Field Investigations of Selected Strategies To Reduce Reflective Cracking in Asphalt Concrete Overlays Constructed over Existing Jointed Concrete Pavements

ERIC D. MOODY

Seven pavement rehabilitation strategies for reducing the extent and severity of reflective cracking of asphalt concrete (AC) overlays constructed over jointed concrete pavements were designed and the effectiveness of the strategies was evaluated. The seven rehabilitation strategies were selected after conducting an extensive literature search of documented attempts to reduce reflective cracking. The general descriptions of the seven strategies selected for this study are (a) full-depth repair; (b) crack and seat; (c) crushed stone base interlayer; (d) open-graded AC interlayer, (e) styrene-butadiene-styrene modified seal coat interlayer; (f) 7.6-cm (3-in.) dense graded, coarse surface AC overlay; and (g) 3.8-cm (1.5-in.) dense graded AC overlay. A technique involving sawing and sealing joints in the AC overlay directly over the transverse joints in the concrete pavement was investigated as well. These seven strategies were constructed under carefully controlled conditions, with continuous documentation of material properties, layer thicknesses, and environmental conditions during construction. The preliminary results of the research project, including early-age performance with respect to reflective cracking, rutting, and pavement profile measurements, are presented.

Reflective cracking has been a major concern of pavement engineers for many years (*1*). Numerous attempts have been made to address this problem, many with only limited success (*2–5*). This paper presents the preliminary results of a research study sponsored by the Texas Department of Transportation aimed at investigating several well-known strategies for reducing reflective cracking of asphalt concrete (AC) overlays placed over jointed concrete pavements (JCPs). The highway selected for constructing the test sections was US 59 located in northeast Texas. This highway was originally constructed in the 1940s as a two-lane, 9-7-9 JCP. The name 9-7-9 JCP comes from the fact that the pavement is 9 in. (22.9 cm) thick along the outside shoulder and 7 in. (17.8 cm) thick along the centerline. Expansion joints were placed in the pavement every 36.5 m (120 ft), and contraction joints where placed every 4.6 m (15 ft). Expanded shoulders were added during the 1960s and 1970s.

This highway is a primary route of the east Texas timber industry, providing direct links to numerous mills in the area and the Port of Houston. The highway has an annual average daily traffic of 16,500 vehicles, with an estimated 2.3 million 18-kip equivalent single axle loads (ESALs) applied to the design lane annually.

Transtec Consultants, 2630 Exposition Boulevard, Suite 10, Austin, Tex. 78703.

DISTRESS HISTORY

Over the years the original JCP has experienced considerable distress because of the extremely heavy traffic and harsh environmental conditions that characterize this highway. The area of east Texas where the test sections are located is characterized as a wet, no-freeze zone. The test site location receives an average of about 127 cm (50 in.) of precipitation per year. The average depth of the water table at the site is 4.0 m (12 ft).

The typical distresses on the test site pavement include pumping, reflective cracking of the AC overlays, joint failures, and some shattering of the original concrete slabs. Figure 1 shows a typical section of this pavement after maintenance crews have sealed both the longitudinal and transverse reflective cracks in the AC overlay.

As a result of the heavy traffic and harsh environmental conditions this JCP has been rehabilitated numerous times over the years. However, because of both inadequate funding and a lack of knowledge regarding the life cycle costs of alternative repair strategies, the typical rehabilitation technique has consisted of simply placing a 3.8-cm (1.5-in.)-thick Type D AC overlay on top of the existing pavement as needed. Table 1 describes the aggregate gradation bands of various Texas Department of Transportation AC mixtures used in the study. The standard rehabilitation

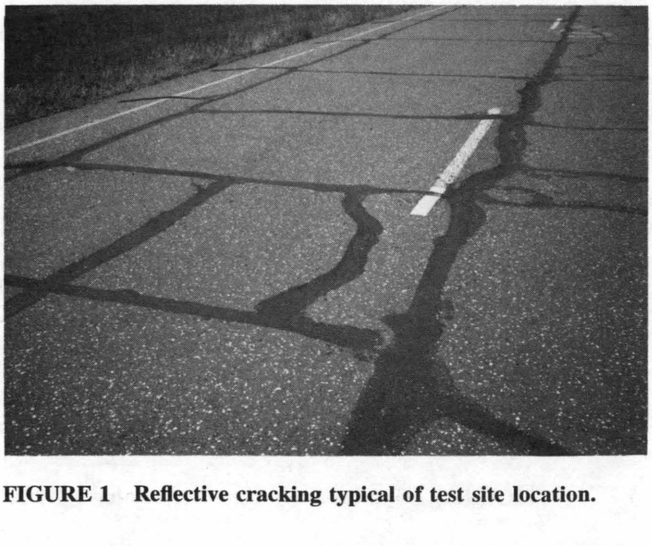

FIGURE 1 Reflective cracking typical of test site location.

TABLE 1 Gradations for Asphalt Mixes Used in the Study

Sieve Size	Type(% Passing) B Fine Graded Base	C Coarse Surface	D Fine Graded Surface	G Open Graded Base
5.1 cm(2.0 in.)				100
3.8 cm(1.5 in.)				50-70
2.5 cm(1.0 in.)	100			30-50
2.2 cm(0.86 in.)	95-100	100		10-20
1.6 cm(0.63 in.)	75-95	95-100		
1.3 cm(0.5 in.)			100	
1.0 cm(0.38 in.)	60-80	70-85	85-100	
0.6 cm(0.25 in.)				
4.75 mm(No. 4)	40-60	43-63	50-70	
2.0 mm(No. 10)	27-40	30-40	32-42	
0.425 mm(No. 40)	10-25	10-25	11-26	
0.178 mm(No. 80)	3-13	3-13	4-14	
0.075 mm(No. 200)	1-6	1-6	1-6	
VMA(% Minimum)	12	13	14	20+

technique described above has been implemented numerous times throughout the history of the highway, and as a result the original JCP is now covered with four AC overlays totaling 17.8 cm (7.0 in.) in thickness. Figure 2 shows the typical cross section of the existing pavement structure.

TEST SECTION DESIGN

After examining deflection data, core samples, and the results of a visual condition survey of US 59, a site was selected for constructing the test sections. The site is located just south of FM 357 in the southbound lanes of US 59, at station 1490+00. Six test sections (R1 to R6), each approximately 305 m (1,000 ft) in length, and a control section (R0) were constructed. Figure 3 shows the general cross section for each test section. The following is a brief description of each test section.

R0: Control

Test section R0 is the control section. In this section a standard 3.8-cm (1.5-in.) Type D AC overlay was placed over the existing AC pavement (ACP). The purpose for this section was to allow for comparison between the performances of the six test sections and the conventional rehabilitation technique used by the Texas Department of Transportation.

R1: Full-Depth Repair

In Test Section R1 the existing ACP was milled, exposing the underlying JCP. Extensive repairs were made to the exposed JCP, including replacing failed joints and repairing cracks in the shattered slabs with high-molecular-weight (HMW) monomer. Deflection testing performed before and after the concrete slabs were repaired confirmed that load transfer was restored across the joints and cracks in the JCP slabs. The inside shoulder of the JCP was extended 2.0 m (6.5 ft) with 22.9 cm (9 in.) of portland cement concrete. After all repairs were made and the shoulder was extended, a one-course surface treatment was applied over the first 152.5 m (500 ft) of the 305-m (1,000-ft) test section. A 10.2-cm (4-in.) Type C AC overlay was then placed in two lifts over the entire test section, completing construction of Test Section R1.

R2: Crack and Seat

In Test Section R2 the existing ACP was again milled and removed. The "crack and seat" technique was then performed on

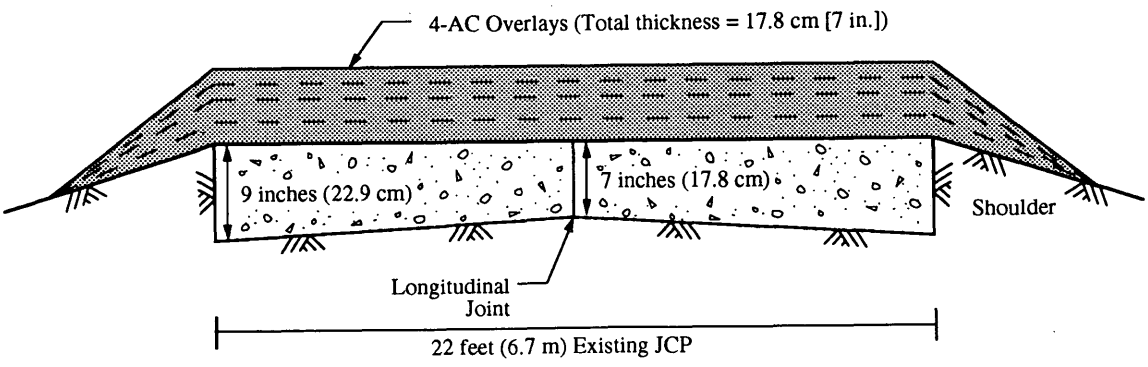

FIGURE 2 Typical cross section of existing 9-7-9 JCP.

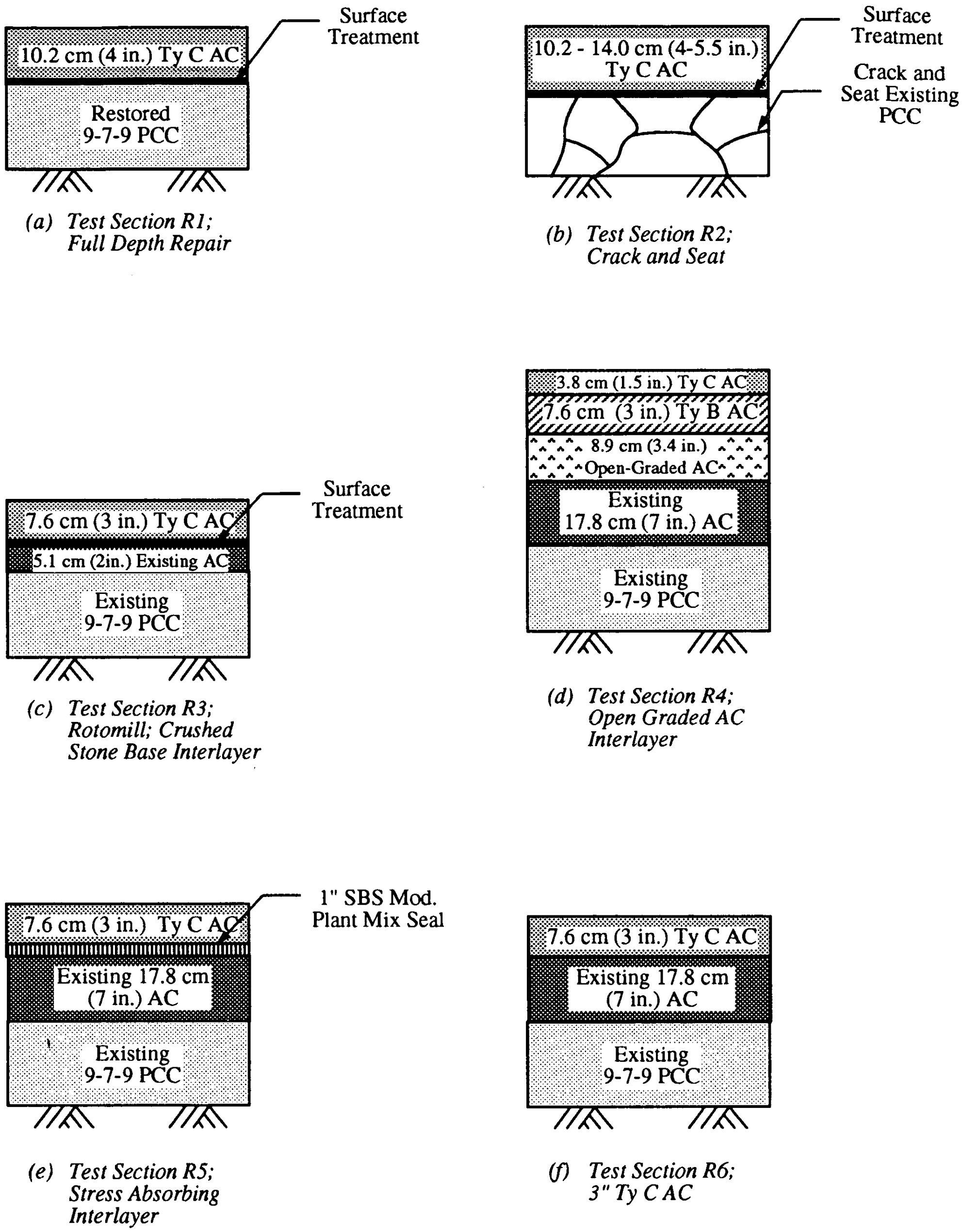

FIGURE 3 **General cross sections of test sections.**

the exposed JCP. A 5880-kg (13,000-lb) drop hammer was used to break the concrete into 61-cm (24-in.) nominal size pieces. The concrete was then ''seated'' with a 50-ton pneumatic-tire roller. After the crack and seat operation was complete, a one-course surface treatment was applied to the entire test section. A 10.2-cm (4.0-in.) Type C AC overlay was then placed on the first half of the test section in two lifts. A 14.0-cm (5.5-in.) Type C AC overlay was then placed on the second half in three lifts, completing construction of Test Section R2.

R3: Crushed Stone Base Interlayer

In Test Section R3, 12.7 cm (5 in.) of the existing 17.8-cm (7-in.)-thick ACP was milled and removed. A 20.3-cm (8-in.) crushed stone base (CSB) interlayer was then placed over the remaining 5.1-cm (2-in.)-thick ACP and compacted. A prime coat and a one-course surface treatment were then applied to the CSB. A 7.6-cm (3.0-in.) Type C AC overlay was then placed over the entire test section in two lifts, completing construction of Test Section R3.

R4: Open Graded AC Interlayer

In Test Section R4 the existing pavement was not disturbed. An 8.9-cm (3.5-in.) Type G AC overlay was placed over the existing surface; this was followed by a 7.6-cm (3.0-in.) Type B AC overlay. This was followed by a 3.8-cm (1.5-in.) Type C AC overlay.

R5: SBS Modified Seal Coat Interlayer

In Test Section R5 a 2.5-cm (1-in.)-thick, styrene-butadiene-styrene (SBS) modified plant mix seal coat interlayer was placed over the existing ACP. A 7.6-cm (3-in.)-thick Type C AC overlay was then placed over the entire section in two lifts, completing construction of Test Section R5.

R6: Type C AC

In Test Section R6 a 7.6-cm (3-in.) Type C AC overlay was placed in two lifts over the existing ACP.

MONITORING PLAN

The monitoring plan for these test sections was broken down into three phases: preconstruction, construction, and postconstruction. The focus of this paper is on postconstruction monitoring. However, the contents of each phase are presented.

Preconstruction Monitoring

Preconstruction monitoring consisted of preparing a historical file on each test section. The file included the results from (a) visual condition surveys, (b) high-definition video recording of the pavement surface, (c) deflection testing, (d) material testing, (e) rut depth measurements, (f) profile measurements, and (g) historical records of traffic. The file contains the historical information necessary to correlate the performance of different test sections with their original distress characteristics.

Construction

Several types of data were collected during construction, including the project engineer's daily progress journal, all relevant mix designs, concrete and asphalt test reports, a visual condition survey of the underlying rigid pavement in those sections where the layer was exposed, both videographs and photographs of the various phases of the project and the machinery used, and environmental data. This data file was also necessary to provide insight into the performance of each test section.

Postconstruction

Immediately after construction and before opening the pavement up to traffic several types of data were collected on each test section. These data included visual condition surveys, deflections, rut depth measurements, and profile measurements. The Automatic Road Analyzer (ARAN) was used to document the road condition, and the profilometer was used to document the profile of the pavement before subjecting it to traffic. Twenty-eight cores were taken immediately after construction to test for density, creep, resilient modulus, tensile strength, and other mix characteristics of the various pavement layers. The cores also allowed further verification of layer thickness.

Long-Term Monitoring

A long-term monitoring plan was established to collect performance data on each test section. The long-term monitoring plan activities include monitoring rut depths, reflective cracking, profile, and in situ material properties. These activities were conducted quarterly for the first 6 months, biannually for the following 18 months, and semiannually thereafter. The frequency and extent of this data collection may be modified as time proceeds. A maintenance cost file will also be maintained for each test section. This information is important for calculating the life cycle costs of each test section.

Weigh-in-Motion Installation

An important part of the postconstruction monitoring plan was the installation of state-of-the-art weigh-in-motion (WIM) equipment in the control section, Test Section R0. This equipment will allow engineers to correlate test section performance with the number of 18-kip ESALs applied to the pavement. The installation of the WIM equipment is documented in a research report (987-2) published by the Center for Transportation Research.

The WIM equipment also provides important information on vehicle classification, traffic counts, axle configurations, axle positions, vehicle speed, and pavement temperature. These data will be very valuable for this research project as well as future research related to vehicle-pavement interaction.

TEST SECTION PERFORMANCE

The test sections have been in place for 2 years. Some interesting results regarding their early-age performances are now available. Pavement distress, including reflective cracking and rutting, are evident, and these are being closely monitored as they occur. Some maintenance activities have also been required. Test Section R5, SBS-modified seal coat interlayer, has already reached functional failure. The following is a detailed description of the key performance characteristics of each test section. That section is followed by a brief description of the initial construction and maintenance costs for each test section.

Roughness Profile

Immediately after construction but before allowing traffic on the test sections, an infrared profilometer was used to measure the profile of each test section in the nondimensional international roughness index (IRI). The profile was measured again after 6, 12, 18, and 24 months of continuous traffic. Figures 4 and 5 show the results of these tests for the inside and outside lanes, respectively.

Although the results of the profile measurements of the inside lane included more variability, the IRI values are still relatively low, ranging from 50 to 90, indicating a relatively smooth pavement with high serviceability [present serviceability index (PSI) > 4.0]. The outside lane has shown a considerable increase in roughness, with IRI values increasing from a range of 60 to 75 to a range of 70 to 140. The averages for both the inside and the outside lanes are presented in Figure 6. The most substantial in-

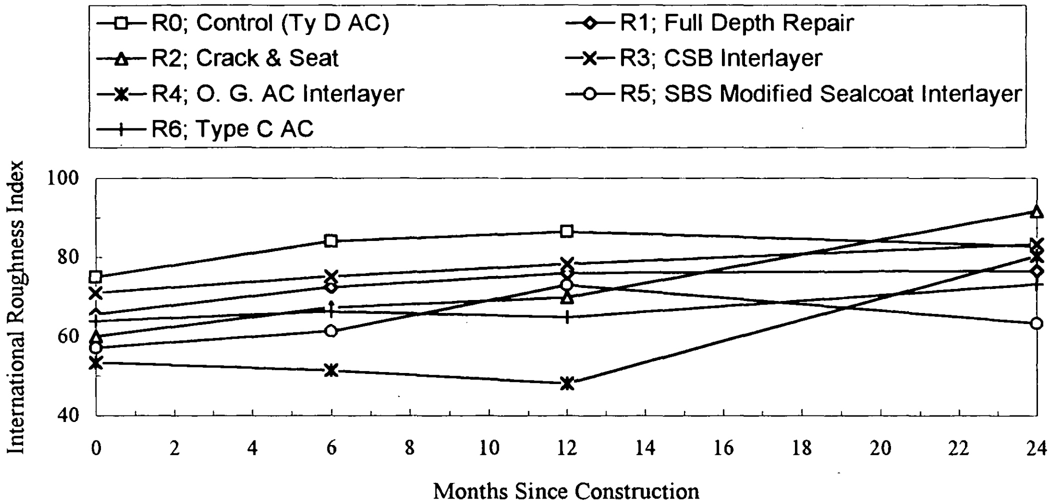

FIGURE 4 International roughness index (inside lane).

creases in roughness have occurred in Test Sections R3 and R4; however, they are still providing good serviceability (PSI > 3.25).

Rutting

In developing the test section designs there was concern that in an attempt to eliminate reflective cracking with various stress relief layers a significant increase in the degree of rutting would result. With the exceptions of Test Section R3, the CSB interlayer, this has not proven to be the case. As shown in Figures 7 and 8 the rut depths have been minimal during the first 18 months of test section performance, ranging from 0.63 to 4.5 mm (0.025 to 0.18 in.). The CSB interlayer test section (Test Section R3) is the exception. Rut depths of 2.5 mm (0.1 in.) were measured in this test section after only 1 month of heavy traffic. These rut depths stabilized during the subsequent 17 months of performance at approximately 4.5 mm (0.17 in.).

Reflective Cracking

Since the primary objective of the present study was to investigate selected strategies for reducing or eliminating reflective cracking, the most important postconstruction data collected have been the periodic condition surveys of reflective cracking. Figure 9 presents the results of surveys collected at 6-month intervals since construction.

Test Section R4, the open graded AC interlayer, and Test Section R3, the CSB interlayer, have shown no reflective cracking. The control section (Test Section R0), crack and seat section (Test Section R3), and the 3-in. Type C AC section (Test Section R6)

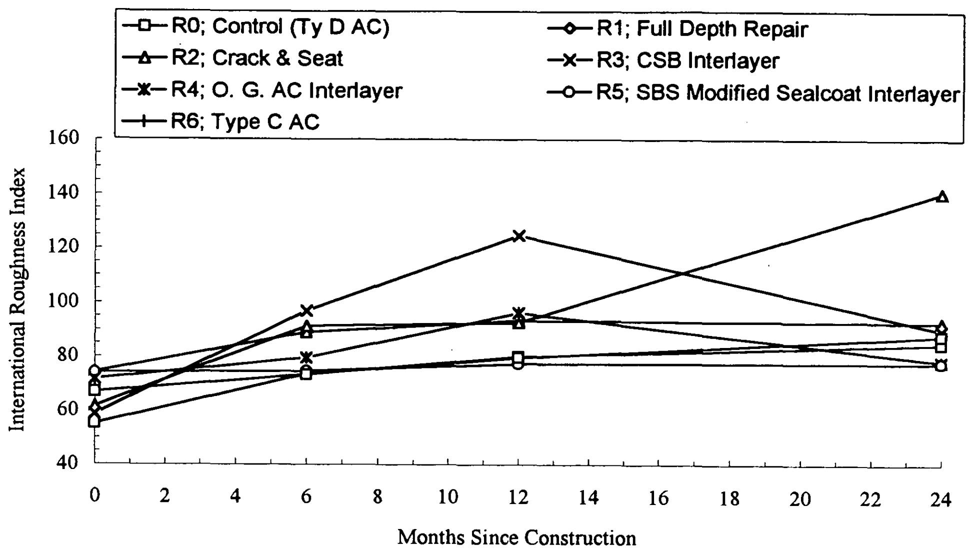

FIGURE 5 International roughness index (outside lane).

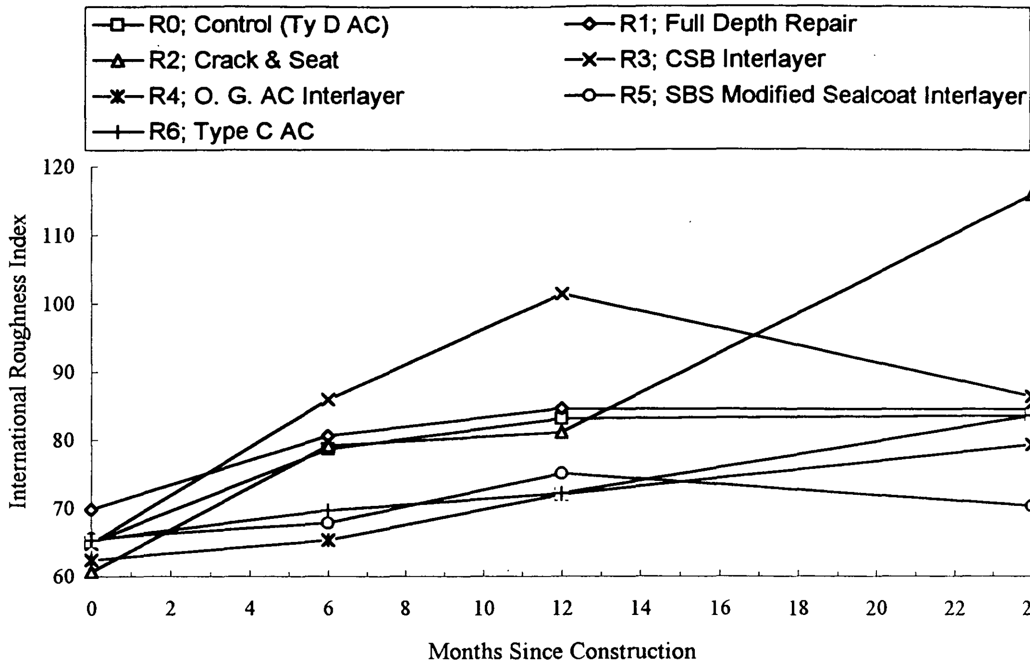

FIGURE 6 International roughness index (average of both lanes).

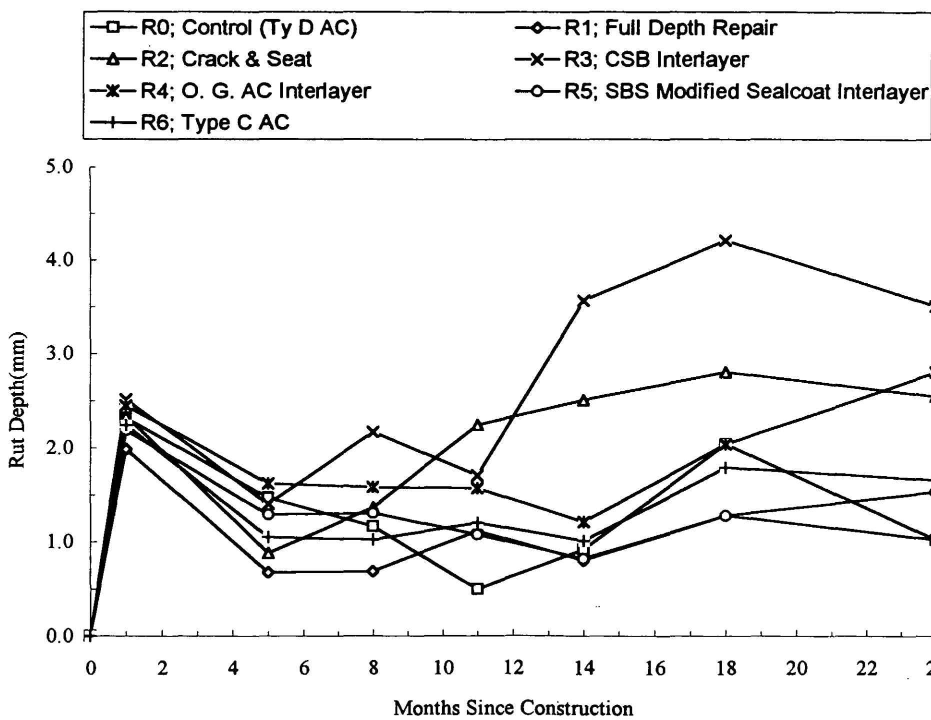

FIGURE 7 Rut depths (inside lane).

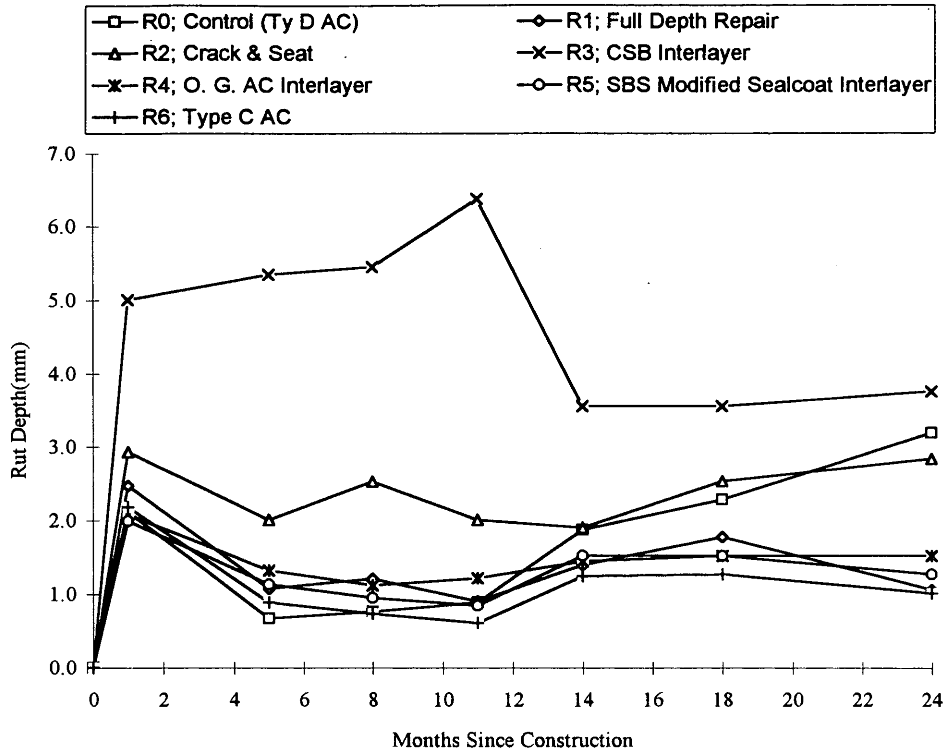

FIGURE 8 Rut depths (outside lane).

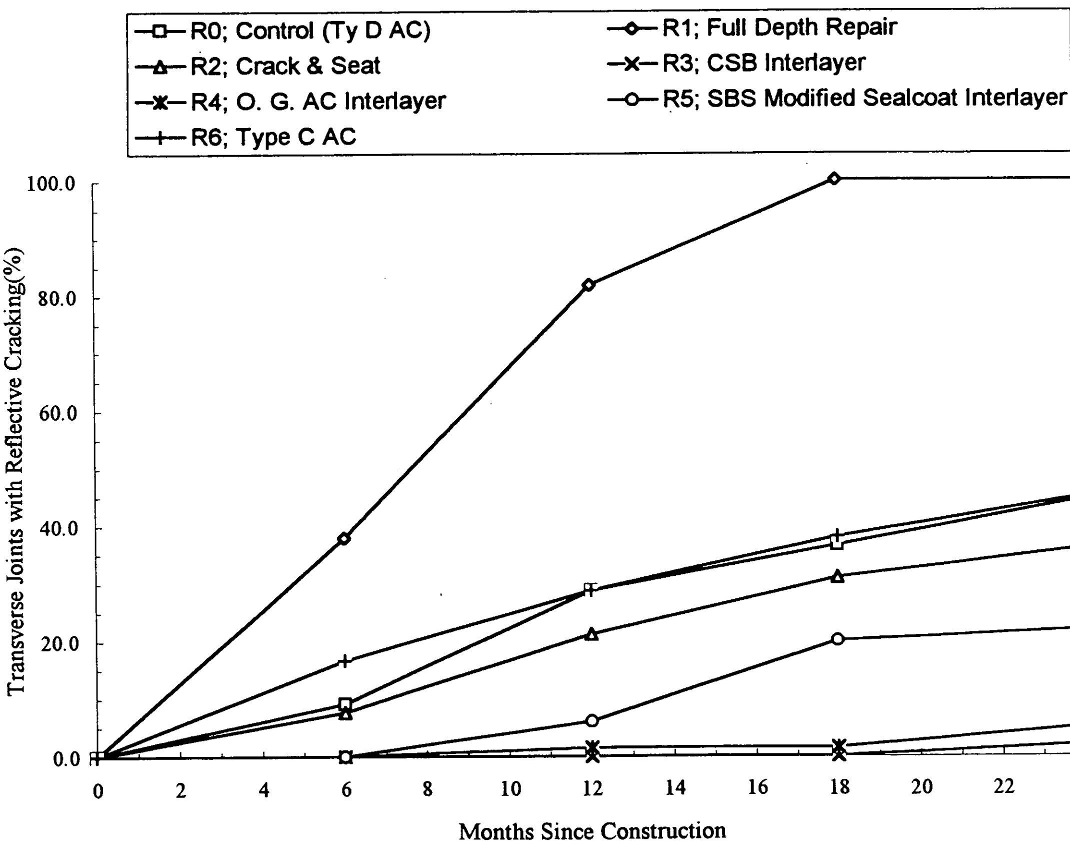

FIGURE 9 Transverse joints showing reflective cracking (percent).

have shown moderate reflective cracking of 20 to 35 percent. The full-depth Repair section (Test Section R1) has shown the most reflective cracking, with 100 percent of the transverse joints reflecting through the Type C AC overlay after 2 years of service. All existing AC was removed on this section prior to placing the AC overlay. This essentially eliminated all stress relief between the existing JCP and the newly placed AC overlay, which has resulted in the extensive reflective cracking.

To date the reflective cracks have not been sealed with hot poured rubber. However, when these cracks are sealed the costs will be documented.

Construction and Maintenance Costs

An important part of the present research effort was to compare test section performance on the basis of life cycle costs. Therefore, a separate cost file has been maintained on each test section. The file includes an estimation of the initial construction costs and all maintenance costs incurred during the life of the test section. Files of each test section can be compared to determine the rehabilitation alternative that provides the lowest life cycle costs. Theoretically, it is the alternative with the lowest life cycle costs that would be adopted by engineers for future rehabilitation efforts on similar pavement sections along US 59.

Since the test sections were relatively short, 305 m (1,000 ft.), only small quantities of certain materials were required to construct the test sections. Because of the relatively small quantities for some bid items, the unit prices bid by the contractor were relatively large. For example, the crack and seat operation for Test Section R3 had a bid quantity of only 275.0 m^2 (330 yd^2) and was bid at $1.20/$m^2$. However, most of this cost was in mobilization. Had bid item quantities typical of a regular paving job been used to bid the project, the price for crack and seat would have ranged from $0.35/$m^2$ to $0.42/$m^2$. Therefore, to compare the construction costs of this test section with those of the others, a value of $0.36/$m^2$ was used for estimating the cost of the crack and seat operation. This type of adjustment was necessary for each of the bid items used to let the job. A similar technique was used for administrative, mobilization, and traffic control, which varied significantly between the test sections. Table 2 gives the estimated construction and maintenance costs for each test section.

As would be expected, the control section (Test Section R0) has the lowest costs to date, at $8.95/$m^2$. The most expensive test section was the section receiving full-depth repair (Test Section R1), with a total cost of $29.69. However, since the SBS-modified seal coat interlayer section (Test Section R5) has already reached functional failure, a significant rehabilitative effort was required. This rehabilitative effort included milling and removing the failed layers and placing an AC overlay. These costs are reflected as maintenance costs in Table 2; however, this action was really a

TABLE 2 Construction and Maintenance Costs for Each Test Section

Work Item	R0	R1	R2A	R2B	R3	R4	R5	R6
Administrative	1.50	2.70	2.70	2.70	1.50	1.50	1.50	1.50
Mobilization	1.50	3.00	3.00	3.00	1.50	1.50	1.50	1.50
Barricades, Signing	0.24	1.68	1.20	1.20	0.24	0.24	0.24	0.24
Traffic Control/Conc. Traffic Barrier	0.60	4.20	4.20	4.20	4.20	0.90	0.60	0.60
Const. Pavement Marking	0.10	0.72	0.78.	0.78	0.10	0.10	0.10	0.10
Remove Pavement Markings		0.20	0.20	0.20				
Construct Detours		0.60	0.60	0.60	0.60			
Plane and Remove Existing Asphalt		1.68	1.68	1.68				
Repair Existing Conc. Paving; Includes HMW Monomer		9.00						
Place Concrete Shoulder		1.56						
Clean and Seal Joints			0.36	0.36				
Crack and Seat Existing Concrete			0.36	0.36				
Grade 3 Aggregate					2.10			
Prime Coat and Surface Treatment			0.24	0.24	0.24	0.24		
Prefabricated Underdrains						0.60		
Underdrain Outfall						0.06		
Tack Coat	0.12	0.12	0.24	0.24		0.12	0.12	0.12
Asphalt Concrete Type C		9.98	9.98	13.73	7.49	3.78	7.56	7.56
Plant Mix Seal Coat- SBS Mod.							3.00	
Asphalt Concrete Type D	4.90							
Asphalt Concrete - Type G						2.64		
Asphalt Concrete - Type B						9.24		
Asphalt Concrete						7.24		
Subtotal; Initial Const. Costs($/$m^2$)	8.95	35.45	25.55	28.93	17.96	28.15	14.62	11.62
Maintenance Costs(PV $/$m^2$)		0.18	1.20	1.20			*12.48	
Total Costs($/$m^2$)	8.95	35.63	26.75	30.13	17.96	28.15	15.10	11.62

* Upon reaching terminal serviceability, this section was milled and overlaid.

full-scale rehabilitation. Nevertheless, this caused the total costs to increase dramatically.

CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the advantages and disadvantages of each rehabilitation technique.

The work done on test Section R1 (full-depth repair), which involved milling and removing the existing asphalt and repairing the original JCP slabs and joints before constructing new overlays, is proving to be one of the more expensive techniques, with essentially no success in reducing reflective cracking. In fact the reflective cracking is most extensive in this test section, with 100 percent of the existing JCP joints producing reflective cracks after 2 years of service. The effort to sawcut and seal the AC overlay directly above the existing JCP joints has also proven to be ineffective in reducing reflective cracking.

Test Section R2 (crack and seat), which involved milling and removing the existing asphalt concrete before performing the crack and seat operation, also had a relatively high initial construction cost. During the first year of service of this section two negative performance characteristics have become evident. First, the crack and seat operation did not fracture the JCP slabs enough to eliminate all reflective cracking. At the end of the first year of service approximately 20 percent of the joints in the JCP have caused reflective cracking in the new asphalt concrete layer. The fractured slabs also do not appear to be providing the necessary structural support to carry the heavy traffic loads on this highway, since pumping of subbase materials has also become evident on this test section.

The early indication is that Test Section R2 (crack and seat) is not providing enough benefit through reduced reflective cracking to offset the substantial cost of detouring traffic on this roadway, milling and removing the existing ACP, and performing the crack and seat technique directly on the existing JCP.

As stated previously the crack and seat operation was performed after all of the existing AC was milled and removed, exposing the original concrete pavement. Future research should be performed to evaluate the benefits of performing the crack and seat operation directly on the AC overlay as opposed to milling and removing the overlay first. A correlation between hammer weight, drop height, and thickness of both the asphalt overlays and JCPs should also be developed. These modified techniques would yield the benefit of crack and seat without the expense of milling and removing the existing ACP.

To date no reflective cracking has occurred on Test Section R3 (CSB interlayer). The primary reason for this is that the CSB interlayer is acting as a sufficient stress relief interlayer. However, this section showed excessive rutting during the first 2 months after construction. Since then the rutting has stabilized. It remains to be seen whether the extra cost of this rehabilitation strategy ($28.93/m^2) will be offset by improved pavement performance.

For test Section R4 (open graded AC interlayer) the rerouting of traffic was required during construction. This significantly increased the cost of constructing this section. However, this section has performed well and no maintenance has been required to date. The IRI values and rut depths have also been well below average. Reflective cracking has not occurred in this section.

Test Section R5 (SBS modified plant mix seal coat interlayer) has performed poorly. This section began exhibiting surface distress after 1 year of traffic. The surface distress consisted primarily of an overall deterioration of the pavement. It appeared to be the combined effect of both stripping and inadequate structural support of the surface layer. This section reached terminal serviceability after only 18 months of service life. It has subsequently required milling and an AC overlay.

Test Section R6 (Type D AC overlay) has the lowest life cycle costs of all the test sections with the exception of the control section. It also has performed relatively well, with no rutting occurring and only a minimal increase in IRI. However, it has shown a moderate amount of reflective cracking, with 35 percent of the existing JCP joints reflecting through the ACP surface.

Significant information and knowledge regarding stress relief interlayers have resulted from the project described here. The test sections will continue to be monitored until they reach minimal serviceability. With the knowledge gained in the study engineers will be better informed when making decisions regarding rehabilitation strategies on pavements with similar distress histories.

REFERENCES

1. *NCHRP Synthesis of Highway Practice 144: Breaking/Cracking and Sealing Concrete Pavements.* TRB, National Research Council, Washington, D.C., March 1989.
2. Lorenz, V. M. New Mexico Study of Interlayers Used in Reflective Crack Control. In *Transportation Research Record 1117,* TRB, National Research Council, Washington, D.C., 1987.
3. *Performance Survey of Crushed Stone Crack Relief Layer.* Arkansas State Highway and Transportation Department, April 1983.
4. The Asphalt Institute. Portland Cement Concrete Rehabilitation Crack Relief Layer Incorporated into Asphalt Concrete Overlay. *ASPHALT Magazine,* Spring 1989.
5. *Proc., Association of Asphalt Paving Technologists,* Vol. 49, 1980.

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