Minimizing Reflective Cracking With Applications of the Rolling Dynamic Deflectometer and Overlay Tester

Dar-Hao Chen,[1] Moon Won, [2] Tom Scullion,[3] and John Bilyeu[4]

ABSTRACT

Since reflective cracking is related to both the existing pavement condition and the properties of the overlay material, quantitative methods are required to assess both the vertical movements of the cracks (or joints) for the entire project and the reflection cracking resistance of the overlay material. Since 2000, the rolling dynamic deflectometer (RDD) has been used in Texas to provide 100 percent coverage of existing joint conditions of concrete pavements being considered for asphalt overlays. The RDD assesses the vertical movements of each joint and identifies the weak support areas and locations where the slabs are rocking. The continuous deflection profiles produced are used to locate areas with high potential for reflective cracking due to poor load transfer and high slab movements. The overlay tester (OT) has been developed as a mix design tool to characterize the ability of an asphalt mix to resist reflective cracking. OT results have not yet been integrated with RDD results to predict the exact extent of reflective cracking that will occur. However, OT results are still good for ranking various mixtures in terms of crack performance, and some guidelines based on OT and RDD results have been developed.

This paper presents a series of case studies illustrating the relationship between the RDD deflection profiles, the OT results of the asphalt mixes, and the resulting field performance. On IH-20 experimental sections in northeast Texas, the RDD identified many locations that have high potential for reflective cracking. The mix used on this project was found to have poor crack resistance and failed the overlay test quickly (2 cycles). Major reflection cracking problems were encountered on this project. At another project, SH-12 in the Beaumont District, no visible cracks have been observed after 2 years of service, despite significant movement detected by RDD. The main reason for the good performance on SH-12 is believed to be due to the thick and flexible overlay mix (the mix lasted more than 900 cycles in the OT). On a section of US-96 in the Beaumont District, the RDD determined that the pavement had good load transfer efficiency across the cracks, and consequently was at low risk of reflection cracking, even though the surface condition was poor, with severe transverse cracks and spalling. A stone matrix asphalt mix with OT life exceeding 700 cycles was placed 5 years ago, and performance to date has been excellent. Based on these case studies, TxDOT has developed criteria for interpreting the RDD deflection data and for defining the required properties of asphalt overlays to provide good performance.

---

[1] Dar-Hao Chen, Ph.D., P.E., Texas Department of Transportation, 4203 Bull Creek #39, Austin, TX 78731; email: dchen@dot.state.tx.us

[2] Moon Won, Ph.D., University of Texas Tech; email: moon.won@ttu.edu

[3] Tom Scullion, P.E., Texas Transportation Institute, 501 CE/TTI Building, Texas A&M University, College Station, TX 77843; email: t-scullion@tamu.edu

[4] John Bilyeu, Texas Department of Transportation, 4203 Bull Creek #39, Austin, TX 78731; email: jbilyeu@dot.state.tx.us

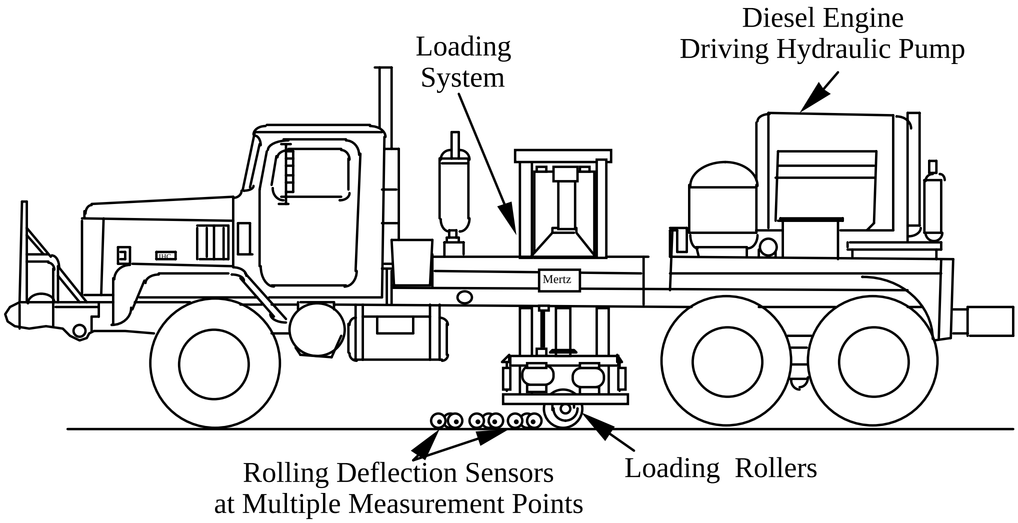
INTRODUCTION

Rehabilitation of aged jointed concrete pavements (JCP) with an asphalt concrete (AC) overlay is problematic, and historically such overlays have been prone to reflective cracking. Although reflective cracking has been studied for a long time, it is still occurring and is responsible for millions of dollars per year in damage. Reflective cracking is defined as the propagation of an existing crack or joint upward to the new pavement surface. Reflective cracking is one of the most common causes of deterioration in overlay systems (Al-Qadi and Baek 2006). The main mechanisms leading to the development of reflective cracking are the differential vertical movements between concrete slabs and the brittleness of the overlay mix, which lacks the ability to resist the differential vertical movements. To minimize the potential for reflective cracking and maximize the success of a JCP overlay project, knowledge of the existing pavement condition and overlay material is vital. Thus, engineers need tools to quantify the severity of the cracks (or joints) to determine the potential for reflective cracking and to measure the resistance of the overlay material to underlying crack or joint movements.

Continuous deflection measurement provides valuable information for determining joint and crack conditions of an existing roadway. Research results (Scullion 2005; Chen et al. 2007; Chen 2008) have clearly demonstrated the capabilities and benefits of the rolling dynamic deflectometer (RDD) in providing continuous deflection data over entire projects. Figure 1 shows a schematic view of the RDD and sensor arrangement.

The RDD is the only operational project-level rolling deflection device in the world that is able to identify problematic areas and to provide joint and crack conditions for rehab strategy optimization. Continuous deflection profiles provide 100 percent coverage and permit pavement engineers to evaluate the entire project, locating sections where more extensive repairs are needed. Chen (2008) and Chen et al. (2007) have used the RDD to locate joints and active cracks with poor load transfer that need to be repaired before overlaying. The RDD typically runs about 1 to 2 mi/h (1.6 to 3.2 km/h), depending on the surface texture and noise transmitted to the rolling sensors. Even at this rate of collection, the RDD is far more efficient at collecting data on all of the cracks and joints than a falling-weight deflectometer (FWD) would be. The FWD machinery has a much lower overhead than the RDD and is better for collecting data at discrete points, typically 0.1 mi (0.16 km) apart. But the FWD would be much slower at collecting data comparable to RDD data, because it would have to stop for about 1 minute every 5 to 15 ft (1.5 to 4.6 m). The FWD has been used on a few of the same projects as the RDD, and the deflections are comparable when normalized to equivalent loads.

The overlay tester (OT) has been applied with success to characterize asphalt mixes' ability to resist reflective and fatigue cracking (Zhou and Scullion 2005; Zhou et al. 2007). Based on extensive laboratory and field performance observation, Zhou and Scullion (2005) found that the OT results matched very well with field cracking. When an asphalt mix lasts more than 700 cycles in the OT, it is thought to have good fatigue resistance (Zhou et al. 2007). Figure 2 shows a comparison of ability to resist reflective cracking for materials A and B after 2 years of tracking. While materials A and B were placed at the same time above the same JCP pavement structure, material A (with OT life exceeding 700 cycles) does not have reflective cracks. There are reflective cracks in the lane with material B because the mix is brittle. The OT life of material B was only 20 cycles. This example clearly demonstrates the importance of mix properties in preventing reflective cracks.



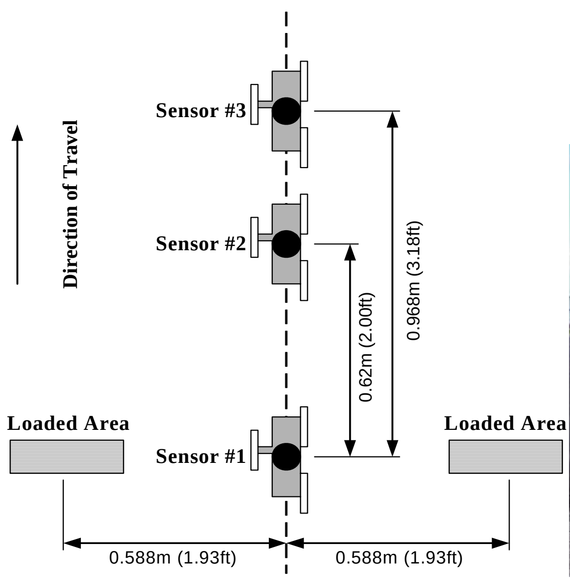
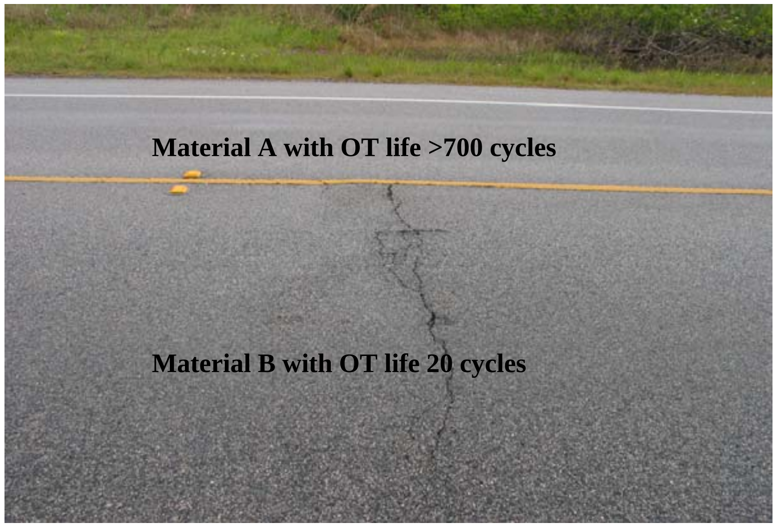


Figure 1. Schematic and general rolling dynamic deflectometer arrangement with typical rolling sensor configuration.



OT = overlay tester

Figure 2. Comparison of ability to resist reflective cracking for materials A and B after 2 years of traffic.

Finding the areas that exhibit poor load transfer and significant slab movement (areas of high potential for reflective cracking) is critical for rehabilitating concrete pavements. Otherwise, reflective cracking and localized failures occur within months of rehabilitation (Amini 2005). The relationships between the RDD, OT, and field performance data from condition surveys are critical for optimum rehabilitation strategy selection. RDD deflection thresholds for identifying areas of high risk of reflective cracking can be established, validated, and improved empirically through field performance monitoring. Also, the ability of different mixtures to resist reflective cracking can be quantified and evaluated under various moving-slab conditions. An increasing number of rehabilitation projects in Texas have been completed using data from both the RDD and OT. The field performance results to date have been very promising. In this study, three highway sections (IH-20, SH-12, US-96,) are presented to demonstrate the benefits of utilizing the RDD and OT for minimizing the reflective cracks.

CASE STUDIES

Interstate Highway 20

The potential of utilizing the RDD for concrete pavement rehabilitation was first realized in Texas in early 2000. The RDD was employed to provide recommendations on the location of repairs needed prior to an intended 4-in. (102-mm) overlay. RDD results indicated that hundreds of locations had significant vertical movements, and needed repairs before the AC overlay. However, due to funding limitations, only 10 locations were repaired before the 4-in. (102-mm) AC overlay was placed. After less than 1 month's trafficking, many locations had reflected cracks. After a couple years of trafficking, many patches had to be done to maintain the ride quality because of the severe reflection cracks. Efforts were made in this study to monitor and correlate the crack locations to the RDD results. The monitoring results show a very strong correlation between reflective cracks and patch locations and the high vertical movements measured by the RDD.

IH-20 is one of the busiest interstate highways in Texas. The estimated 20-year design traffic for this pavement is 87.2 million equivalent single-axle loads (based on 2004 traffic data). After years of heavy traffic, this section of highway needed to be rehabilitated. The main reason for the rehabilitation on IH-20 was the severe transverse cracking that caused poor ride quality. The original typical section consisted of 4 in. (102 mm) of AC overlay; 8 in. (203 mm) of continuously reinforced concrete pavement (CRCP); 7 in. (178 mm) of cement-treated base (CTB); 6 in. (152 mm) of CTB subbase; and 6 in. (152 mm) of select material. Although it is a CRCP, the pavement acts like a JCP in many places because the steel reinforcement was ruptured (as was evident during the slab repair). Note that before the rehabilitation, there were already many locations with full-depth repairs intended to maintain structural integrity. The rehabilitation scheme was to first mill off the 4-in. (102-mm) surface AC overlay, then do full-depth repairs to the CRCP at selected locations, followed by placing a new 4-in. (102-mm) AC overlay. The rehabilitation was completed in November 2002.

With reference to the RDD deflection sensors shown in Figure 1, research results (Chen et al. 2007; Chen 2008) have demonstrated that *W1−W3* is a good indicator for reflective cracking potential, especially in areas where *W1−W3* exceeds 6.5 mils on an AC surface without milling. *W1−W3* is usually at a maximum when sensors 1 and 3 are on either side of a joint. A higher *W−W3* value is interpreted as a poorer load transfer across a joint or crack. *W1−W3* deflections for IH-20 (eastbound lane, before milling) are presented in Figure 3. The unit used on the Y-axis (and hereafter) is mils/10 kips, which represents the measured deflection in mils under 10 kips of peak dynamic force. As shown in Figure 3, numerous locations have significant spikes where the *W1−W3* deflection exceeds 6.5 mils. These spikes indicate locations with poor load transfer or significant relative vertical movements.

Figure 4 illustrates the pavement condition before milling, after milling, and 1 year after the 100-mm AC overlay. Even though there were significant vertical movements, no full-depth repairs were performed at this location, and cracks reflected through within 1 year. In fact, numerous reflective cracks were observed on IH-20 after only a few days. The lab results on the cores taken from IH-20 indicated that the 100-mm AC overlay was stiff and rut resistant, but had relatively poor crack resistance. Under the Hamburg Wheel test, the AC overlay had rutting of less than 12.5 mm after 20,000 cycles at 50C. The AC cores were tested with the OT, and it only took 2 cycles to fail the specimens. This means the AC overlay is very brittle and prone to crack. After traffic resumed, numerous locations like those shown in Figure 4 were observed, and many patches had to be placed in 25 months or less. The distress condition survey indicated that there were 90 locations (63 reflected cracks plus 27 patches) with distress after 25 months.

The conclusions from the IH-20 projects are as follows: (1) many areas with very poor load transfer and significant slab movements were not repaired before placing the 4-in. (102-mm) overlay; (2) a brittle mix with an OT result of 2 cycles was placed on a pavement with high potential for reflective cracking; (3) these factors led to very early and severe reflective cracks.

Two more projects were monitored to evaluate the proposed criteria for the RDD deflections and OT results. The tentative threshold values beyond which performance problems are anticipated are *W1−W3* deflections of 5.5 on exposed concrete surface or 6.5 mils on an asphalt surface with underlying concrete pavement; and, to minimize reflection cracking potential, the proposed overlay should last longer than 700 cycles in the OT.

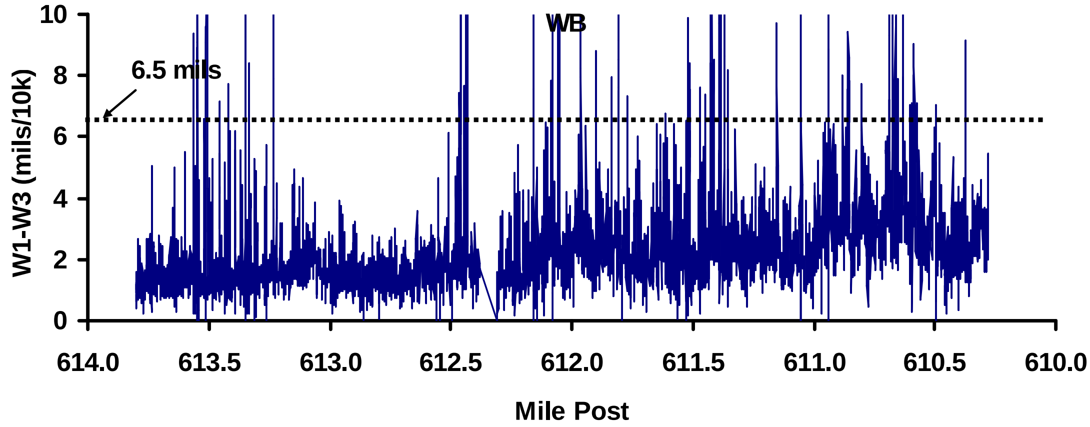


Figure 3. *W1−W3* continuous deflections before milling for IH-20. Spikes indicate poor load transfer or significant vertical movements that indicate a high potential for reflective cracking.

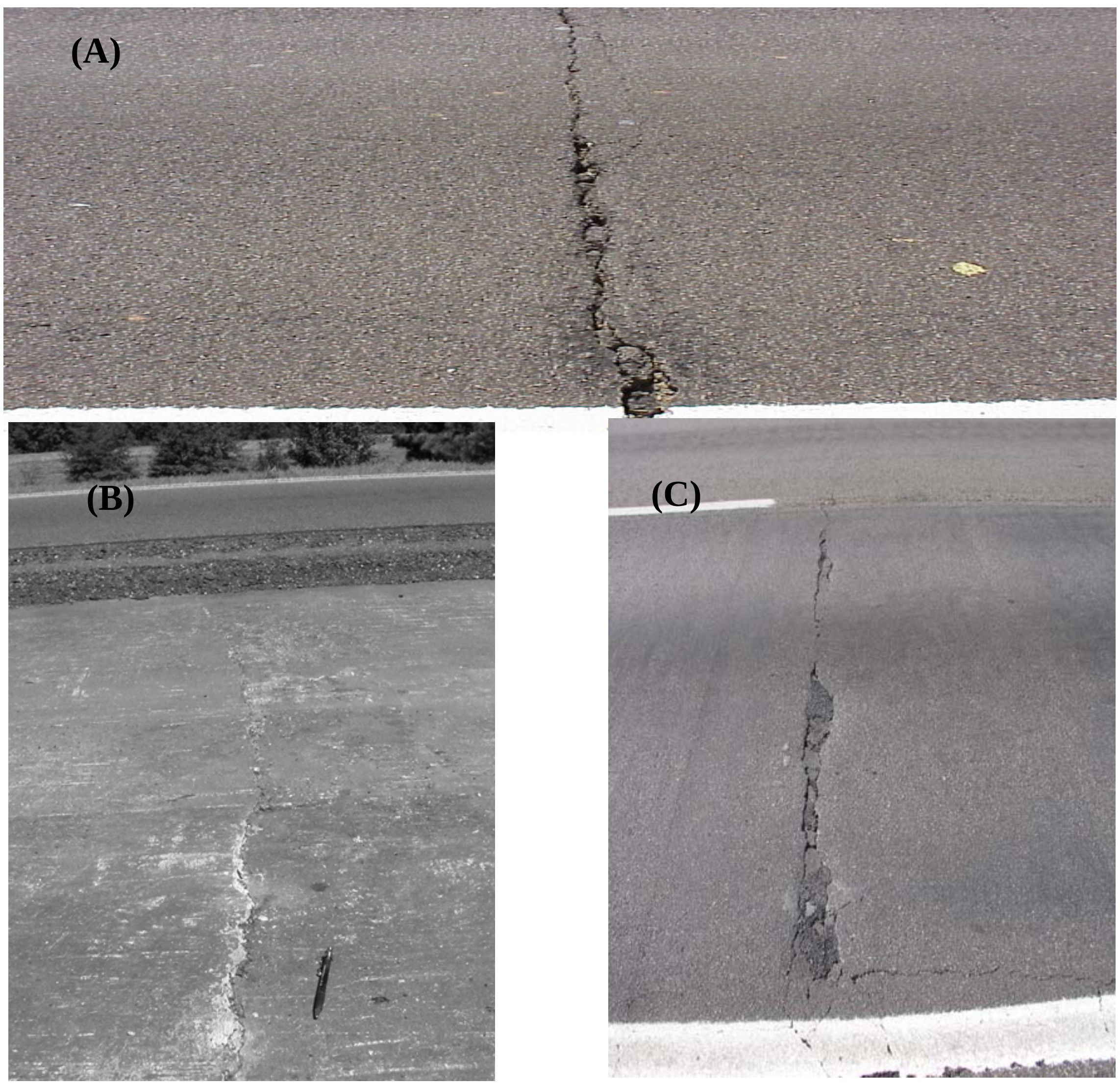
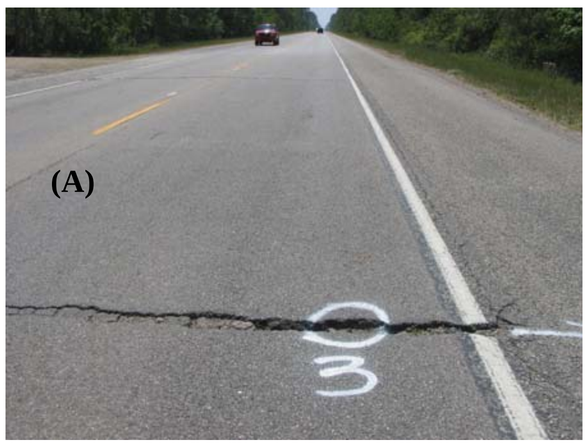
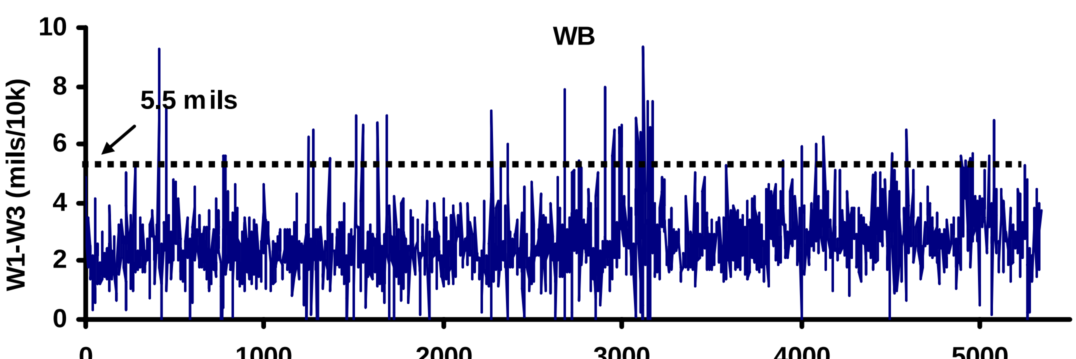


Figure 4. Pavement conditions along IH-20 (A) before milling, (B) after milling and before overlay, and (C) with reflected cracks 1 year after overlay.

State Highway 12

The SH-12 project demonstrates a successful application of the RDD and OT to minimize the reflective cracks on a JCP that had poor load transfer and significant slab movements. The construction records indicated that the last rehabilitation (an overlay of 3 in. [76 mm] of AC) was completed in 2001. However, the AC was unable to resist the reflective cracking, as shown in Figure 5A. Due to the cracking and poor ride quality, SH-12 needed to be rehabilitated in 2006. The 2006 rehabilitation consisted of milling the existing AC overlay; repairing the JCP; and overlaying it with a 1-in. (25-mm) rich bottom layer (RBL) AC, 2 in. (51 mm) of Type D AC, and 1.5 in. (38 mm) of porous friction course (PFC) wearing surface. RBL has been tested with the OT and has a life exceeding 900 cycles, when the test was terminated. The RBL was placed in June 2006. The typical features of RBL are fine gradation, use of high quality aggregates, and high binder content. Typically the binder content for RBL ranges from 6 percent to 8.5 percent. The RBLs in Texas are designed to pass both the prevailing Hamburg wheel tracking test (for rutting and moisture susceptibility) and the OT for crack resistance. Efforts have been made to monitor the section and track the long-term performance.





(B)

Figure 5. Pavement conditions and rolling dynamic deflectometer (RDD) measurements on SH-12: (A) pavement conditions before milling; (B) RDD continuous profiles after milling.

A typical continuous deflection profile collected on SH-12 is shown in Figure 5. RDD tests were performed on the milled JCP surface. Research results (Chen et al. 2007; Chen 2008) indicated that exposed concrete surfaces with a *W1–W3* deflection exceeding 5.5 mils indicates a high potential for reflective cracking.

The average IRI before the 2006 rehabilitation was approximately 110 in/mi (1,760 mm/km). The 2006 rehabilitation effectively reduced the IRI to approximately 52 in/mi (832 mm/km). The IRI has remained at approximately 60 in/mi (960 mm/km) for the last 2 years. A condition survey conducted in January 2009 indicated no visible reflective cracks. This demonstrates that even with significant slab movements, the treatment of 1-in. (25-mm) RBL AC, 2-in. (51 mm) Type D AC, and 1.5-in. (38 mm) PFC was able to deter the reflective cracking. The main reasons for good performance on SH-12 are the flexible RBL mix, thicker overlay (4.5 in. [114 mm]), and the porous wearing surface mix with a high air void of approximately 20 percent. Continuous monitoring of the section will be conducted to determine when the reflective cracks appear.

U.S. Highway 96

A 40-year-old CRCP on US-96 was being considered for major rehabilitation for the first time. Extensive spalling of the original CRCP near the transverse cracks was evident. The spalling was found to be limited to the top 50 mm. The pavement consists of 8 in. (203 mm) of CRCP and 4 in. (102 mm) of CTB. The roadway condition before rehabilitation is shown in Figure 6A. A candidate rehabilitation strategy proposed by the District consisted of placing an SMA overlay, 3 in. (76 mm) thick. The main concern with the placement of the overlay was the potential for reflective cracking. Since the reflective cracking is highly related to movement of the slabs at the cracks, the District requested an RDD survey to assess the support under the slabs at the cracks, as shown in Figure 6B. The continuous deflection profile collected by the RDD at this site is shown in Figure 6C. In view of Figure 6C, it was found that no cracks had *W1–W3* deflection exceeding 5.5 mils, indicating good load transfer and little reflective cracking potential.

The District placed the SMA overlay approximately 5 years ago, and the performance so far has been excellent with no visible cracks. SMA cores were taken and tests were conducted by the OT. The specimens yielded more than 700 cycles to failure, as the OT was terminated at 700 cycles and no crack was observed at that time.

It was believed that the success of the project on US-96 is due to the combination of the low potential of the CRCP slab for reflective cracking, as determined by the RDD, and the excellent properties of the SMA overlay for resisting reflective cracking, as determined by the OT.

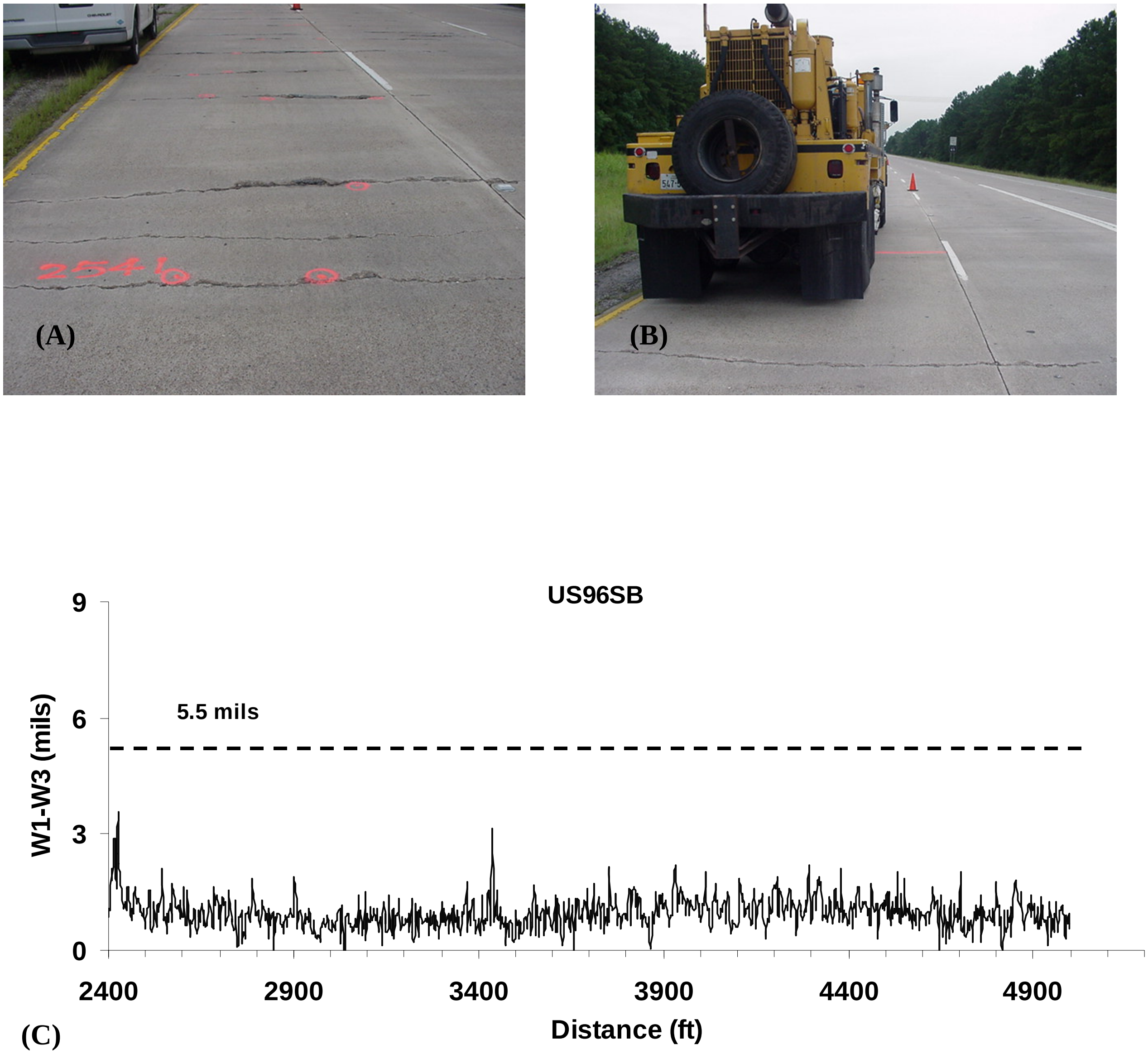


Figure 6. (A) Pavement condition of US-96 before rehabilitation with severe cracking and spalling; (B) rolling dynamic deflectometer testing (RDD); (C) RDD continuous deflection profile (on top of exposed concrete surface) for southbound direction.

CONCLUSIONS

The combination of the RDD and the OT was used on three concrete pavement rehabilitation projects in Texas. The RDD was used to rate the suitability of each project for an asphalt overlay, based on joint movement. The OT was applied to characterize each mix's ability to resist reflective cracking. The threshold values (a) $W1-W3$ = 6.5 mils for a composite pavement with an old AC overlay, (b) $W1-W3$ = 5.5 mils for exposed concrete pavements, and (c) 700 cycles from the OT were employed to evaluate three field rehabilitation projects (IH-20, SH-12, US-96). Conclusions and observations are given as follows:

1. On IH- 20 there were many locations that had $W1-W3$ deflections exceeding 6.5 mils. After 25 months of field monitoring, there were 63 reflected cracks (many severe) and 27 patches. The RDD data collected prior to the overlay identified the areas of high reflective cracking potential. The mix used on IH-20 was very brittle, as core samples failed in 2 cycles when they were tested by the OT. Brittle mix on pavement with high reflective cracking potential leads to premature failure. This demonstrates the ability of the RDD and OT to characterize the existing pavement condition and the overlay materials.

2. No visible cracks have been observed on the SH-12 project after 2 years of service, despite the significant movement ($W1-W3$ deflection > 5.5 mils) detected by the RDD. The main reasons for the good performance on SH-12 are the flexible RBL mix, the thicker overlay (4.5 in. [115 mm]), and the porous wearing surface mix with a high air void of approximately 20 percent.

3. Although there were severe transverse cracks and spalling on US-96, all $W1-W3$ deflections were less than 5.5 mils (at low risk for reflective cracking). SMA was placed 5 years ago, and the performance is excellent. SMA was tested with the OT, and its life exceeded 700 cycles. It was believed that the success of the US-96 project due to the combination of the CRCP's low potential for reflective cracking and the SMA's excellent properties for resisting reflective cracks.

4. Through case studies, the combination of RDD and OT testing, and the use of three threshold values show excellent potential to address problem of reflective cracking.

The RDD is now being widely used on most concrete pavement rehabilitation projects in Texas. The data are used by designers to identify entire problem areas where corrective action is needed before placement of the overlay. In other projects, localized problems (loose joints) have been identified and rehabilitated with retrofitted dowels before the overlay. In another recently completed project, the RDD data is one input into a new TxDOT overlay design program that is currently under evaluation (Zhou 2008). The overlay tester is now a standard test in Texas (Tex Method 248E), and the overlay tester criteria have now been incorporated into standard mix design specifications (CAM SS 3155, 2008).

REFERENCES

Al-Qadi, I. L., and J. Baek. 2006. "FE Modeling of Reflective Cracking Initiation and Propagation: Investigation of the Effect of Steel Reinforcement Interlayer on Retarding Reflective Cracking in HMA Overlay." Transportation Research Board Annual Meeting, Paper #06-3003.

Amini, F. 2005. "Potential Applications of Paving Fabrics to Reduce Reflective Cracking" (FHWA/MS-DOT-RD-05-174). Mississippi Department of Transportation, Jefferson City.

Chen, Dar-Hao, F. Zhou, K. Stokoe, J. Lee, J. Bilyeu, and S. Hu. 2007. "Threshold Values for Reflective Cracking Based on Continuous Deflection Measurements," *Canadian Journal of Civil Engineering*, *34*(10), pp.1257–1266.

Chen, Dar-Hao. 2008. "Field Experiences With the RDD and Overlay Tester for Concrete Pavement Rehabilitation," *Journal of Transportation Engineering*, *134*(1), pp. 22–33.

Scullion, T. 2005. "Using Rolling Dynamic Deflectometer and Ground Penetration Radar Technologies for Full Coverage Testing of Jointed Concrete Pavements" (Research Report 4517-2). Texas Transportation Institute, College Station.

TxDOT. 2004. "Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridge." Texas Department of Transportation, Austin.

Zhou, F., and T. Scullion. 2005. *Overlay Tester: A Rapid Performance Related Crack Resistance Test* (FHWA/TX-05/0-4467-2). Texas Transportation Institute, College Station, p. 85.

Zhou, F., S. Hu, T. Scullion, Dar-Hao Chen, and X. Qi. 2007. " Development and Verification of the Overlay Tester Based Fatigue Cracking Prediction Approach." *Journal of the Association of Asphalt Paving Technologists*, *75*, pp. 524–577.

Zhou, F., S. Hu, T. Scullion, and X. Hu. 2008. "Development of an Advanced Overlay Design System Incorporating Both Rutting and Reflection Cracking Requirements" (Research Report 5123-3). Texas Transportation Institute, College Station.

ACKNOWLEDGMENTS

The support and assistance provided by Dr. Fujie Zhou, Mr. Miles Garrison, Ms. Susan Chu, Dr. Jeffrey Lee, and Dr. Kenneth Stokoe are much appreciated.