipitation.

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. Except for minor spikes (all else than 90 Deg-F degree-days) on multiple years, the annual freezing index at the site has remained at or close to zero, which implies winter issues are not major contributors to the performance of the pavement test section.

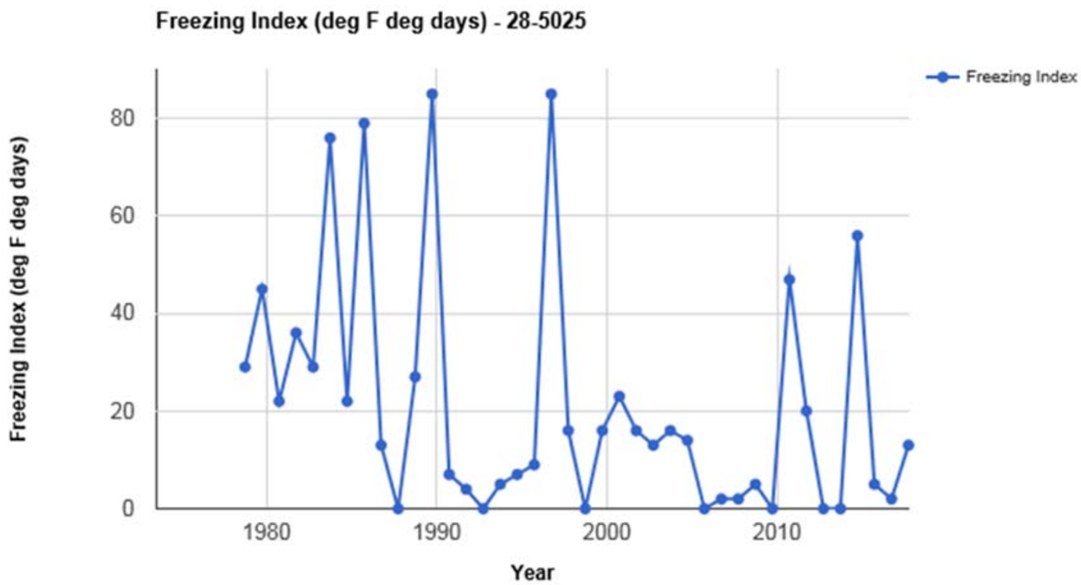


Figure 3. Time history of annual air temperature freezing index.

Truck Volume History

Figure 4 shows the annual average daily truck volume data in the LTPP test lane by year. The red triangles represent counts provided by the Mississippi DOT, while the blue diamonds represent truck count estimates derived based on data reported to LTPP by the Mississippi DOT. While not perfect, there appears to be agreement between the two counts. The figure also shows that truck volumes have steadily increased from around 150 trucks in the early 1980s to around 500 trucks per day in 2010s; i.e., it has more than tripled over the nearly 40 year time period in question.

Pavement Distress History

This section summarizes the distresses observed at the test section during the period of 1989 to 2014 (CN = 1), which is when the last round of measurements was performed. Only transverse cracking and spalling associated with those cracks have been observed at the test section during the pavement surface distress surveys. No longitudinal cracking, punchouts or patching has been observed at the test section since it entered the LTPP program.

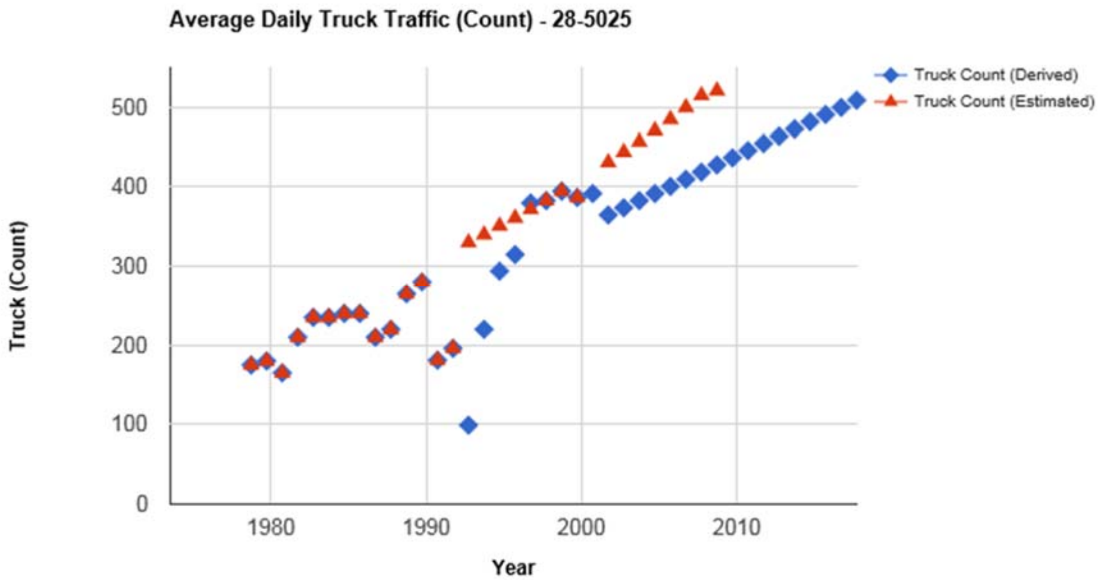


Figure 4. Average annual daily truck traffic history.

Figures 5 and 6 show the time history of the number and length of transverse cracks. They include data derived from automated distress surveys (35-mm Black & White continuous photographs) between 1989 and 2003, and from manual distress surveys performed between 1991 and 2014, the year of the last survey to date. As shown in these two figures, the number of transverse cracks increases from 126 in 1989 to 178 in 2014, while the length of that cracking increases from approximately 500 ft to almost 2,100 ft over the same time period. The latest measurements represent a full-lane width transverse crack every 2.8 ft, which falls on the low side of the desirable 3.5 to 8 ft crack spacing (which is part of the design process), but spacings of 1.5 to 6 ft are not unusual.

The steady increase in the number and length of transverse cracking over time (and hence the short crack spacing) support the hypotheses that the increase in deflections and the reduction in moduli of the CRCP layer are directly related to the transverse cracking. However, the load transfer efficiency (LTE) of the transverse joints has remained between 88% and 92%, which are considered good values, throughout the life of the test section. In turn, this implies that while structural capacity of the pavement is steadily deteriorating, load transfer at the transverse cracks resulting from the longitudinal steel and aggregate interlock is still performing well.

The time history plot of rutting on the test section is shown in Figure 7. As shown, rutting of the pavement test section has remained close to 0.1 inches throughout the life of the test section. It is hypothesized that the measured rutting is associated with ablative wear of the surface, albeit the use of winter traction control devices such as studded tires or chains is not expected to be an issue at the test section.

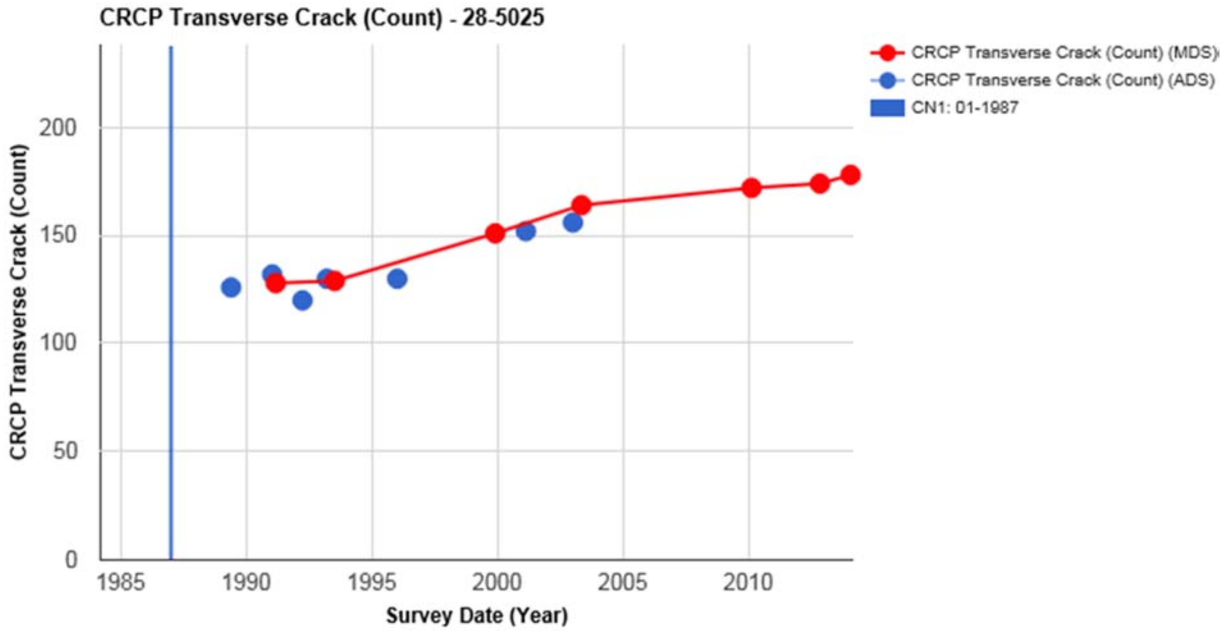


Figure 5. Time history of the number of transverse cracks.

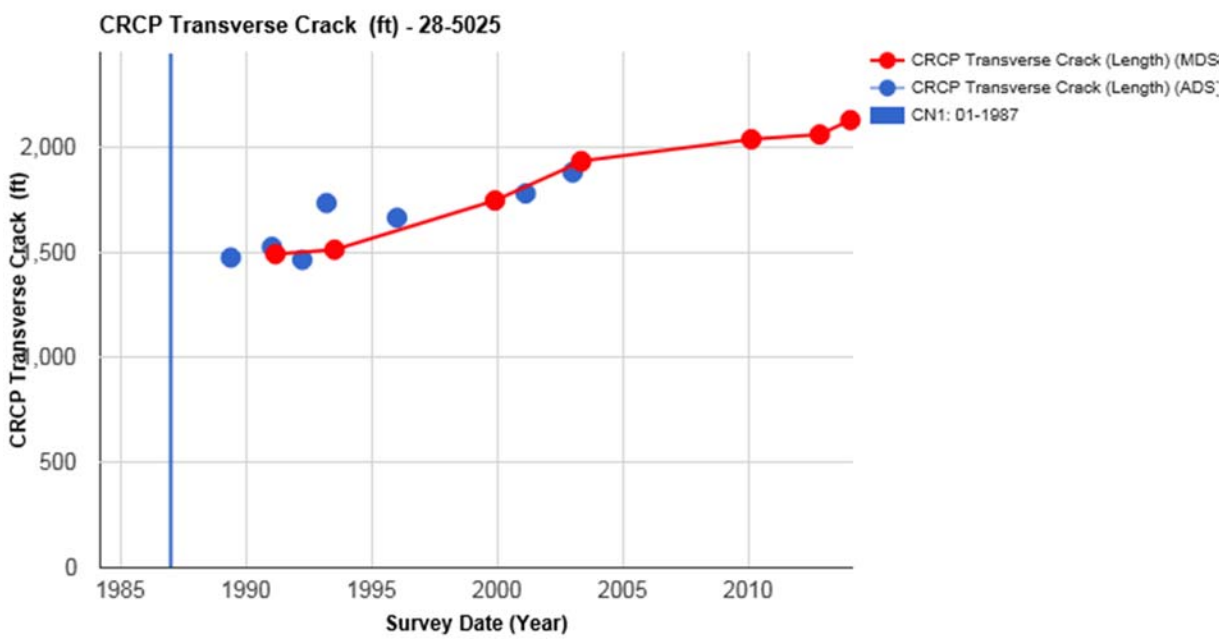


Figure 6. Time history of the length of transverse cracks.

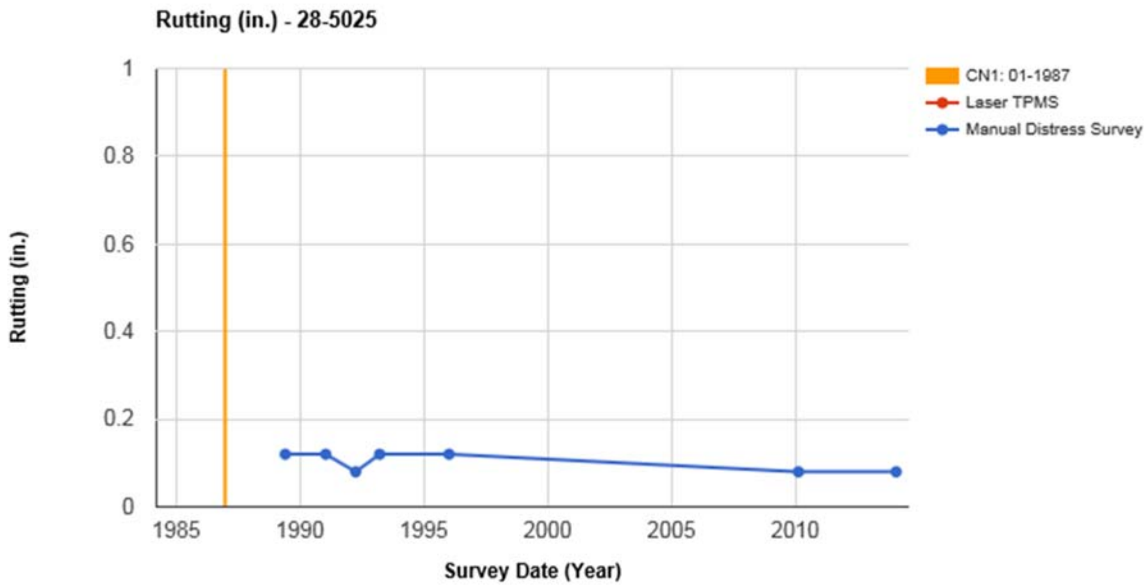


Figure 7. Time history plot of average rut depth computations.

Similarly, the time history of roughness measurements is shown in Figure 8. As shown, the IRI has remained close to 80 inches/mile throughout the life of the test section within the LTPP program.

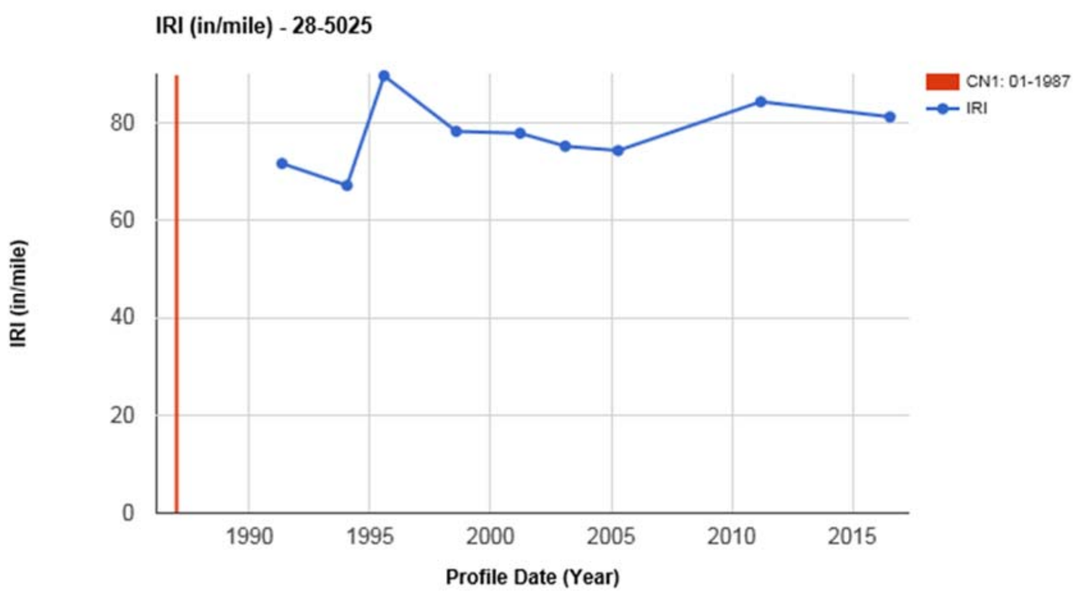


Figure 8. Time history plot of pavement roughness.

Pumping, which is defined in the LTPP distress manual as seeping or ejection of water from beneath the pavement through cracks or joints. In some cases, it is detectable by deposits of fine material left on the pavement surface, which were eroded (pumped) from unbound subsurface support layers. The general mechanism of pumping is thought to lead to creation of punchouts. As shown in Figure 9, the number of rated pumping instances has varied over the years. However, even with the short transverse crack spacing, no punchouts have ever been observed on this test section. Looking at the photograph of the test section in Figure 10 taken during the distress survey performed in 1999, which was rated as the most severe pumping event, this appears to be water seeping to the pavement surface at cracks on the outside edge of the pavement and not eroding of the unbound subsurface layers typically associated the typical pumping mechanism on CRCP.

Figure 11 is a photograph of test section 28_5025 taken during the last distress survey conducted in 2012. This photograph was taken from the leave end of the test section looking back in the direction of traffic. It is interesting to note the growth of grass along the outside pavement edge. It is postulated that this grass growth is from water pushed to the outside pavement edge due to cross slope and not the traditional pumping mechanism associated with CRCP pavements with unbound base.

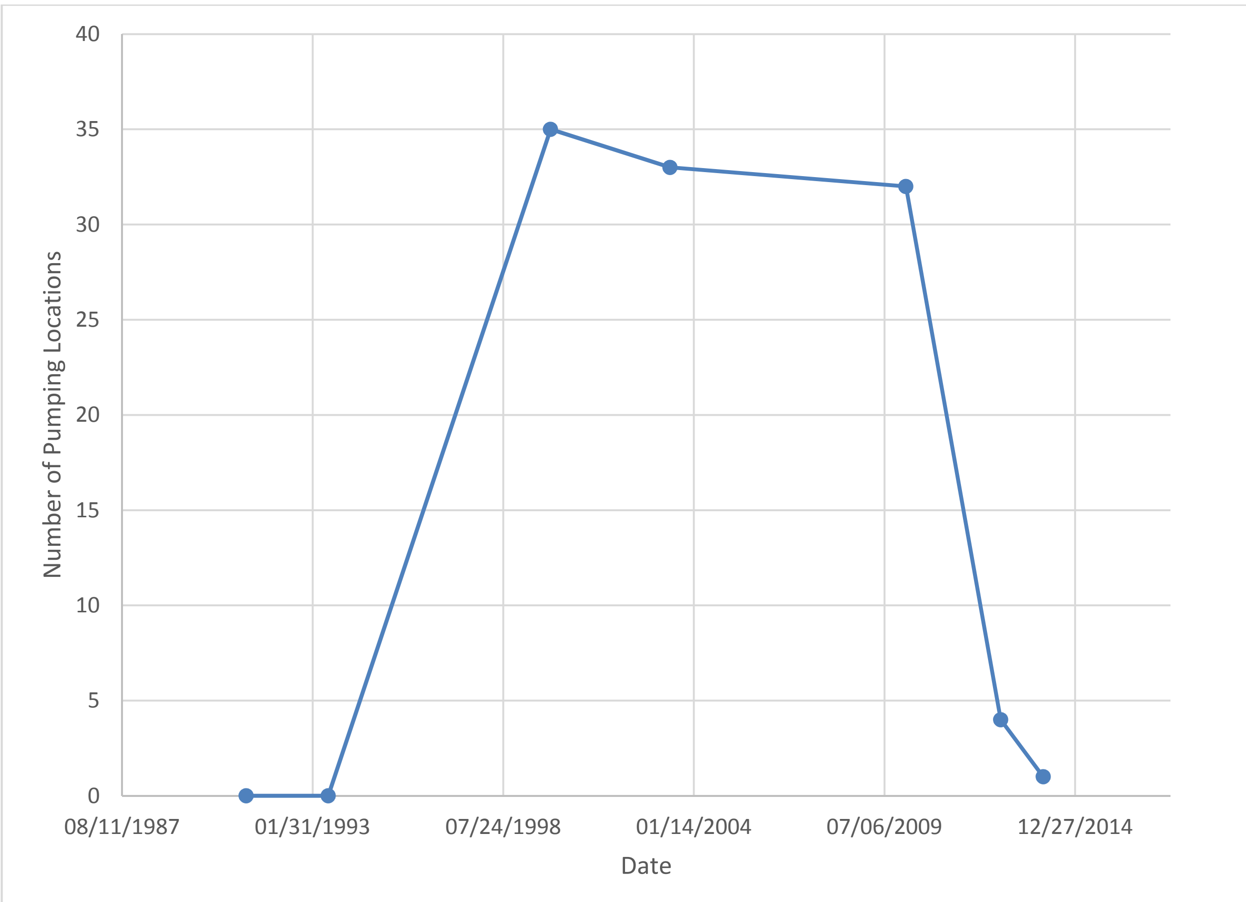


Figure 9. Time history plot of number of pumping locations on section 28_5025.

Figure 10. Photograph of test section 28_5025 taken during 1999 manual distress survey.

Figure 11. Photograph of test section 28_5025 taken in 2012.

Other interesting distress observations include:

- This test section experienced no punchouts over its life to date. Traditional CRCP mechanistic interpretations indicate that short transverse crack spacing tends to result in more punchouts.
- There were no patches applied to this test section. Patches on CRCP are usually associated with punchouts.
- The test section did exhibit a significant amount of spalling, although looking at the test section pictures, spalling in the left lane appeared to be worse than in the study lane.
- After 2010, the amount of scaling and surface polishing dramatically increased.

SUMMARY OF FINDINGS

In this review of information concerning the performance history of test section 28_5025, the following information was presented:

- The nominal 8" thick CRCP over a 4-inch-thick AC stabilized base pavement structure has performed well over the past 41 years without any maintenance. While the test lane qualifies as a zero-maintenance structure, from photographs, it appears that some maintenance to address crack spalling in the adjacent left lane has been performed.
- The design specification used in Mississippi at the time consisted of a standard cross section modified by underlying soil conditions as shown in the 1973 paper included in Appendix A of this document. The LTPP database indicates this test section did not have any soil stabilizing material added to the subgrade, which appears to be consistent with a coarse grained silty-sand subgrade material.
- The number of transverse cracks has increased over time, which is consistent with the behavior of long-term studies of CRCP. On this site, the average spacing between transverse cracks in 2014 is approximately 3 feet. While this average spacing approximates the distance between the transverse steel reinforcement, the locations of the transverse cracks do not appear to have a uniform pattern. Older design concepts from the 1970's suggested that transverse crack spacing less than 5 feet might result in increased punch-outs. This test section has not exhibited any punchouts or corrective maintenance events to address punchouts.
- IRI of the test section has remained in the 80 inches/mile range, which is consistent with a smooth pavement structure. The IRI measurements do not appear to reflect the increased transverse joint spalling, number of transverse cracks, or degradation of the pavement surface.
- Significant pavement pumping locations were reported in some of the distress surveys on this test section. The time history of pavement pumping was inconsistent. It peaked in 1999 and by 2014 it was just about nonexistent. The importance of pavement pumping on CRCP pavements is thought to be due to eroding of the base structure under the outside edge of the pavement. This eroding leads to punch-outs at the lane edge that requires maintenance events to repair. This test section has no reported punch out or patches. In the pictures taken during performance of the distress surveys, what was rated as pumping appears to be water seeping to the pavement surface at the outside pavement edge and no eroding of the unbound base layers is apparent.

FORENSIC EVALUATION RECOMMENDATIONS

While sufficient data appear to be available to explain the performance of the Mississippi 28_5025 test section, it is recommended that the desktop study be extended as follows:

- Include this test section in the LTPP long life extended pavement performance monitoring classification. After more than 40 years, while some PCC surface distress is being noted, the smoothness and structural characteristics are still excellent. This includes continued monitoring until 2026, or until the pavement section receives an overlay.
- During the next manual distress survey, have the distress surveyors investigate the reported pumping locations in previous surveys. The topic of interest is to see if fines from the unbound base or subgrade are being eroded to the surface, or if the reported pumping is due to seep of water from the bound AC base layer to the outside edge of the pavement surface. The shoulder on this pavement section has a very coarse texture, which could make detection of subsurface eroding to the shoulder surface difficult.
- Additional FWD testing and backcalculation of layer moduli is recommended to confirm the hypothesis that the deflection increase with time is likely to continue the downward trend in CRCP modulus. As part of this effort, layer moduli should also be backcalculated from the 2003 deflection data.
- To investigate what went right at this test section location, perform coring at locations adjacent to the LTPP test section, with the same pavement design, that experienced punchouts to examine the differences in subgrade materials and pavement structure. This coring could take place at the time of the distress survey and FWD testing to limit the need for traffic control to one day.

Appendix A. 1973 Paper by T.C. Paul Teng on CRCP Design in Mississippi

C1.1.6

another Teng paper from SASHTO

CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

Prepared by

T. C. Paul Teng, Assistant Research & Development Engineer
Mississippi State Highway Department

Presented to

The Construction Committee
Southeastern Association of State Highway and
Transportation Officials

32nd Annual Meeting
Hot Springs, Arkansas

October 1973

Mississippi ranks third in the nation in mileage of Continuously Reinforced Concrete Pavement. Almost 900 miles of two-lane pavement are in use in Mississippi. On a nation wide basis, more than 10,000 miles of two lane pavement were in use or under contract at the end of 1971. Thirty-three states currently have some CRCP; 19 have 100 miles or more including two states that have over 1,000 miles. The use of CRCP is increasing rapidly. Therefore, it is important that highway engineers have a complete knowledge of the design, construction, performance and maintenance of this type of pavement. This report brings together Mississippi's experience on the construction of CRCP.

Unlike most other states, Mississippi's standard CRCP design procedure was primarily based on the research findings of the state's own early experimental projects constructed in DeSoto and Jones County. The Second Progress Report by the American Concrete Institute on the Design of CRCP and the Minimum Criteria for Federal-Aid Roads established by the then Bureau of Public Roads also played an important role in these standard design procedures.

Mississippi uses stabilized base and subbase under all CRCP pavements. Design based on the CBR value and the anticipated traffic load, usually the design of 6 inches soil cement base and 6 inches lime treated subbase (may vary as required by soil condition) is used. Beginning in 1971, the design of 4 inches asphalt concrete base and 6 inches granular subbase or 6 inches lime treated subbase (as required by soil condition) has been tried on several projects.

The standard thickness for CRCP in Mississippi is 8 inches. Strength for the concrete is not specified. However, it is a general practice in the field that the concrete should provide a modulus of rupture of

525-550 pounds per square inch at 7 days and 700 PSI or more at 28 days when tested by the third point method.

The amount of longitudinal steel is 0.6%. Only deformed bars (with 60,000 PSI yield strength) are allowed although smooth wire fabric was tried on two projects during the early 1960's construction and has since been discontinued as one of the CRCP design alternates. The current design uses #5 bars at 6½ inch spacing and has 0.037 square inch of bond area per cubic inch of concrete. #5 bars at 36 inch spacing are used as transverse reinforcement. Like most other states, Mississippi specifies the longitudinal reinforcement slightly above mid-depth. It is the intent of the Mississippi design that the Specified Value for longitudinal bars shall be 3-3/4 inch from center of bar to top surface of the concrete. The Unit of Deviation shall be ± 1/8 inch. The lot size for conformance determination shall be 1,000 feet of pavement. Chair spacings shall not be greater than 36 inches center to center (longitudinal) and 27 inches (transverse). Additional chairs shall be used if necessary to meet the steel placement requirements. The minimum length for laps is 20 inches and usually the laps are skewed (60 degrees from center line).

The 20 inch lap length works fine for most projects. However, at the beginning of a project where the adjacent project was completed several months earlier in another construction season, fragmental distress was found on top of the first lapped splices. (Slide 1). A few cores taken at random within the distressed area show an excellent quality of concrete but were broken at the middle where the steel is located.

A close observation, made during the repair operation, indicated that the distress was not caused by construction and that the concrete was in good condition. Presence of the failure, which coincided with the lapped splices, suggested that it may be due, at least in part, to the very high tensile stresses in the steel ahead of the construction joint which caused a decrease in bond at the splice where the concrete was poured several months later in another construction season. It is possible that the serious slab separation at the distressed area was preceded or accompanied by progressive reduction in bond between the closely spaced cracks.

It is recommended that if a new project is to be added to an existing project, which was constructed several months earlier in another construction season, the length of the first lapped splice should be more than the regular design of 20 inches. The exact length of such lap is directly related to the local environment and is pending further study and experiments. An effort will be made to refer this special problem to the researchers at the University of Texas who are currently conducting a study on the design of CRCP for the National Cooperative Highway Research Program for possible inclusion into the NCHRP study. Before the new criteria becomes available however, 30 inches is recommended for use at these locations. Consideration should also be given to adding extra cement to the first few batches of concrete at the beginning of the new project construction. This will allow mortar to coat the drums, truck, etc. and will also give additional strength to the concrete immediately beyond the construction joint.

At the construction joints, longitudinal bars are required to extend a minimum length of 5 feet. No additional steel was installed at the construction joints on 5 projects built during 1962-63. Since then #5 deformed bars, 5 feet long, placed at 6.5 inches, have been used as additional steel.

For the first five years of practice, 5 lug anchors were used for bridge ends and 4 lug anchors for pavement ends. Since 1967, 4 lug anchors have been used for both bridge and pavement ends because the continuing measurements from the Jones County experimental project do not indicate any difference in pavement movement between 4 and 5 lug anchor installations.

In Mississippi, lug anchor is the only type terminal treatment used to restrain movement. The wide flange beam joint has been used successfully by many states. However, in Mississippi, no plan has been made to adopt this design because it is felt that the highly expansive subgrade soil in Mississippi may create other problems when the wide flange beam joint is used and therefore supersede the original purpose of this type design, i.e., to minimize maintenance costs and provide load transfer across the gap in the pavement under the flange.

Base and subbase construction are the same for CRCP as for jointed pavement. The support of reinforcement on high chairs was the original installation method and has been an accepted standard for many years. In Mississippi, this method is the only one permitted with slip form paving. Forms were used only on a few projects during the early 1960's.

Generally, the materials, mixing, handling and placing of concrete for CRCP are no different than for jointed pavement. Concrete used for Mississippi's CRCP projects usually has a cement factor of 1.40 (about 5.6 bags/cubic yard) which is the same as jointed pavement, but only slip form paving for CRCP uses air entrained concrete. Air entrained concrete shall contain not less than 3% nor more than 6% air. The limit for the concrete slump is between 1.5 and 2 inches.

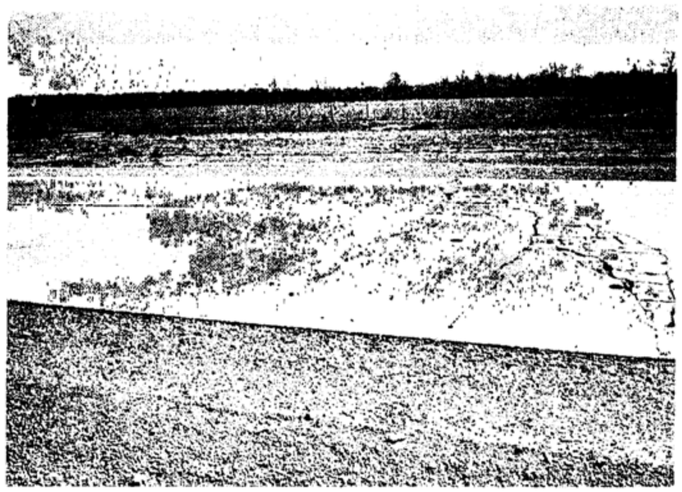
Proper vibration of the concrete is very important. The internal vibrations should be done in such a manner as not to dislocate the steel. The present Mississippi specification for consolidation of portland cement concrete pavements was written from the AASHO specification. However, as a result of a National Experimental and Evaluation Program on Proper Vibration of Portland Cement Concrete Pavements sponsored by the Federal Highway Administration, plans have been made to change the minimum impulse per minute for vibrators from 7000 to 9000 (measured in air). A tachometer will be used to measure and set the frequency of the vibrator. Detailed findings of this research study were presented during last years SASHTO meeting held in Florida.

Before 1968, longitudinal sawed joints were used on all projects. Since that time, the polyethylene strip has been used for longitudinal center joint. When first adopted, the 4 mil strip was used. In 1969 the thickness of the strip was increased to 8 mils. Some states have reported that random longitudinal cracking has developed on projects with polyethylene strip type of center joint. But in Mississippi no such cracking has been found.

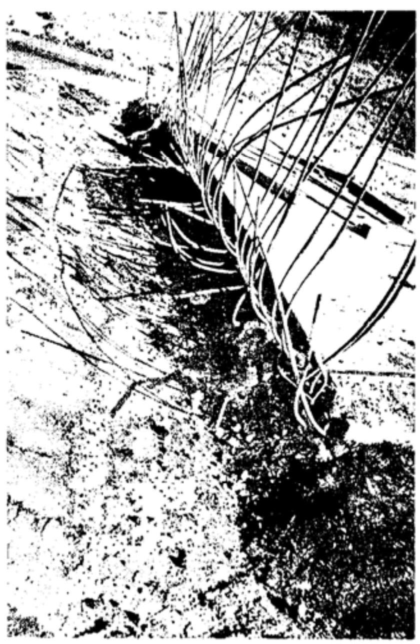
White pigmented impervious membrane and white polyethylene sheeting have both been used successfully for the curing of concrete for CRCP. Field surveys also indicated that these two curing methods do not appear to affect the pavement cracking pattern.

Usually the plans specify that the pavement (except the splicing steel), base, subbase, and subgrade all end at the termination station of the project. For CRCP, this created a problem for the construction of the adjacent project that would be constructed later. As shown on slide 2, the contractor for the adjacent project has to bend the splicing steel in order to construct the base, subbase and subgrade. Under this condition, the construction joint for the sublayers can not be properly constructed to provide continuity and very often provides a weak plane when high stresses develop.

It is recommended that when a continuously reinforced concrete pavement project is to be continued with another project, special end construction arrangement be made to allow continuity of all base structure layers. This can be accomplished by requiring the first contractor to extend the base layers 30 to 50 feet beyond the termination station of the project.



Slide 1



Slide 2