State of Florida
Department of Transportation

Evaluation of an Asphalt Rubber Membrane Interlay to Mitigate Reflective Cracking: Baker County SR 2 Experimental Project

FDOT Office
State Materials Office

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Experimental Project Location
FIN 207919-1-52-01
County Section 27020-3509
State Road 2
Baker County

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EXECUTIVE SUMMARY

Florida first experimented with an asphalt rubber membrane interlayer (ARMI) more than 30 years ago. Today, an ARMI is the primary reflection crack mitigation technique used by the Florida Department of Transportation (FDOT). In general, FDOT's experience with ARMI's has been mixed. Prior experience has indicated that reflection cracking can be delayed when a pavement system, including the ARMI, is designed and constructed properly. However, it has been noted that construction quality is a universal concern among the districts and some feel that the cost of an ARMI does not necessarily justify the performance. Since flexible pavements represent most pavements in Florida an ARMI is most often used when cracks cannot be entirely removed during a mill and overlay operation. However, ARMIs have also been used to mitigate reflection cracking of rigid pavement joints. In 1998, an experimental project was initiated to study the effectiveness of an ARMI to mitigate reflective cracking in an asphalt overlay of a flexible pavement. The experimental project was established on the eastbound lane of State Road 2 in Baker County, Florida. Of the five test sections constructed, two sections included an ARMI while the other three sections were constructed with varying structural and overbuild thicknesses. More than 900,000 ESALs have been applied to the pavement since it was resurfaced. Pavement performance has been monitored annually. Rut depth and ride quality remain within acceptable ranges. Cracks found on the sections are primarily longitudinal cracks in the wheel path. A limited number of cores show the presence of shallow top-down cracks. One core from Section 1 showed a full-depth crack that traversed the ARMI. The sections that included an ARMI (Sections 1 and 2) had similar or a greater amount of cracking than the sections without an ARMI. Initial cracks were observed in each of the five test sections within the first 4 to 5 years. Based on the performance data measured in this project, an ARMI does not appear to delay cracking. Because a detailed crack map showing the surface conditions prior to resurfacing was not avialble, it was not possible to assess whether the observed surface cracks had reflected from pre-existing cracks. Furthermore, it is unclear how many cracks had originated from the surface.

INTRODUCTION

When an extensively cracked flexible or concrete pavement is overlaid with asphalt concrete, it is only a matter of time before the existing distresses exhibited in the original pavement reflect through the new overlay. Florida's first experimentation with an ARMI was conducted in 1978 on State Road (SR) 60 in Hillsborough County (*3*). Today, an ARMI is the primary reflection crack mitigation technique used by FDOT (*1, 2*). In general, FDOT's experience with ARMI's has been mixed. Prior experience has indicated that reflection cracking can be delayed when a pavement system, including the ARMI, is designed and constructed properly. However, it has been noted that construction quality is a universal concern among the districts and some feel that the cost of an ARMI does not necessarily justify the performance. In 1998, an experimental project was constructed on SR 2 in Baker County to evaluate the effectiveness of an ARMI. Annual monitoring and testing have been conducted since construction to assess ARMI's relative field performance.

OBJECTIVE

The objective of this study was to determine the long-term performance of an ARMI and assess its effectiveness in mitigating reflection cracking of an asphalt overlay on an existing flexible pavement. Performance was evaluated in terms of deflection, pavement smoothness, rutting, and cracking. This report covers the period from the initial reconstruction in 1998 until 2011.

BACKGROUND

Mechanics of Reflective Cracking

The basic mechanism of reflection cracking is related to stress concentrations developed in the asphalt overlay due to differential movement of cracks and joints of the original pavement. Crack and joint movement can be induced by environmental effects and traffic loading. Horizontal movements due to moisture and temperature changes generate stress concentrations at joints and cracks. In this scenario, reflection cracks initiate at the bottom of the overlay (*4, 5*). Vertical movements created by upward curled joints generate a tensile force in the top of the asphalt overlay and may initiate cracks at the surface (*5*). Top-down reflective cracks are more prone in aged pavements during cooler weather when they are the most brittle. Reflective cracks due to environmental effects are dependent on the magnitude and rate of temperature change, crack spacing, crack width, slab width, and overlay characteristics.

Traffic loading of overlaid cracked and jointed pavements can create differential vertical movements at the crack and joint. This differential movement of the original pavement generates a shear stress concentration in the overlay. Reflection cracking due to vertical movements created by traffic induced loads is dependent on the magnitude of the vertical movement differential and asphalt overlay characteristics (*4, 5*).

Reflection cracking (or any cracking for that matter) is more prevalent in cold weather when an aged pavement is the most brittle. Several studies have indicated that the time until reflective cracking is observed depends greatly on the climate of the region (*4, 7*). In a survey of State Highway Agencies, Bennet et al. found that states that observed the greatest time until the appearance of reflective cracking were also states that had the warmest climates (*4*). According to the survey, 24 percent of agencies observed reflective cracking within one to two years after construction, 48 percent reported two to four years, and 24 percent (including Florida) developed reflective cracking after 4 years on the average (*7*). Several methods have been developed to mitigate reflective cracking with varying levels of success. Some of the most common methods are shown in TABLE 1 and include treatment of the existing surface and/or cracks, modification of the asphalt overlay mixture, crack arresting interlayers, stress/strain absorbing interlayers, reinforcement of the overlay, and crack control.

TABLE 1 Reflection Cracking Mitigation Methods

Treatment	Comment
Treatment of existing surface and/or cracks (*4, 5,6*)	Crack-and-seat or rubbelization of concrete pavements may be performed to reduce slab length and minimize or eliminate thermally induced horizontal movements. Cracks/joints with excessive differential deflection or subsurface voids may be repaired full-depth or undersealed. Existing cracks in flexible pavements can be removed or minimized by milling, full-depth reclamation, hot-in-place recycling, and cold-in-place recycling.
Asphalt overlay mixture modification (*4, 7*)	The overlay thickness can be increased, and mixture properties modified to improve the fracture resistance of the overlay.
Crack arresting interlayers (*5, 6*)	Open-graded crack relief layers are used to reduce differential horizontal and vertical movements by insulating the existing pavement and breaking or reducing the bond between the overlay and existing pavement. Differential deflections at joints/cracks are absorbed or distributed due to the increased thickness and lower modulus of the crack-relief layer.
Stress/strain absorbing interlayers (*4*, *5*)	Stress/strain absorbing membrane interlayers (SAMI) are often less than 1-inch-thick nonstructural layers that include chip seals, thin bituminous layers with low viscosity asphalt, bond breakers, geotextiles, and composite layers. The goal of a SAMI is to dissipate differential horizontal movement of the existing pavement and overlay. These solutions are reported to have minimal ability to dissipate differential vertical movement across the joint/cracks induced by traffic.
Overlay reinforcement (*5*)	Overlays are reinforced using steel, geotextiles, and geogrids. The reinforcement is intended to distribute the stresses caused by horizontal and vertical movements occurring at the joint/crack. When large vertical movements occur at a joint, reinforcement will keep the reflective crack tight when it forms
Crack control (*5, 6*)	Crack control methods do not aim to prevent or delay reflective cracks, but rather to control their severity. This method requires the overlay to be sawed and sealed above the joints in PCC pavements. This method can also be used for existing flexible pavements with regularly spaced transverse cracks.

FLORIDA'S EXPERIENCE

An ARMI is composed of an asphalt rubber binder (ARB) and a single layer of a No. 6 stone aggregate cover material. The ARB consists of a PG 67-22 asphalt binder modified with a minimum of 20 percent ground tire rubber (ARB-20). The ARB-20 is placed at a rate of 0.6 to 0.8 gal/yd^2 while the No. 6 stone is applied at a rate of 0.26 to 0.33 ft^3/yd^2. Finally, a rubber-tired roller is used to seat the stone into the ARB-20.

As mentioned previously, FDOT first experimented with an ARMI more than 30 years ago. Over this period, each District has utilized ARMIs with varying degrees of success. Since flexible pavements represent most pavements in Florida, an ARMI is most often used when cracks cannot be entirely removed during a mill and overlay operation. However, ARMIs have also been used to mitigate reflection cracking of rigid pavement joints. An informal survey of District Bituminous Engineers was conducted during the summer of 2010 to determine the depth and variety of District experience. In general, there was a wide range of experience. A summary of the survey is presented below:

- Younger DBE's and those who recently joined the Florida Department of Transportation (FDOT) have limited experience with an ARMI since many roadways already include an ARMI from previous rehabilitation efforts. In addition, ARMI's are expensive, and the perceived benefit does not always justify the cost, particularly in the current economy.
- Construction quality was a concern among all Districts. A competent contractor with proper equipment and trained personnel is essential.
- Some Districts reported localized increases in rutting when an ARMI was used. Limited field studies have been performed but have generally been inconclusive. It was noted that intersections should receive special consideration.
- Good performance, in terms of reflection cracking, is possible if the pavement system (including ARMI) is designed and constructed properly.

In addition to the SR 2 experimental project, Florida has implemented three other long-term monitoring projects and an Accelerated Pavement Testing (APT) study over the years that included the use of an ARMI. The first of these projects was constructed in 1978 on SR 60 in Hillsborough County (*8*). This short-term project investigated ten 1,000-foot-long experimental sections. Four of the structures included an ARMI, two received an asphalt rubber seal coat and the other four consisted of standard constructions with variable thicknesses. An ARMI was located directly below an open graded friction course (OGFC) in two of the sections. An ARMI, leveling course, and a 1.5- or 2.5-inch overlay were placed above the existing pavement in the remaining sections that included an ARMI. After a six-month period, extensive rutting and bleeding was observed in the wheel paths of the sections with an ARMI placed directly below the OGFC. No significant rutting or other distresses were found in the sections with the ARMI placed below the structural and leveling courses during the six-month evaluation.

Starting in 1993 and extending through 1995, FDOT initiated the rehabilitation of seven deteriorating concrete pavement sections along the I-10 corridor in the northern part of Florida. The original 9-inch plain jointed concrete pavement included 20-foot joint spacing and was placed on a 12-inch cement stabilized base. A crack-and-seat process was used to crack the original pavement into 36-inch maximum size pieces. An ARMI layer, 4 inches of typical Florida structural asphalt mixture, and a 0.5 inch open-graded friction course (OGFC) was constructed on the cracked-and-seated concrete. The pavement sections were monitored annually for 10 years to evaluate performance (*9*). Five out of the seven sections exhibited average rut depths of approximately 0.35 inches after 10 years. Two sections were resurfaced due to excessive rutting in 2000 and 2001. The excessive rutting was thought to be related to asphalt mixture issues. Cracks were first observed within five to seven years. Overall, the pavement performance was thought to be satisfactory.

In 2009, a project was constructed on SR 10 in Gadsden County. This project consists of five sections constructed over a jointed and cracked PCC pavement. Four of these sections include a 1.5-inch Superpave structural layer and a 1-inch dense graded friction course (DGFC). One of these sections includes an ARMI and another has a 1 inch open-graded crack relief layer (OGCRL). A 2.5-inch structural layer and 1-inch DGFC was placed on the fifth section. To date, approximately 200,000 ESALs have been applied to the experimental sections. The section with the ARMI was found to have some reflection cracks during the first annual evaluation. Cracks were also observed on two of the sections without a crack relief layer during the second annual evaluation. No reflection cracks have yet been observed on the section with the OGCRL. It is too early to form long term conclusions regarding the performance of the ARMI or the OGCRL, but it is alarming that reflection cracks have already been observed on the section utilizing an ARMI.

Finally, an APT study was recently concluded that investigated an ARMI's contribution to rutting. The APT study found that an ARMI placed as deep as 4 inches contributed to instability rutting when the pavement is subjected to a combination of slow-moving truck loads and in-depth pavement temperatures that approach or exceed 115°F. These conditions are not uncommon at intersections or ramps during the summer. Based on the findings of this study, it was recommended that an ARMI not be placed on pavements subjected to slow moving and concentrated truck loads such as intersections, ramps and toll plazas due to the potential of instability rutting at these locations.

PROJECT DESCRIPTION

The experimental project was constructed in January 1998 and consists of five sections located in the eastbound lane of SR 2 in Baker County a few miles east of the Columbia County line as shown in FIGURE 1. The roadway consists of two 11-foot lanes with 2-foot paved shoulders. The pavement structure and limits of the 2,500 feet long experimental sections are shown in FIGURE 2. FIGURE 3 shows traffic history from monitoring site 270053 located at milepost 13.952. More than 900,000 ESALs have been applied to the experimental sections. A ground penetrating radar (GPR) survey of the sections shown in FIGURE 4 estimated the total thickness of the asphalt layer to be 5 inches for Section 1, 6 inches for Sections 2, 3, 4, and 7 inches for Section 5. The asphalt base thickness was on average just over 6 inches for each section.

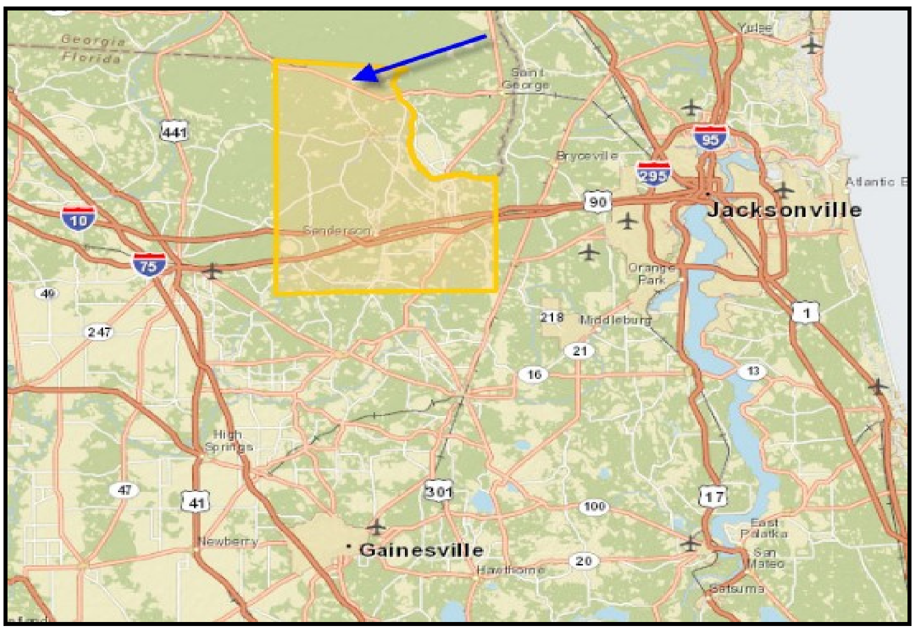
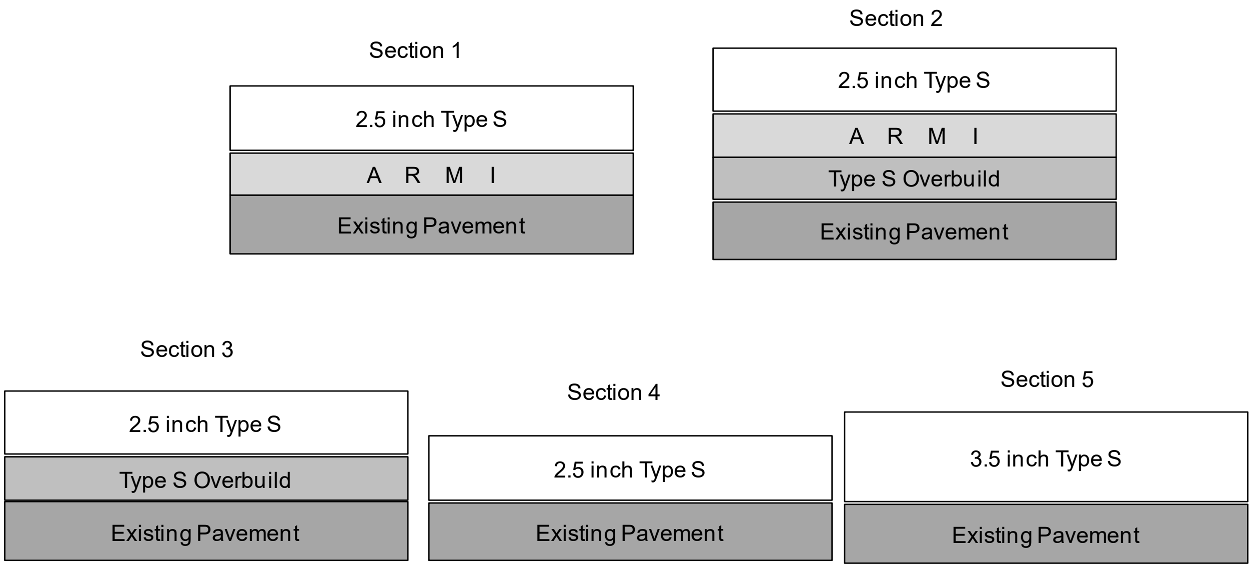


FIGURE 1 SR2 Experimental Project Location



Note: The experimental sections included an asphalt base.

Section	1	2	3	4	5
Milepost	7.000 to 7.474	7.474 to 7.947	7.947 to 8.421	8.421 to 8.894	8.894 to 9.367
Station	369+60 to 394+60	394+60 to 419+60	419+60 to 444+60	444+60 to 469+60	469+60 to 494+60

FIGURE 2 Experimental pavement sections and limits.

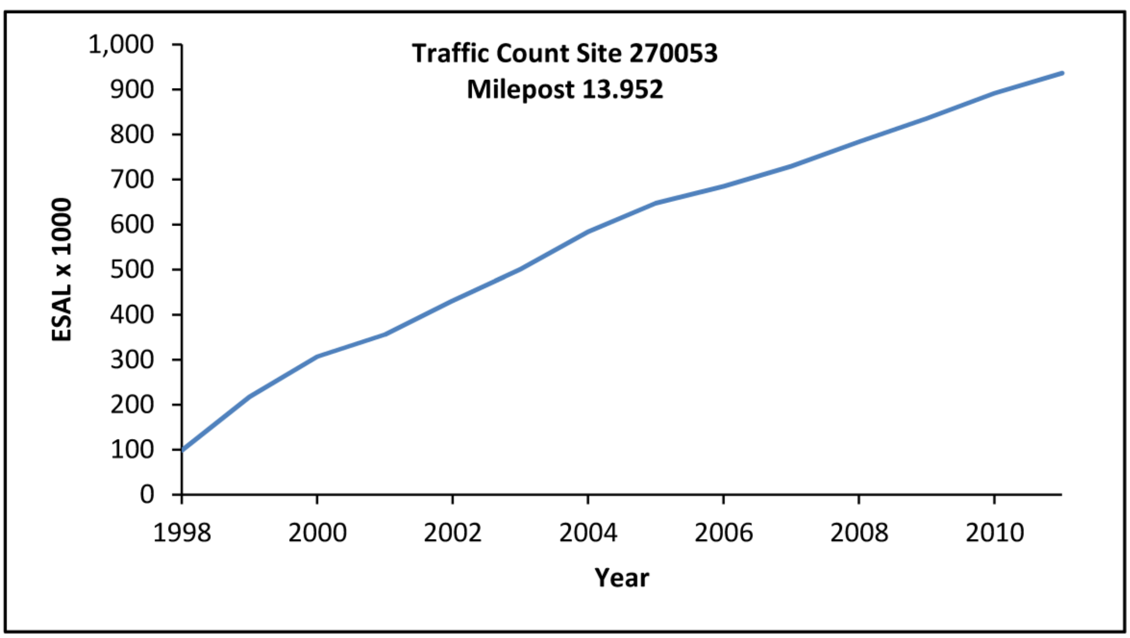


FIGURE 3 SR 2 traffic data.

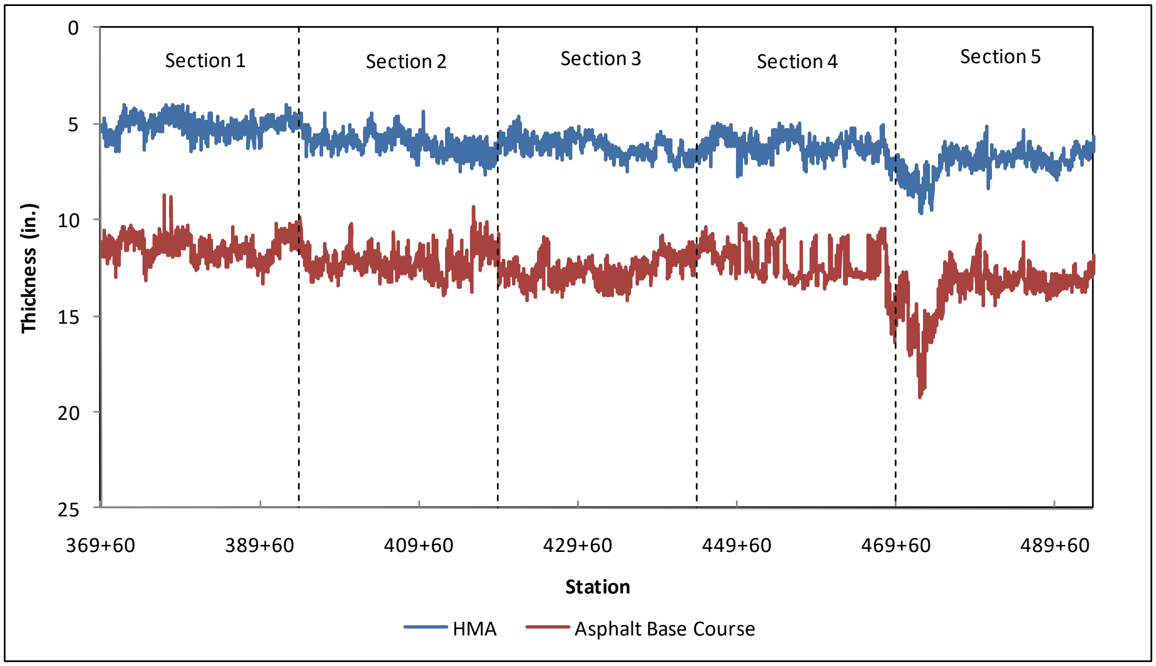


FIGURE 4 GPR estimated layer thickness.

PAVEMENT PERFORMANCE MONITORING

The State Materials Office (SMO) conducts annual pavement performance monitoring of experimental projects during the same time of the year to better control variability due to seasonal changes (e.g., temperature, rainfall, etc.). The experimental project on SR 2 is typically evaluated in February. The primary parameters used to evaluate the performance of the experimental sections include:

1. Pavement deflection/stiffness
2. Pavement smoothness
3. Asphalt surface permanent deformation (rutting)
4. Pavement cracking

Pavement Deflection

Annual deflection measurements are made in the outside wheel path of each lane. A photograph of a FWD is shown in FIGURE 5. A typical testing configuration includes the following:

- A 12-inch load plate
- A 9-kip load
- Deflection sensors placed at 0, 8, 12, 18, 24, 36, and 60 inches from the load plate

FIGURE 5 Falling Weight Deflectometer.

The stiffness of a pavement system may be inferred through the analysis of deflection basins or by estimation of layer moduli through back calculation or forward calculation. In general, analysis of deflection basins and forward calculation techniques are more straight forward than backcalculation procedures. The deflection basins measured during 1998 and in 2011 are shown in FIGURE 6. In both sets of basins, Section 1 is the weakest and Section 5 is the stiffest. The stiffness of the upper asphalt layers was estimated by calculating a surface deflection parameter. Variability in asphalt surface stiffness over the life of the project is shown in FIGURE 7. The surface deflection parameter is calculated as follows:

Surface deflection parameter = D (0) – D (8)

Where,

D(i) = Deflection measured at i inches from the load plate.

The surface deflection parameter also shows that Section 1 is the least stiff and Section 5 is the stiffest. In addition, Section 3 is stiffer than Section 2 and Section 4 is stiffer than Section 1. The only difference in these sections is that an ARMI is present in Sections 1 and 2.

Deflections were adjusted for variations in load and asphalt temperature. The BELLS equation was used to estimate the mid-depth asphalt temperature and a procedure reported by the Federal Highway Administration (FHWA) was used to adjust the deflections (*10*).

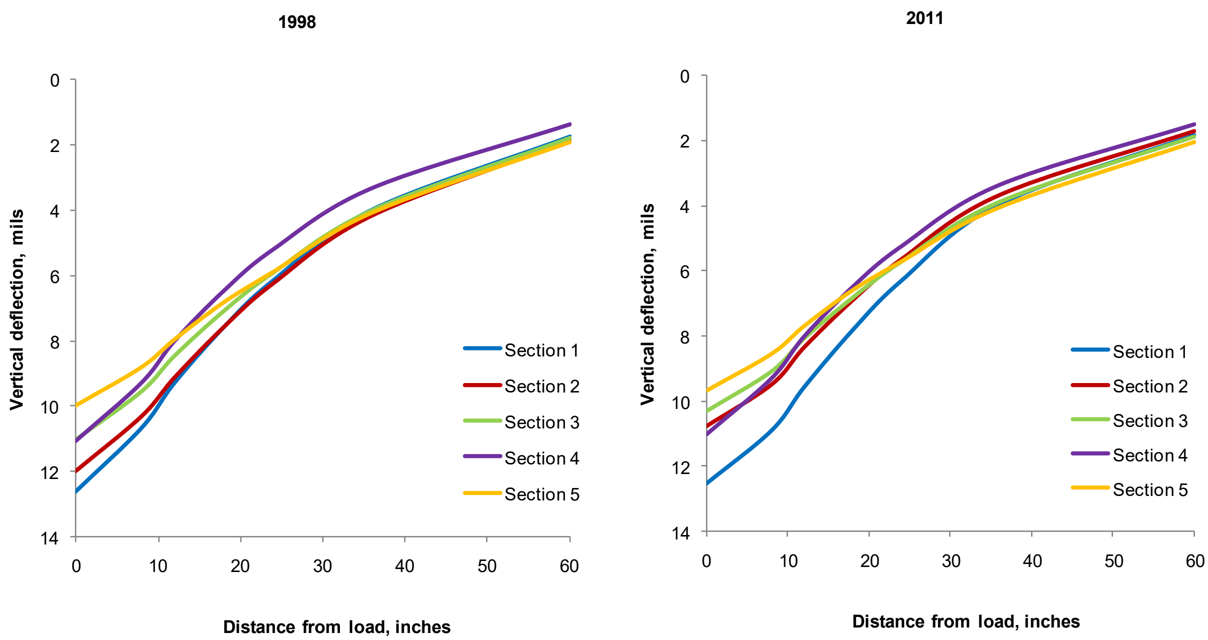


FIGURE 6 SR 2 deflection basins.

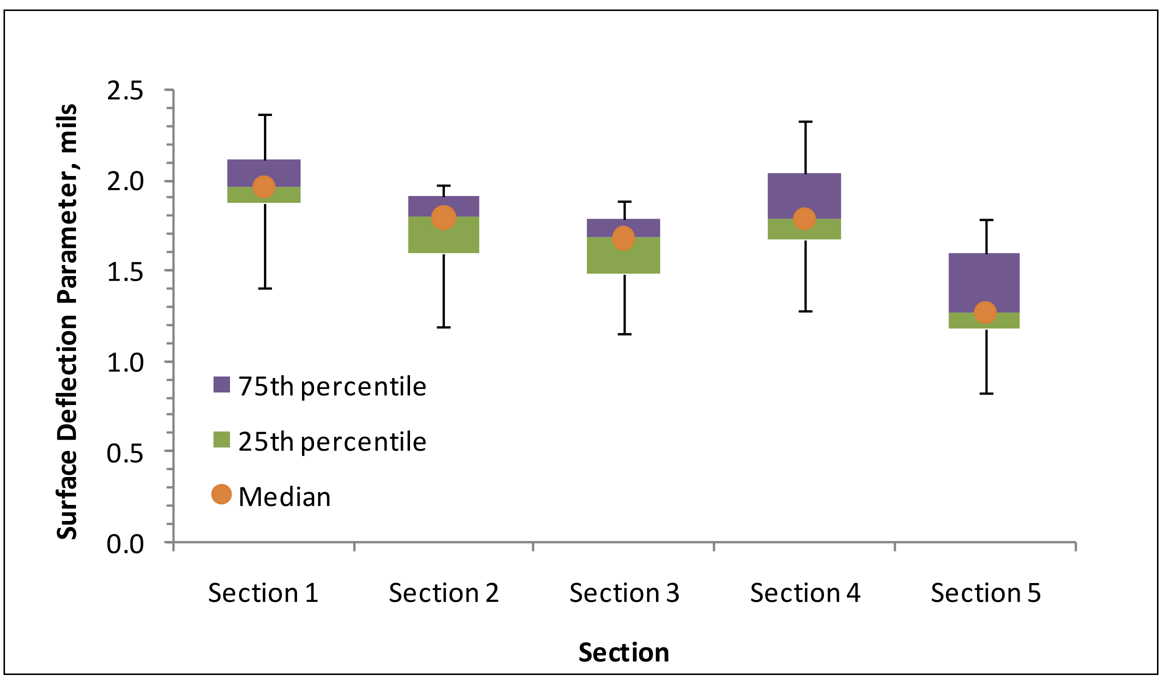
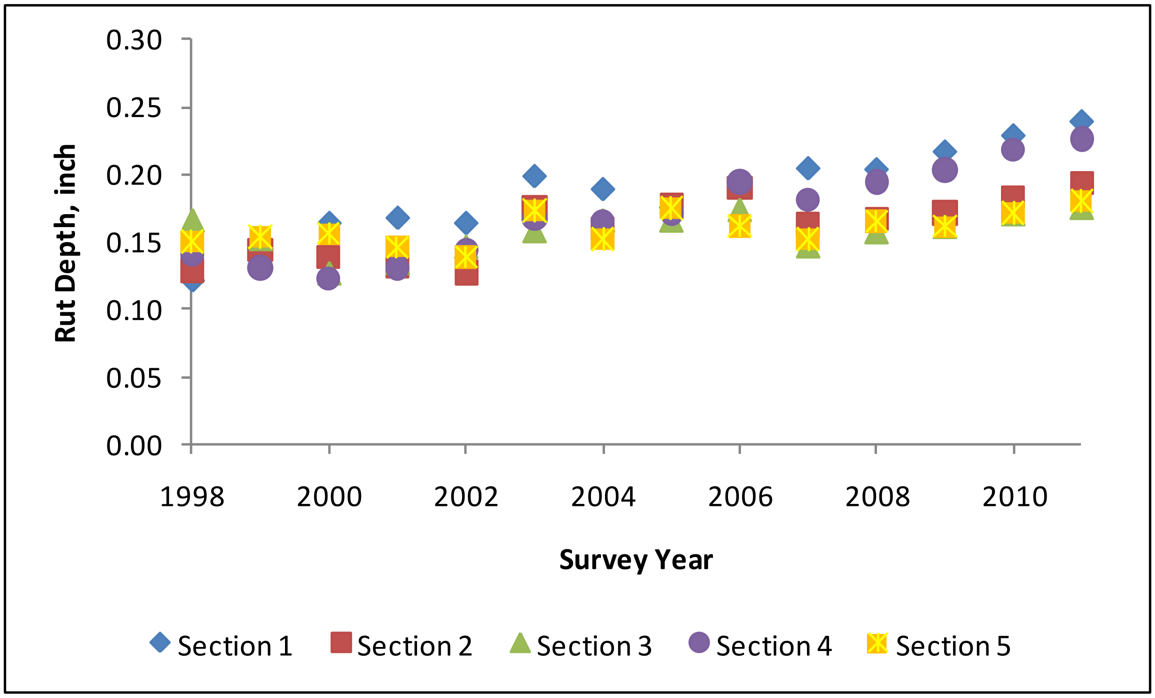


FIGURE 7 Surface stiffness measured from 1998 to 2011.

Permanent Deformation

Permanent deformation, or rut depth, is measured manually each year. Currently, the average rut depth for the sections ranges from 0.17 to 0.24 inch. Overall, there is not a considerable difference between the rut depths of the sections and the rut depth is within an acceptable range. FIGURE 8 summarizes the rut depth measurements.



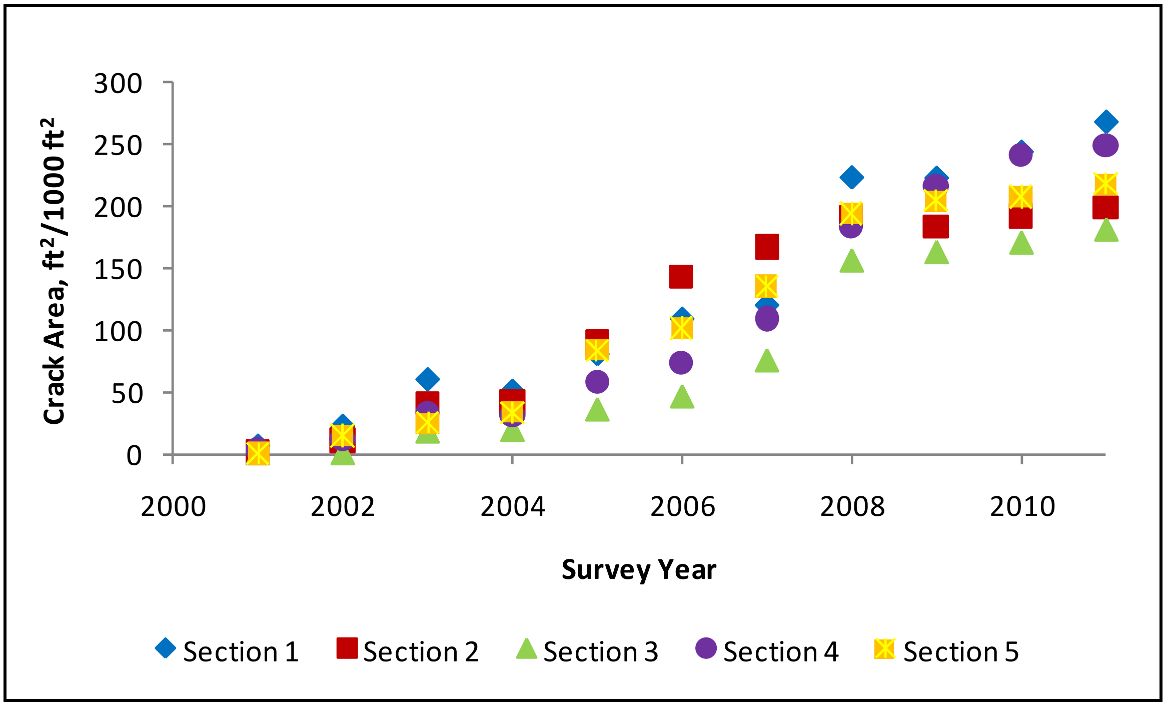
2011 Rut Depth Measurements					
Section	1	2	3	4	5
Rut Depth, inch	0.24	0.19	0.17	0.23	0.18

FIGURE 8 SR 2 rut depths.

Cracking

The first cracks were observed within 4 to 5 years of construction for each section. Longitudinal cracking found in the wheel paths make up most cracks. Some transverse cracking in between the wheel paths was observed in Section 1. Very little transverse cracking was found in the other sections. The greatest amounts of cracks were found in Sections 1 and 4. Figure 9 shows the crack survey measurements.

Six cores were collected during the 2009 survey, three of which had transverse cracks that were found to be shallow top-down cracks. Full-depth transverse cracks were cored in Sections 1 and 3. TABLE 2 summarizes the information gathered from the cores and core photographs are presented in FIGURE 10.



2011 Crack Survey Measurements					
Section	1	2	3	4	5
Years until first crack	4	4	5	4	5
Total Cracks, $ft^2/1000\ ft^2$	223	166	151	207	182
Transverse Crack, $ft^2/1000\ ft^2$	27	3	4	3	1

FIGURE 9 State Road 2 cracking.

TABLE 2 2009 Core Descriptions

Section	Station	Core Description
1	372+10	Shallow transverse top-down crack
1	377+65	Full-depth transverse crack
2	406+70	Shallow top-down transverse crack
3	439+90	Full-depth transverse crack
4	465+60	Shallow top-down transverse crack
5	477+30	Shallow crack in asphalt base

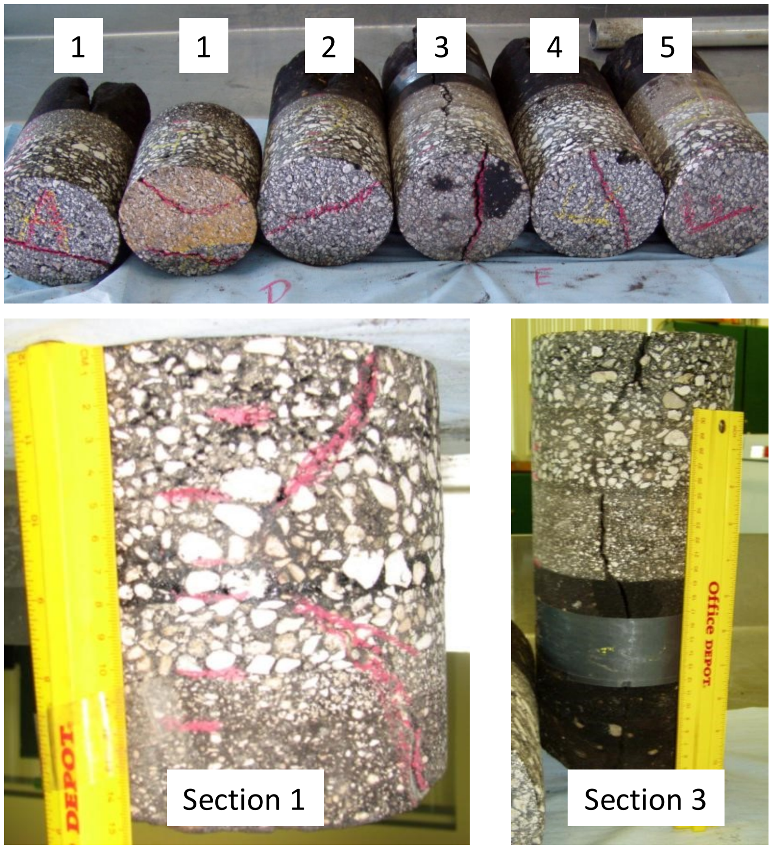


FIGURE 10 Core photographs.

Ride Quality

Roughness is reported in terms of Ride Number (RN) and International Roughness Index (IRI) according to ASTM E 1489 (RN) and ASTM E 1926 (IRI), respectively. The RN is a profile index that rates the rideability of a road using a 0 to 5 scale that corresponds to a user's perception of pavement roughness. A RN of 5.0 represents a perfect ride quality while an RN of 0 corresponds to a virtually impassable surface. An IRI of 0 in/mile represents a perfectly smooth surface. The RN of each section has remained above 4.0 and the IRI is below 75 inches/mile for each section, representing a good ride quality. FIGURE 11 and FIGURE 12 show the RN and IRI for each survey year, respectively.

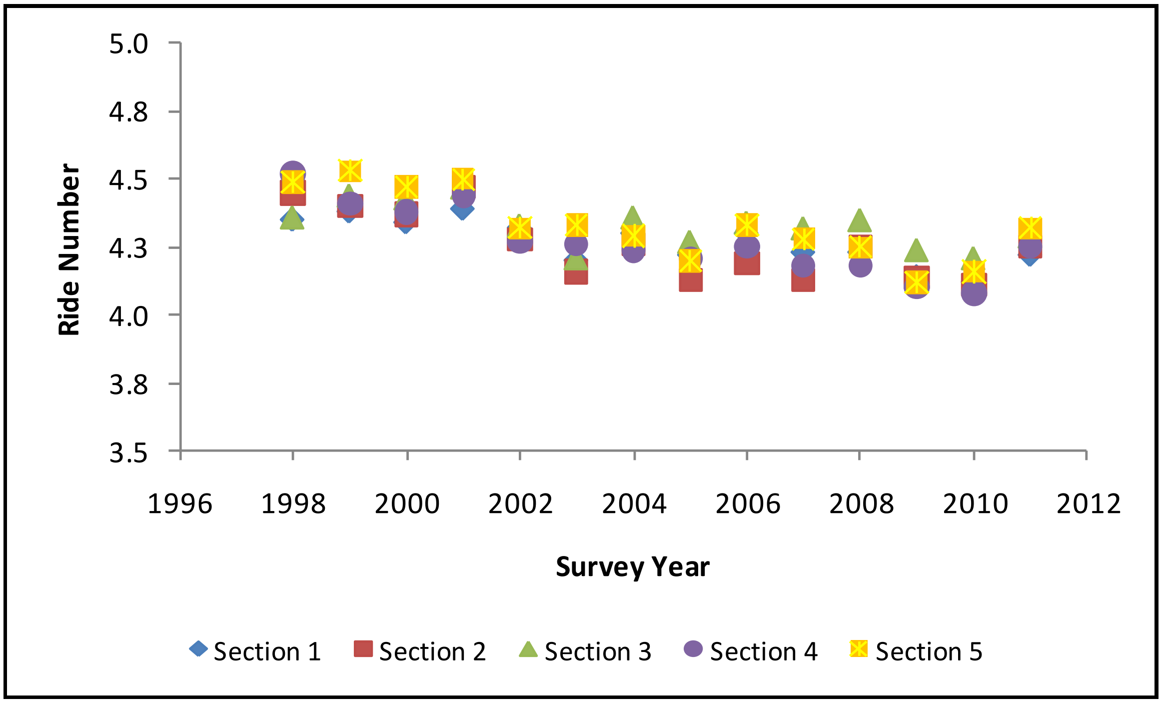


FIGURE 11 SR 2 ride quality.

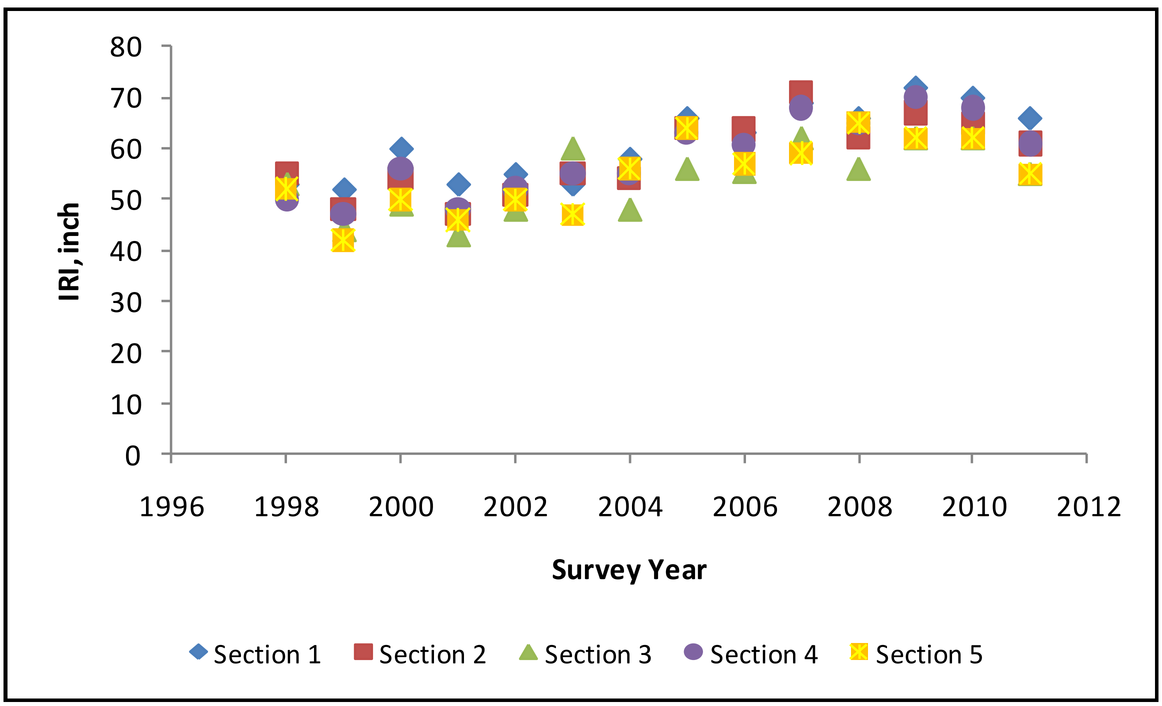


FIGURE 12 SR 2 roughness (IRI).

SUMMARY AND CONCLUSIONS

The performance of the SR 2 experimental sections has been monitored since 1998. More than 900,000 ESALs have been applied over this time period. Rut depth and ride quality remain in acceptable ranges. Cracks found on the sections are primarily longitudinal cracks in the wheel path. A limited number of cores showed that shallow top-down cracks were present. One core retrieved from Section 1 showed a full-depth crack that traversed the ARMI. The sections that included an ARMI (Sections 1 and 2) were found to have similar or a greater amount of cracking than the sections without an ARMI. Initial cracks were observed in each of the test sections within 4 to 5 years. Based on the SR 2 performance data, an ARMI has not appeared to delay cracking. Unfortunately, a detailed crack map prior to resurfacing is unavailable to assess if observed surface cracks were potentially reflected from existing cracks. Furthermore, it is unclear how many cracks originated from the surface.

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