EFFECTIVENESS OF CRACK RELIEF TECHNIQUES TO MITIGATE REFLECTIVE CRACKING IN ASPHALT OVERLAID CONCRETE PAVEMENT

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ABSTRACT

This study focused primarily on evaluating the effectiveness of five crack relief treatments to mitigate reflective cracking of asphalt overlaid concrete pavement including 0.5 inch Superpave 9.5 mm Nominal Maximum Aggregate Size (NMAS) structural course (SP-9.5), 1.5 inch SP-12.5, 2.5 inch SP-12.5, 1.0 inch Open-Graded Crack Relief (OGCR), and 0.5 inch Asphalt Rubber Membrane Interlayer (ARMI). Pavement performance was evaluated in terms of deflection, ride quality, rutting and cracking. Also, an evaluation of cracking performance based on the dissipated energy concept using Falling Weight Deflectometer (FWD) load-deflection time history data was presented. The results indicated that 0.5 inch SP-9.5, 1.5 inch SP-12.5, and 2.5 inch SP-12.5 treatments show relatively greater potential for reflective crack mitigation efficiency than the 1 inch OGCR or 0.5 inch ARMI. More reflective transverse cracks corresponding to the Portland Cement Concrete (PCC) base slab joints occurred in areas with thinner Asphalt Concrete (AC) overlay and were most predominant in the 0.5 inch ARMI section. Areas with more transverse cracks had relatively greater dissipated energy indicating a higher potential for pavement deterioration and/or damage rate. Therefore, the dissipated energy approach can be used as a reliable indicator of pavement cracking performance. Thinner AC overlay may reduce the reflective cracking mitigation potential of crack relief layers.

INTRODUCTION

Background

When an extensively cracked flexible or rigid pavement is overlaid with Asphalt Concrete (AC), it is only a matter of time before cracks in the existing pavement reflect through the new overlay. This type of distress, termed reflective cracking, is a well-known phenomenon that a crack reflects up into and through the new pavement overlay above the discontinuities in the old pavement. These cracks accelerate moisture-induced damage in the AC layer and deteriorate the unbound layers by allowing water into the underlying layers. In general, this occurs in AC overlays placed over rigid pavements where the failure mechanism is associated with the stress concentrations in the AC overlay primarily due to differential movements at cracks and joints of the existing Portland Cement Concrete (PCC) pavement *(1-3)*.

The Florida Department of Transportation (FDOT) first studied and then began implementing Asphalt Rubber Membrane Interlayer (ARMI) as a reflective cracking mitigation technique for rehabilitation projects where the existing cracks cannot be completely removed by milling *(4-6)*. Over the past 30 years, the effectiveness of ARMI has been widely evaluated using several experimental and field performance monitoring projects. Presently, an ARMI is one of the primary reflective cracking mitigation techniques used in Florida. However, FDOT's experience using this technique has been mixed and the efficacy of the ARMI is still questionable. Previous experiences indicated that reflective cracking could be delayed using an ARMI that is properly designed and constructed. However, there were concerns among some district engineers that an ARMI may negatively impact rutting and cracking which does not justify the cost of an ARMI. Therefore, there is a need to investigate alternative reflective crack mitigation techniques so that the most effective method can be determined for enhanced pavement performance.

During the last decades, numerous research studies have been conducted to develop methods and materials to prevent reflective cracks from occurring within the design period. However, most of the materials and methods in use today only delay or limit the severity of the reflective cracks. Although advances have been made in understanding the reflective cracking phenomenon, there is limited practical and technical guidance on assessing when a given pavement can be effectively treated with reflective crack control measure, what constitutes an effective method for a given situation, how to apply the treatment, and how to evaluate the effectiveness of the treatment before and after its application.

In 2009, the FDOT initiated an experimental project constructed on SR-10 in Gadsden County, Florida, to evaluate the effectiveness of five different crack relief techniques, including an ARMI, an Open-Graded Crack Relief layer (OGCR), and three different AC thickness overlays over existing plain jointed PCC base. Pavement performance based on rutting, cracking, and ride quality has been monitored since construction in 2010. This paper provides an assessment of field performance of the various alternative treatments over a four year period.

Objectives and Scope

The primary objective of this study is to evaluate the effectiveness of five reflective crack mitigation treatments of an asphalt overlaid PCC pavement, including 0.5 inch SP-9.5, 1.5 inches SP- 12.5, 2.5 inches SP-12.5, 1.0 inch OGCR, and 0.5 inch ARMI. Pavement performance was evaluated based on deflection, ride quality, rutting and cracking. Also, the dissipated energy computed from FWD load-deflection time history data has been used to support the results of the field cracking performance evaluation.

FAILURE MECHANISM OF REFLECTIVE CRACKING IN ASPHALT OVERLAID CONCRETE PAVEMENT

The most prominent driving force of reflective cracking is the horizontal movement concentrated at the cracks and joints in the existing pavement as shown in FIGURE 1 *(3)*. Owing to the bond between overlay and existing pavement, tensile stress is induced in the AC overlay directly above the cracks and joints. This horizontal movement can be introduced by the combination of temperature change and traffic wheel load. A crack occurs when the induced tensile stress exceeds the strength of the overlay mixture causing it to propagate to the surface. Reflective cracking caused by this mechanism initiates at the bottom of the overlay just above the cracks and joints.

Change in temperature creates a temperature gradient within the existing pavement, which leads to cracking from the surface of the AC overlay *(6)*. In addition, moving traffic loads can cause differential vertical movement of the existing PCC slab across the cracks and joints in the PCC pavement. This differential vertical movement may be due to voids under the PCC pavement at the cracks and joints (i.e. the voids caused by pumping), or inadequate condition on the PCC pavement including deficient PCC slab support or poor load transfer. This causes bending and/or shear stress in the AC overlay near the cracks and joints, and eventually results in reflective cracking.

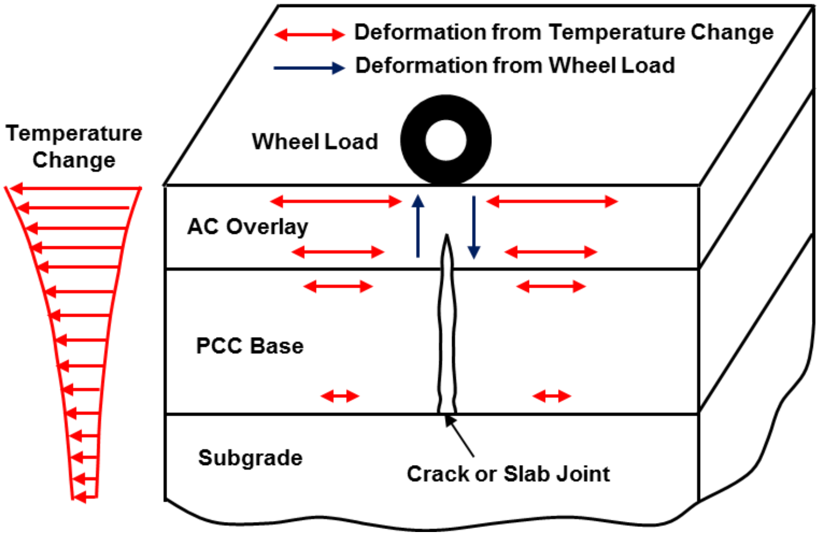


FIGURE 1 Reflective cracking in AC overlay with PCC base (Von Quintus et al. 2010)

PROJECT DESCRIPTION

The experimental test sections were opened to traffic in 2010 and are located in the eastbound and westbound passing lanes of SR-10/US-90 in Gadsden County, Florida. The project consists of five 1,370 feet test sections constructed over a pre-existing PCC base. Prior to the rehabilitation, this roadway exhibited transverse cracking particularly in the Eastbound Passing Lane (EBPL/R1) and the Westbound Passing Lane (WBPL/L1). The cracks had a consistent 20 feet spacing supposed to be reflective cracking from the joints of the overlaid PCC slabs. FIGURE 2 shows SR-10 with reflective cracks before rehabilitation in 2010.

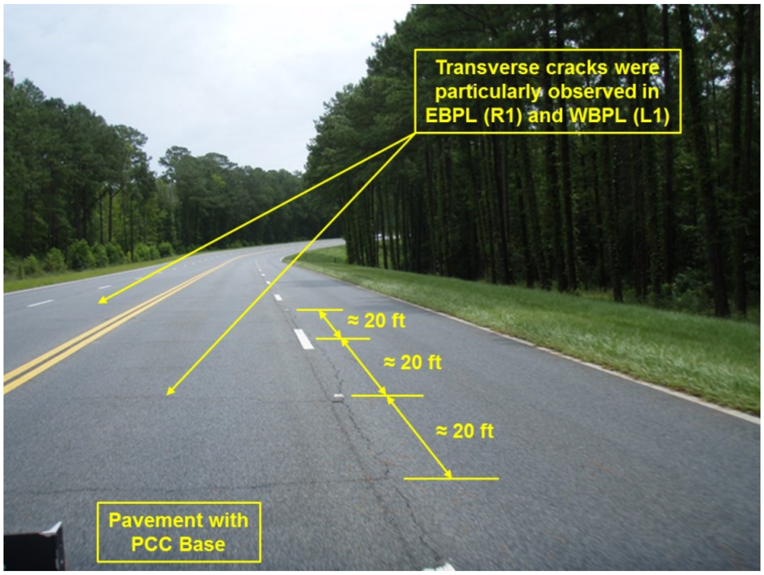


FIGURE 2 SR-10 project section

The design called for milling 3 inch of the existing AC layer and placing a 1.5 inches of SP-12.5 structural course in sections 1, 2, 4, and 5, and a 2.5 inches of SP-12.5 in section 3. In addition, section 1 received a 0.5 inch of asphalt SP-9.5, section 4 received a 1.0 inch of OGCR, and section 5 received a 0.5 inch of ARMI. All five test sections received a 1.0 inch of FC-9.5 dense graded friction course. The traffic loading along the eastbound and westbound direction of the test sections was approximately 2.5 million 18 kip equivalent single axle load (ESALs) applied for each lane after four years since the 2010 rehabilitation.

The mixtures used for structural and friction courses were designed for a traffic level C which corresponds to 3 to 10 million ESALs over 20 years design life. Also, the OGCR was placed in accordance with developmental specification section 340 *(7)* that requires a 1.0 inch thickness, 4 to 5 % binder content, 20 to 24 % air voids, and the use of a liquid anti-stripping agent. Lastly, the ARMI was applied according to the Florida Flexible and Rigid Pavement Design Manuals *(8)* that require the use of 20 % asphalt rubber binder (ARB-20) placed at a rate of 0.6 to 0.8 gal/yd^2, No. 6 stone placed at 0.26 to 0.33 ft^3/yd^2 with a rubber tire roller, and a minimum thickness of 1.5 inches.

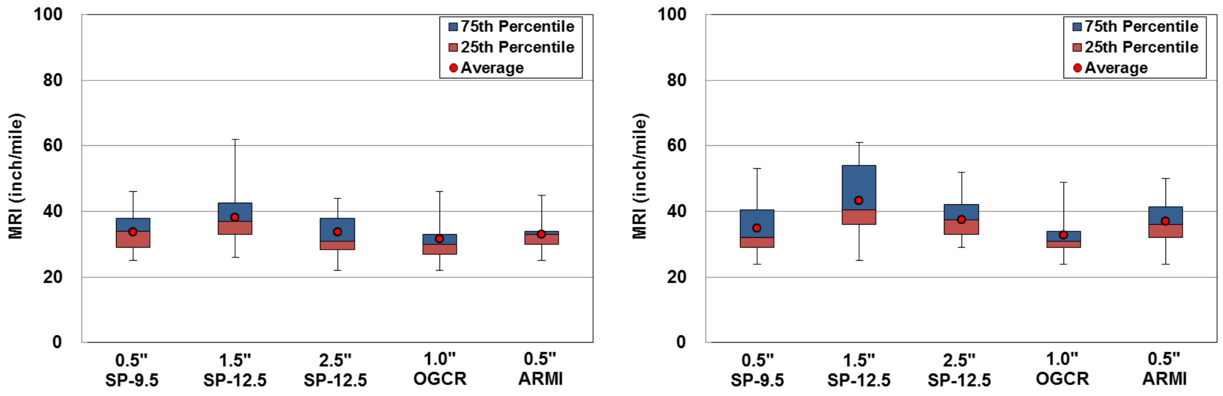
PAVEMENT PERFORMANCE EVALUATION

The FDOT State Materials Office (SMO) conducted annual performance monitoring of the test sections around the same time of the year to better control variability due to seasonal changes (e.g. temperature, precipitation, etc…). The primary parameters used to evaluate the performance of the experimental sections include ride quality, pavement deflection, asphalt surface permanent deformation (rutting), and cracking.

Ride Quality

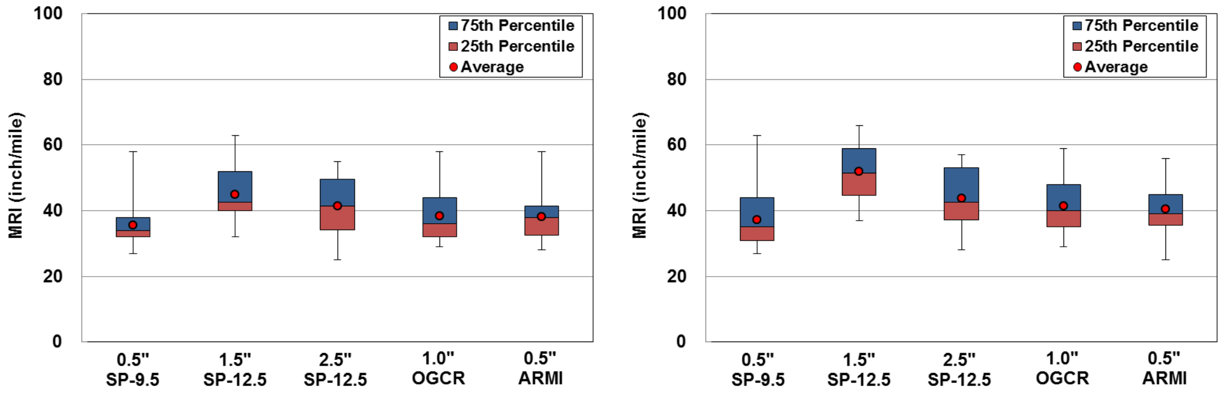
Ride quality was evaluated using the elevation profile data collected with a Multi-Purpose Survey Vehicle (MPSV). The MPSV's inertial profiling system uses laser height sensors and accelerometers mounted in the front bumper of the host vehicle to generate longitudinal profile traces in the left wheelpath (LWP), right wheelpath (RWP), and between the wheelpath (BWP). Mean Roughness Index (MRI), used as the smoothness performance indicator, is the average International Roughness Index (IRI) for the LWP and RWP which is the cumulative vertical movement of the vehicle divided by the distance traveled expressed in inches per mile (inch/mile), where the rating scale ranges from 0 indicating no roughness to infinity *(8)*.

In this study, the MRI values were processed at 1 inch sampling interval and reported at 0.01 mile interval in accordance with ASTM E 1926 *(9)*. FIGURE 3 shows the MRI results for the pavement sections with the different crack relief treatments, in 2010 (just after construction) and 2014, respectively. In all FIGURES, EBPL and WBPL stand for East Bound Passing Lane and West Bound Passing Lane, respectively. There was practically no significant difference in ride quality among the test sections with different crack relief techniques. Overall, all test sections exhibited a good ride performance which has remained relatively stable over time as indicated by the little change in MRI values since 2010.



(a) WBPL (L1) – 2010

(b) WBPL (L1) – 2014

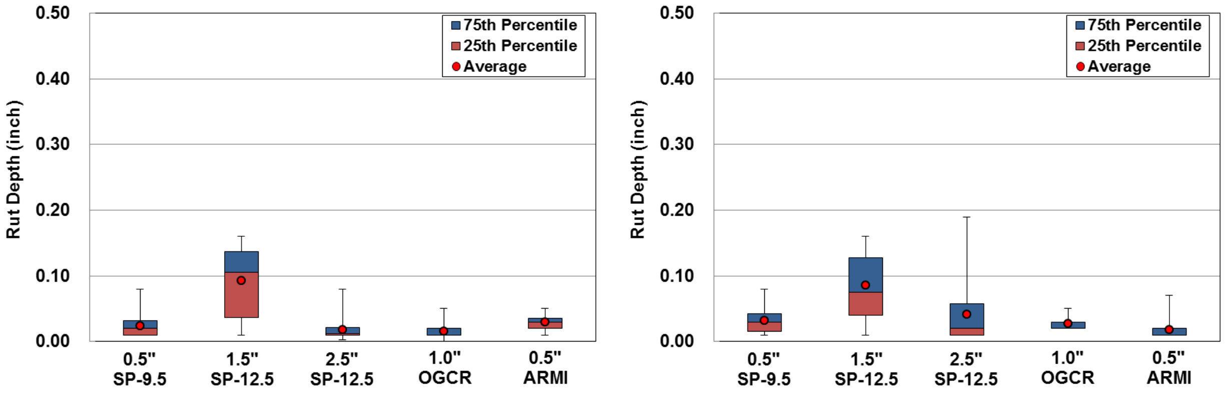


(c) EBPL (R1) – 2010 (d) EBPL (R1) – 2014

FIGURE 3 Mean Roughness Index (MRI)

Rutting

Permanent deformation, or rut depth, was measured manually in the right wheelpath using a 6 foot straightedge and depth measuring gauge. As shown in FIGURE 4, rutting overall was minimal in all test sections (i.e. less than 0.1 inch average rut depth). However, the 1.5 inch SP-12.5 section exhibits a relatively higher rate of increase in rut depth over time since the rehabilitation in 2010 compared to other sections.



(a) WBPL (L1) – 2014 (b) EBPL (R1) – 2014

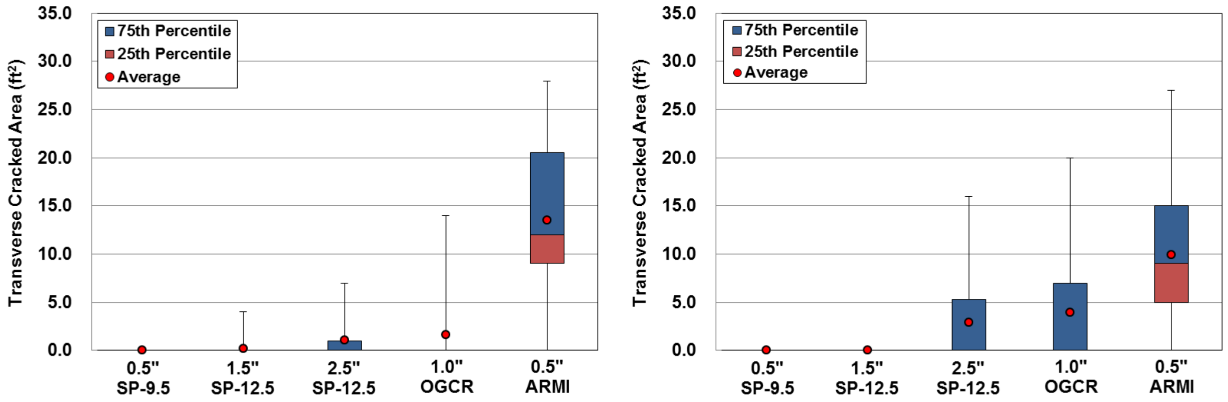
FIGURE 4 Rut depths from manual rut measurements

Cracking

Crack measurements were conducted according to the procedure in Florida's Flexible Pavement Condition Survey Handbook *(8)*. Each section was subdivides into 28 to 30 individual 50 feet sub-sections during the field manual crack evaluation. TABLE 1 shows the number of years after rehabilitation before the first transverse crack was observed. Transverse cracks were first observed in the 2.5 inch SP-12.5, 1.0 inch OGCR, and 0.5 inch ARMI sections 2 years after construction. FIGURE 5 shows a summary of transverse crack measurements. The ARMI section shows relatively higher transverse crack amount as compared to other sections. It is clearly indicated that transverse crack is dominant for ARMI section.

TABLE 1 First Transverse Crack Observation

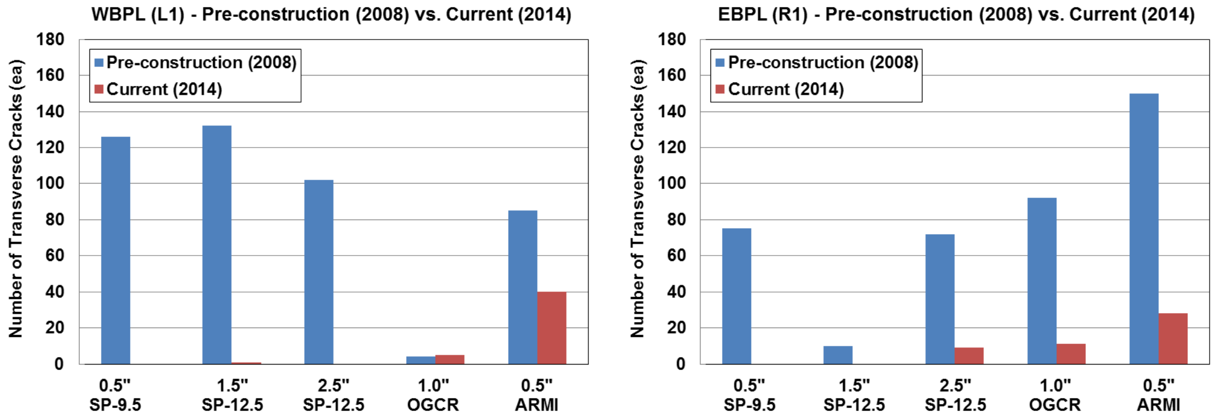
Section	First Transverse Crack Observation After Rehabilitation (Year)				
	0.5” SP-9.5	1.5” SP-12.5	2.5” SP-12.5	1.0” OGCR	0.5” ARMI
WBPL (L1)	No Crack	4	5	2	2
EBPL (R1)	No Crack	No Crack	2	2	2



(a) WBPL (L1) – 2014 (b) EBPL (R1) – 2014

FIGURE 5 Transverse cracked area for test sections evaluated

FIGURE 6 illustrates a comparison between the number of transverse cracks observed before construction in 2008 and those observed in 2014. MPSV high resolution pavement images were used to manually identify and measure the transverse crack using a point and click approach. Field verification showed the transverse cracks measured from images matched well with those obtained from manual field survey. Overall, the 0.5 inch SP-9.5, 1.5 inches SP-12.5, and 2.5 inches SP-12.5 sections exhibit a relatively greater potential for reflective crack mitigation efficacy.



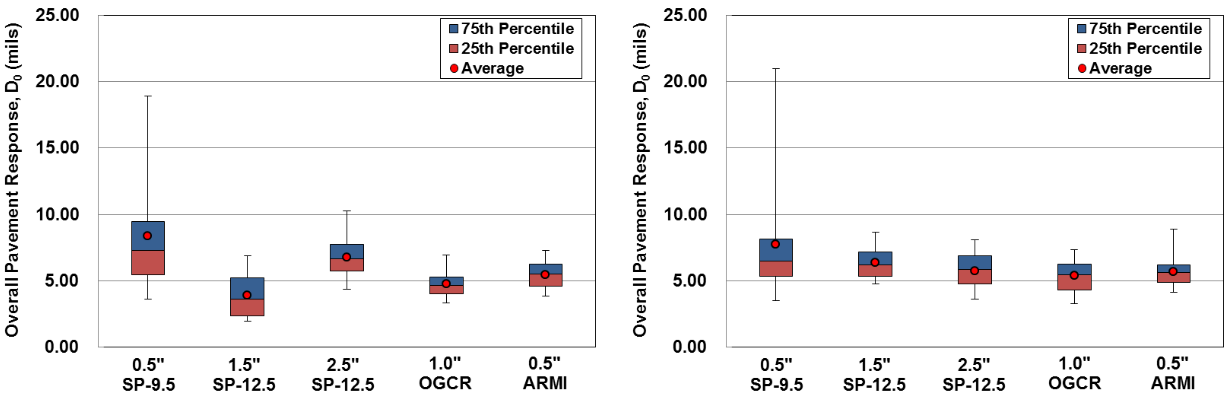
(a) WBPL (L1) (b) EBPL (R1)

FIGURE 6 Number of transverse cracks in pre-construction and current conditions

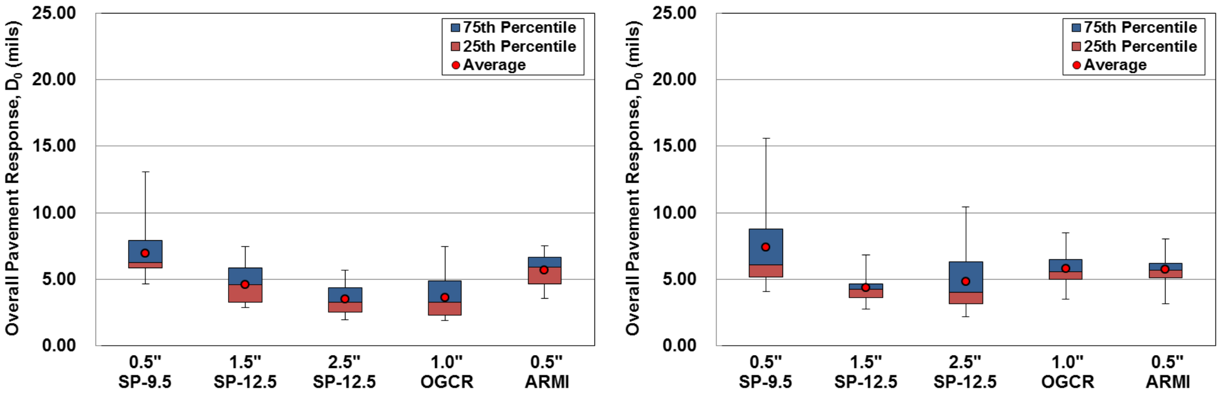
Pavement Deflection

Annual deflection measurements were conducted in the right wheelpath using a falling weight deflectometer (FWD) to evaluate pavement structural condition of each test section. A typical FWD testing configuration was used which includes a 12 inch load plate, a 9 kip applied load, and deflection sensors placed at 0, 8, 12, 18, 24, 36, and 60 inches from the load plate. The relative stiffness and performance indicators of a pavement system can be inferred through the analysis of key deflection parameters, the shape of the deflection basins, and load-deflection time history. The FWD tests were conducted within a short time period, similar temperature conditions, and away from areas with cracks or any other visible surface distress.

The deflection measured directly below the load plate indicates the stiffness and the elastic compression of the entire pavement structure. FIGURE 7 shows the overall pavement response results for the test sections evaluated just after construction (2010) and after four years of service (2014). In general, no significant difference in the overall pavement responses was identified among the test sections. Section 1 with 0.5 inch SP-9.5 exhibited higher variability due to a localized area with significant cracking. However, as of the 2014 condition survey, no reflective transverse cracks with 20 feet spacing were observed in section 1.



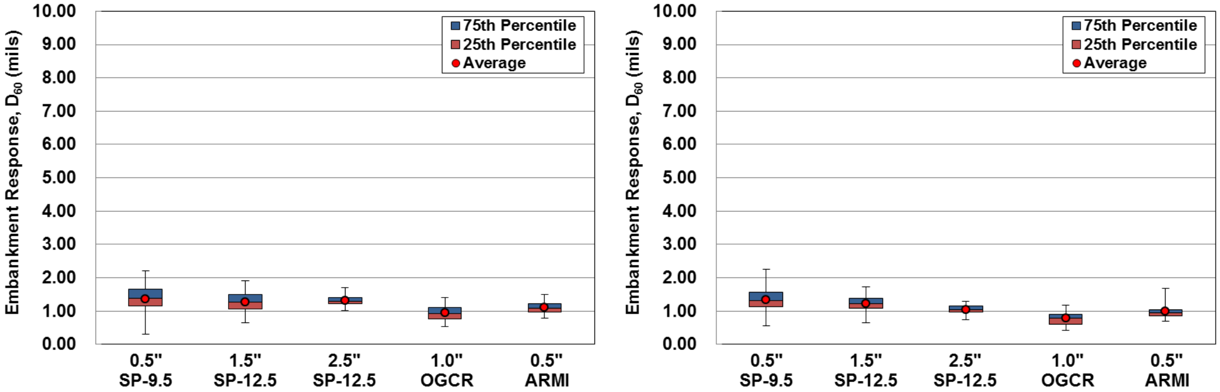
(a) WBPL (L1) – 2010 (b) WBPL (L1) – 2014



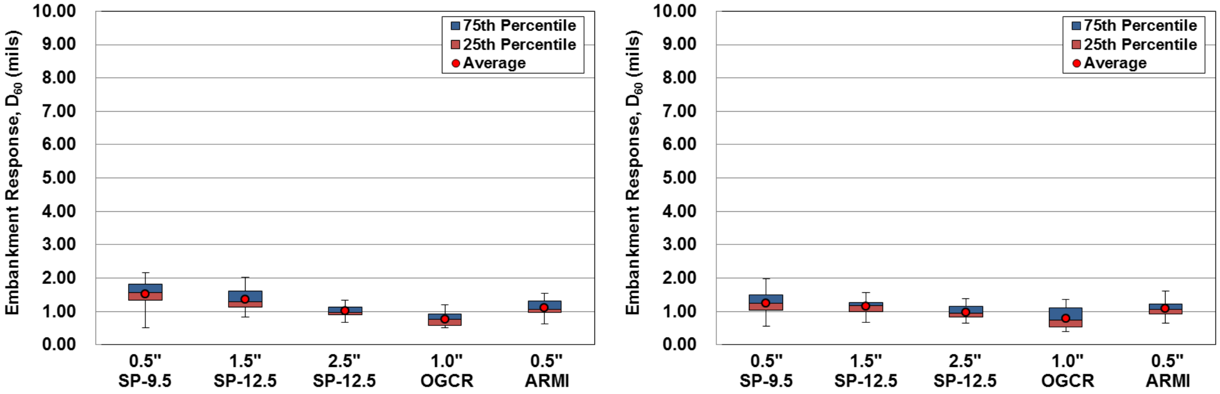
(c) EBPL (R1) – 2010 (d) EBPL (R1) – 2014

FIGURE 7 Overall pavement response (D_0)

The deflection measured by the further deflection sensor located at 60 inches from the load is usually representative of the embankment (or subgrade) response as shown in FIGURE 8. The results show no significant difference in embankment response among the sections with different crack relief treatments. However, it should be noted that the presence of a PCC base above the embankment may affect the deflection response.



(a) WBPL (L1) – 2010 (b) WBPL (L1) – 2014

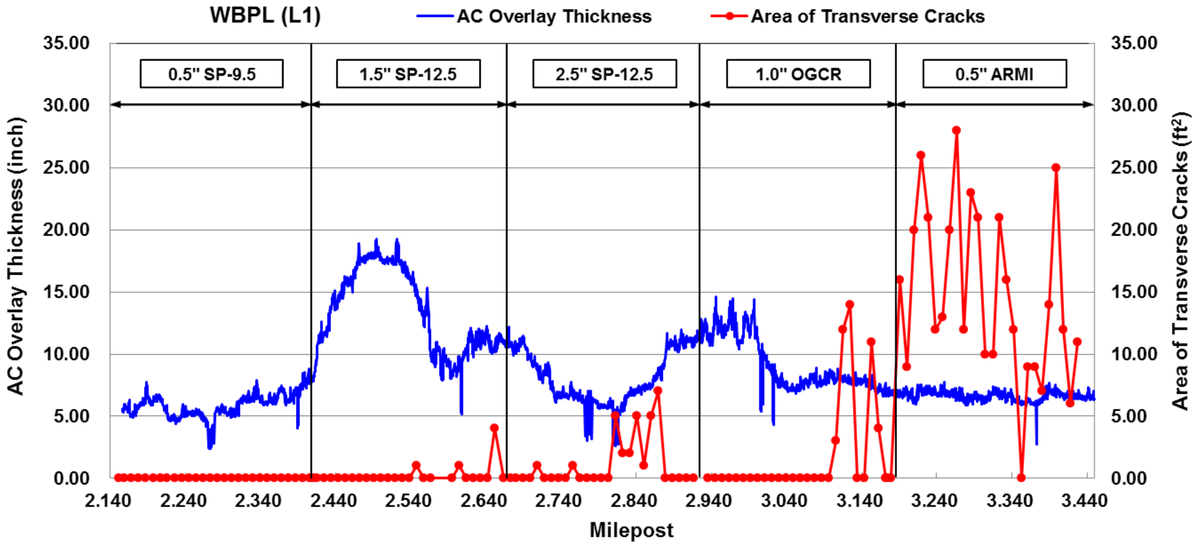


(c) EBPL (R1) – 2010 (d) EBPL (R1) – 2014

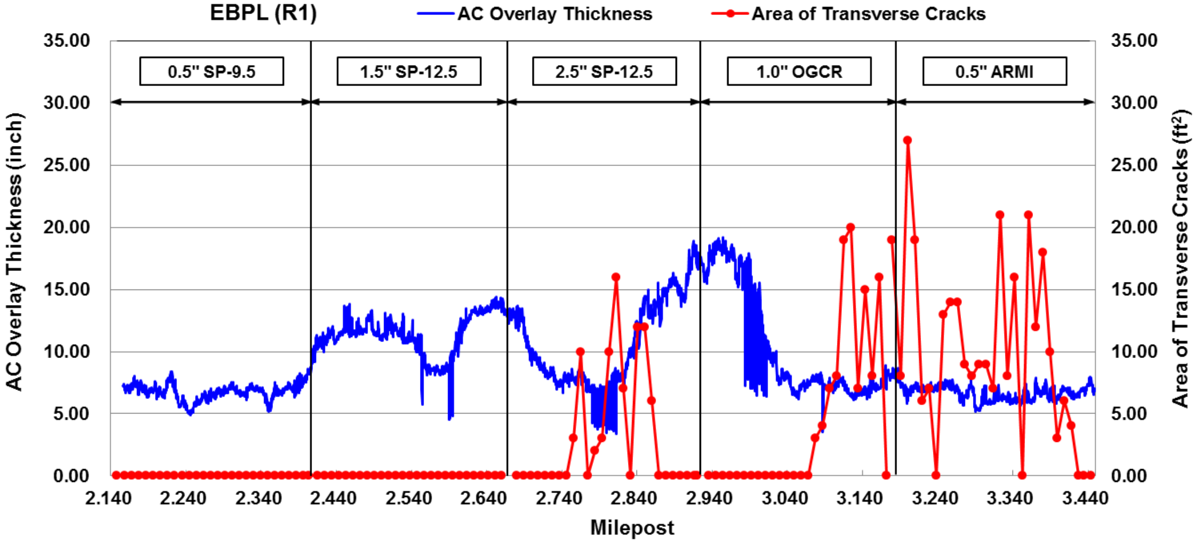
FIGURE 8 Embankment response (D_{60})

Further Discussion

The results from the cracking performance evaluation have shown the reflective transverse cracks were predominant in the ARMI section. A new approach was used to validate this observation and to determine the presence of other contributing factor(s) associated with field cracking performance. FIGURE 9 shows the relationship between AC overlay thickness obtained from Ground Penetrating Radar (GPR) data and the measured area of transverse cracks. It appears that transverse cracking is likely associated with AC overlay thickness as cracks generally occurred in areas with a relatively thinner AC overlay. Conversely, the thicker AC overlay over the PCC may have resulted in reduced potential for reflective cracking. This is in line with previous research work indicating that thicker AC overlay thickness is capable of reducing the levels of stress and strain near the existing crack tip in the PCC *(10)*. Also, the thicker AC overlay can provide better insulation to the PCC. Consequently, the lower slab temperature and reduced temperature differential lead to less slab curling, slab expansion, and contraction which in turn result in delaying the reflective cracking process compared to a pavement with thinner AC overlay. However, it is interesting to note that the 0.5 inch SP-9.5 section with a relatively thinner AC overlay exhibited better cracking performance and thus a potentially better reflective cracking mitigation treatment.



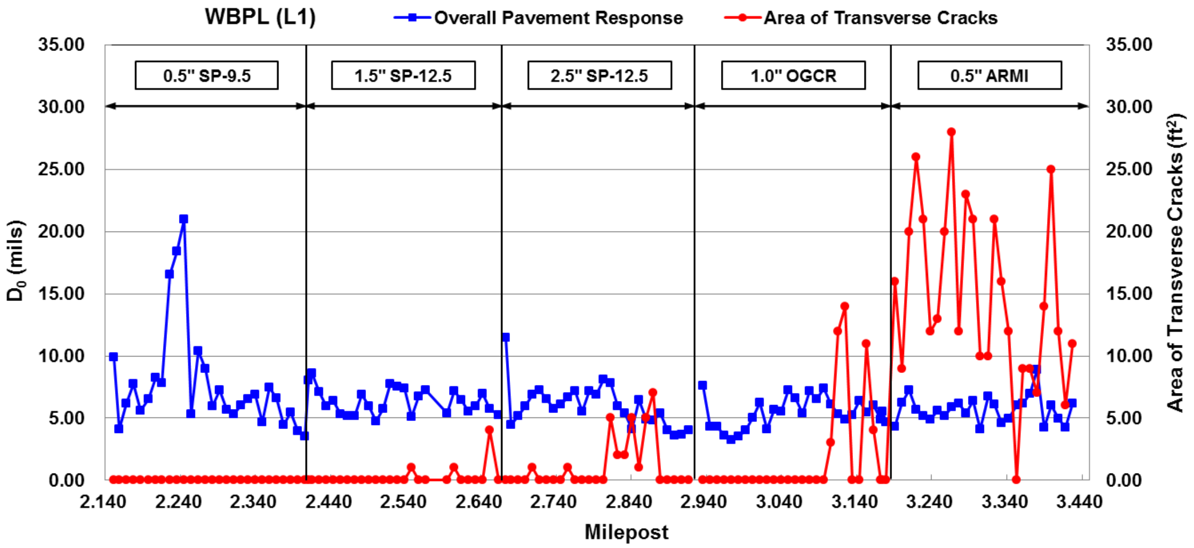
(a) WBPL (L1) – 2014



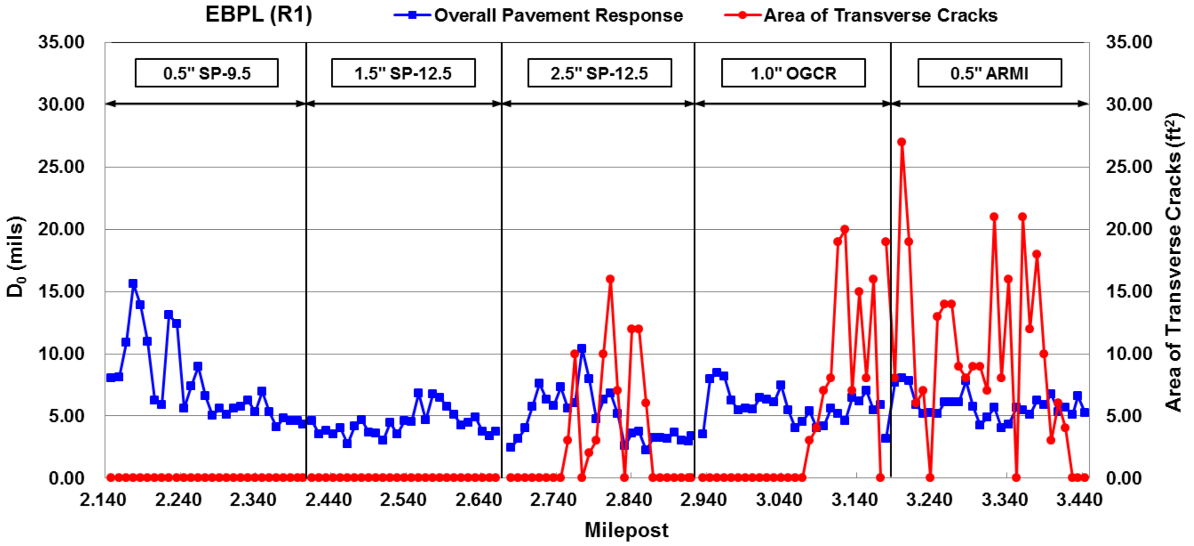
(b) EBPL (R1) – 2014

FIGURE 9 AC overlay thickness vs. transverse cracking performance

The results of overall pavement deflection response and transverse cracking are shown in FIGURE 10. There is no apparent relationship or trend between the two variables. Therefore, one may not effectively distinguish the cracking performance from the FWD maximum deflection results alone. Further analyses were conducted to better explain the reflective cracking performance observed among the test sections based on the dissipated energy approach presented in the following section.



(a) WBPL (L1) – 2014



(b) EBPL (R1) – 2014

FIGURE 10 Overall pavement responses vs. transverse cracking performance

FWD LOAD-DEFLECTION TIME HISTORY ANALYSIS

The dissipated energy, which is defined as the difference in areas under the stress-strain curve during the loading and unloading portions indicated as a hysteresis loop, is one of the important properties used to characterize viscoelastic materials. This approach has been widely used for fatigue damage and/or performance evaluation of asphalt materials. The rate of change in dissipated energy versus load cycles to failure indicates a unifying concept for damage accumulation. In this study, the FWD time history data were analyzed to determine whether any relationship exists between the computed dissipated energy and field cracking performance that may not be captured through maximum deflection analysis. Since significant differences in test temperature were identified between each test section, only the 2014 data for 2.5 inches SP-12.5, 1.0 inch OGCR, and 0.5 inch ARMI sections of WBPL (L1) were analyzed as they had similar surface temperature during the FWD testing as shown in FIGURE 11.

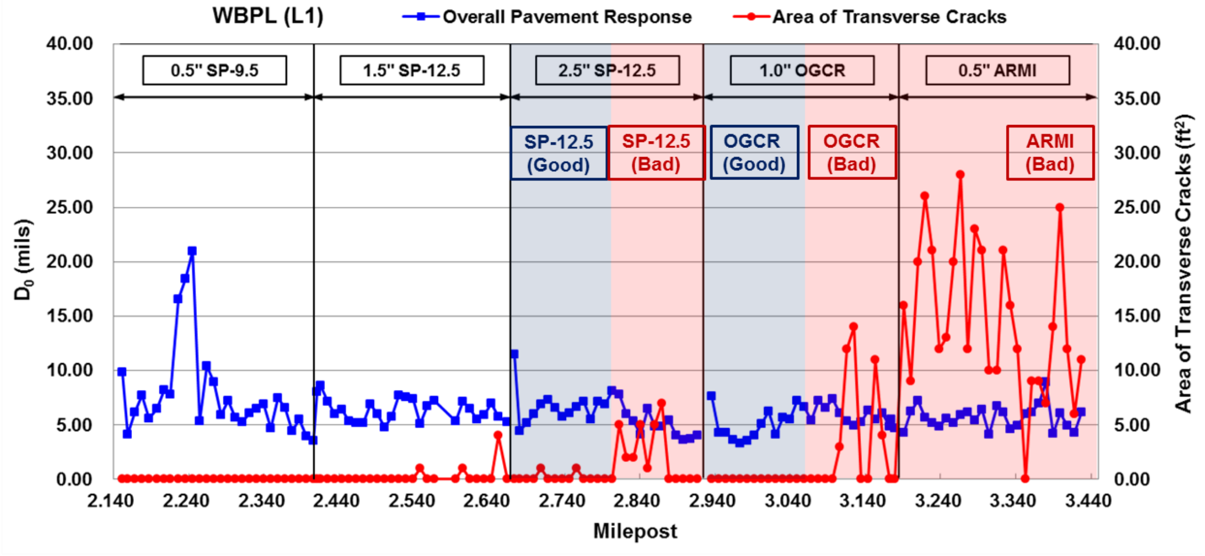
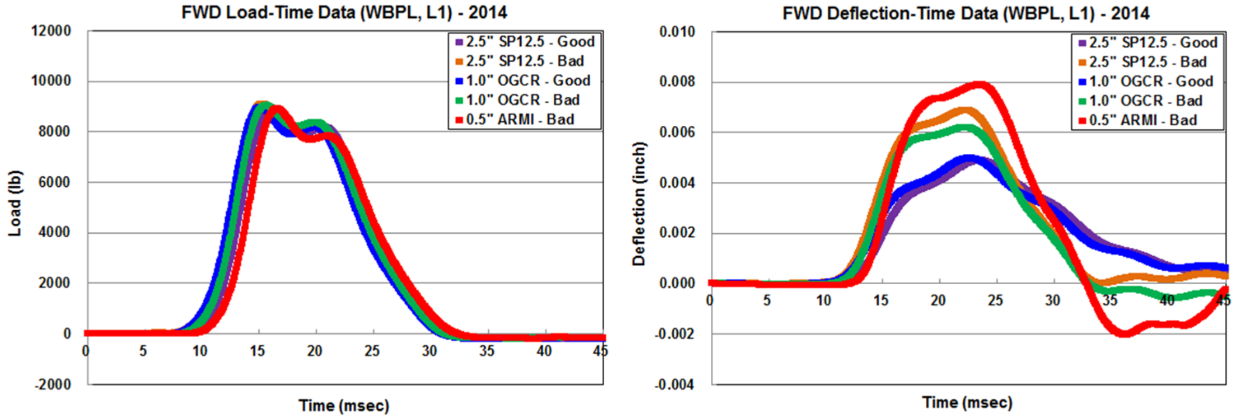


FIGURE 11 Areas selected for FWD time history data analysis

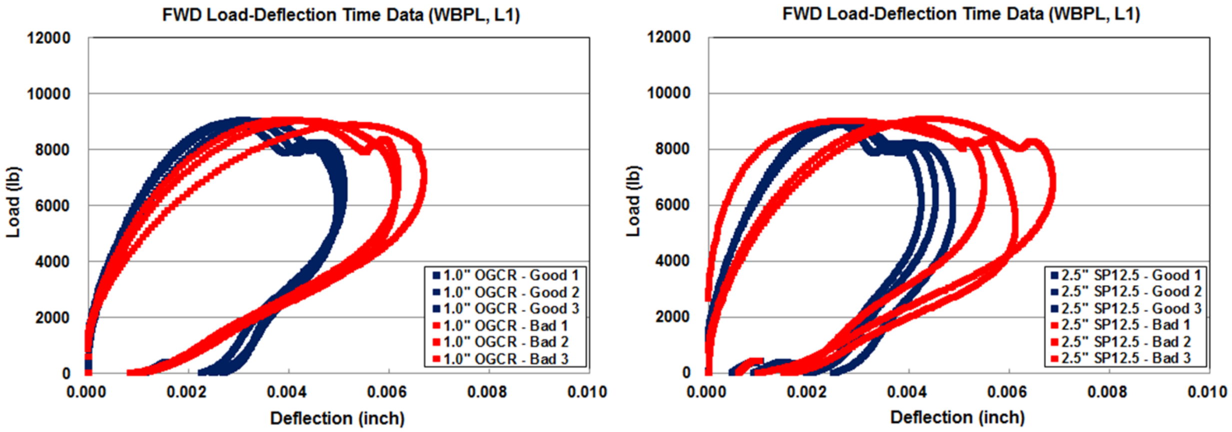
Three replicates of the FWD time history data per section were used for the analysis. FIGURES 12 (a) and (b) exhibit the FWD load and deflection time history plots for each test section. The load-time plot shows that in general, consistent loading conditions were applied for all test sections as indicated by the near identical magnitude, shape of loading over time, and time frame (i.e. pulse duration) from approximately 10 to 30 milliseconds (msec). It is interesting to note the different response characteristics within and between test sections with good and bad cracking performance as illustrated in FIGURE 12 (b). Also, the trend of deflection-time response appears to be associated with the thickness of AC overlay.



(a) FWD load-time plot (b) FWD deflection-time plot

FIGURE 12 FWD load and deflection time history plots

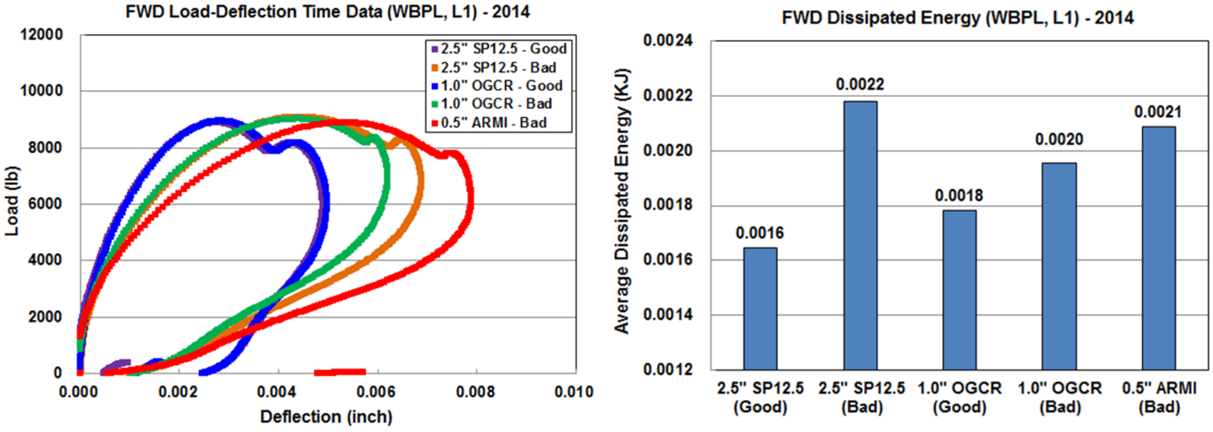
The dissipated energy was calculated using the FWD load-deflection time history data from each test section. FIGURES 13 (a) and (b) are examples of the load-deflection time history plots obtained from 1.0 inch OGCR and 2.5 inch SP-12.5 sections respectively, including both areas with good and bad cracking performance. The results indicate that different FWD load-deflection time history responses were found between sections with different cracking performance.



(a) 1.0 inch OGCR section (b) 2.5 inch SP-12.5 section

FIGURE 13 FWD load-deflection hysteresis loops

As indicated by the different shape of the resulting hysteresis loops in FIGURE 14, test sections with bad cracking performance generally exhibited larger hysteresis loops (i.e. greater dissipated energy) than sections with good cracking performance. This observation supports the findings from previous studies that the magnitude of dissipated energy is related to the rate of pavement damage or deterioration *(11)*. The results suggest that the difference in structural capacity of layered flexible pavement system can be better captured using the dissipated energy approach. Therefore, the dissipated energy appears to be a potential indicator of pavement structural response characteristic that can be used to evaluate pavement performance.



(a) Hysteresis loops (b) Dissipated energy

FIGURE 14 FWD load-deflection hysteresis loops and dissipated energy

CONCLUSION

The effectiveness of different type of crack relief techniques on mitigating reflective cracking for asphalt overlaid concrete pavement was evaluated using field pavement performance data including FWD deflection, ride quality, rutting, and cracking. FWD load-deflection time history data was used to further explain the observed field performance characteristics of the various treatments. A summary of findings and conclusions is presented as follows.

- Overall, the pavement sections with different crack relief techniques exhibited good rutting and smoothness performance.
- In general, 0.5 inch SP-9.5, 1.5 inches SP-12.5, 2.5 inches SP-12.5 sections show greater potential as reflective cracking mitigation treatments.
- Reflective cracks from the PCC slab joints were predominant in the section with 0.5 inch ARMI.
- The dissipated energy approach appears to better capture the difference in structural capacity of pavement sections with different cracking performance.
- It was identified that areas with greater dissipated energy was associated with higher rate of pavement deterioration and/or damage as indicated by bad cracking performance.

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DISCLAIMER

The content of this paper reflects the views of the authors who are solely responsible for the facts and accuracy of the data as well as for the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Florida Department of Transportation. This paper does not constitute a standard, specification, or regulation. In addition, the above listed agency assumes no liability for its contents or use thereof.

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