Performance of Bonded CRCP Overlay in Texas

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Abstract

As of 2012, there are 17,336 lane miles of Portland cement concrete (PCC) pavement managed by the Texas Department of Transportation (TxDOT), out of a total 196, 821 lane miles in Texas. Many miles of PCC pavement have approached or exceeded their design lives and need rehabilitation. PCC pavements that need rehabilitation now or in the near future were built thinner than today's standard and are accordingly structurally deficient. Bonded concrete overlay (BCO) provides an optimal rehabilitation option for pavements that are structurally deficient. Over the years, BCO has been utilized in Texas to strengthen existing continuously reinforced concrete pavement (CRCP), with overlay thickness from 2 inches to 8 inches. In general, the performance has been satisfactory; however, in several projects, distresses occurred at early ages and forensic evaluations were conducted, which included continuous deflection testing using rolling dynamic deflection (RDD) and total pavement acceptance device (TPAD), deflection testing using Falling Weight Deflectometer (FWD), and other testing including bond strength testing. The findings include (1) BCO performance depends, to a large extent, on the structural condition of the existing CRCP as indicated by slab deflections evaluated by FWD or TPAD, (2) adequate amount of longitudinal steel reinforcement in BCO layer significantly improves CRCP BCO performance, (3) coarse aggregate type in BCO concrete has a significant effect on BCO performance, and (4) discontinuities in existing pavement, such as joints at bridge approach slabs, were problem areas with distresses in BCO. To ensure good performance of CRCP BCO on PCC pavement, it is recommended that (1) the entire project be evaluated with deflection testing device to identify areas with deflections more than 8 mils at 9,000 lbs for strengthening by removal of existing concrete and base layers and replacement with new concrete, (2) deflection threshold values be developed for CRCP BCO on jointed concrete pavement, and (3) longitudinal steel be provided in BCO.

Introduction

There are many miles of Portland cement concrete (PCC) pavements in Texas that have provided satisfactory performance for much longer than their original design lives. Some of them are still in good structural and functional condition, even though they were under-designed for the traffic they have served. These under-designed pavements still present valuable assets to the Texas Department of Transportation (TxDOT), and with adequate rehabilitation, these pavements will provide good performance for many years to come. Bonded concrete overlays (BCO) could provide cost-effective rehabilitation methods for structurally deficient PCC pavements. Over the years, TxDOT built a number of BCO projects and their performance varied, from poor to excellent.

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The variations in the performance could be due to inadequate design or construction including material selection. Currently, there are two BCO design procedures available – one is in the 1993 AASHTO Pavement Design Guide (referred to as AASHTO method in this manuscript) and the other by Portland Cement Association (PCA) (AASHTO 1993, Portland Cement Association, 1984). These two design methods are based on quite different principles. AASHTO method is largely based on empirical principles while PCA method is purely mechanistic. A challenge in BCO design is how to determine the "effective" thickness of the existing pavement. In the AASHTO method, two approaches are taken for the evaluation of the structural capacity of the existing pavement. One is from visual observation of the pavement condition in terms of number of distresses, and the other on the remaining fatigue life of the concrete pavement. Fatigue life approach is not applicable in most of the old PCC pavements in Texas, since the actual loading applications in old PCC pavements, in general, have been more than original design traffic. If this approach is adopted, the remaining life would be negative, and the AASHTO method cannot work. Accordingly, if the AASHTO method is used for BCO design, visual observation method should be used. On the other hand, in PCA method, the effective thickness of the existing pavement is not directly evaluated. Instead, the ratios of wheel load stress at the edge condition to strength at the bottom of the hypothetical new pavement and BCO are compared, and the slab thickness of BCO is determined so that the ratio in the BCO is less than or equal to that in the hypothetical full-depth new pavement. In Texas, most of the PCC pavement have tied concrete shoulder, and the critical stress will be in the interior condition; accordingly, PCA method is not applicable. Accordingly, visual observation of the pavement condition is the only method applicable for the evaluation of the effective slab thickness of the existing pavement. However, this method is more applicable to plain jointed pavements (JCP)—or CPCD (Concrete Pavement Contraction Design) as it is called in Texas, than to continuously reinforced concrete pavement (CRCP). It is primarily because the way the AASHTO method was developed. According to the AASHTO method, the difference between the effective slab thickness of the existing pavement and actual slab thickness is quite small, resulting in quite small slab thickness for BCO, quite often not more than 4 inches. If the slab thickness is less than 4 inches, it is difficult to build CRCP, since placing longitudinal steel with adequate concrete cover will be a challenge. Because of the limitations in the BCO design procedures applicable to Texas condition, most of the BCO designs in Texas were developed based on engineering judgement.

In this paper, three BCO projects that have significance in terms of performance and technical development are presented. They are 4-in BCO on Loop 610 North in the Houston District, 7-in CRCP BCO on US 75 in the Paris District, and 4-in CRCP BCO on US 287 in the Wichita Falls District.

(1) BCO projects on Loop 610 North in the Houston District

This BCO project is located on IH 610 North between East T. C. Jester Blvd and IH 45 in Houston. This is an eight-lane highway, with four lanes in each direction. The original mainlane pavement structure consisted of 8-inch CRCP over 1-inch asphalt stabilized base (ASB) and 6-inch cement stabilized subbase (CSB). The top 6 inches of subgrade was treated with lime. The median and outside shoulders consisted of asphalt concrete pavement on cement stabilized base. The original pavement was built in 1960. Four-inch BCO was placed in January, 1986 as a part of a research project, whose objective was to develop optimum BCO system. The variables included in the study were reinforcement type (fiber vs welded wire fabric (WWF)) and coarse aggregate type (crushed limestone (LS) vs siliceous river gravel (SRG)). Another variable included was the condition of the existing pavement. The condition of the existing pavement was based on the number of punchouts and patches, as well as percent spalling. Slab thickness of the overlay was not a design variable, as all the sections were 4-in thick. A total 10 sections were developed and placed as an experiment as shown in Table 1. Each test section was about 600-ft long.

Table 1 Factorial Design of Test Sections

Test Section No.	Aggregate	Reinforcement	Distress Level
1	SRG	WWF	Moderate
2	SRG	WWF	No Distress
3	SRG	WWF	Moderate
4	SRG	Fiber	Severe
5	SRG	Fiber	Severe
6	SRG	WWF	Severe
7	LS	WWF	Severe
8	LS	WWF	No Distress
9	SRG	WWF	Severe
10	SRG	WWF	No Distress

The structural condition of the pavement was evaluated by deflection measurements with a Dynaflect. Deflection testing was conducted before and after BCO. Figure 1 shows the testing results, which indicates 4-in BCO reduced deflections by about 40 percent. This information illustrates the capability of BCO in enhancing the structural capacity of the under-designed PCC pavement.

Figure 2(a) shows the condition of the pavement in Section 1, which shows quite tight transverse crack. As indicated in Table 1, WWF was used in this Section with SRG as coarse aggregate. Figure 2(b) illustrates severe spalling in Section 4, where fiber and SRG were used. It shows that fiber was not able to prevent severe spalling. Figure 2(c) shows excellent condition of BCO in Section 7, where WWF and LS were used. Both Sections 4 and 7 were in “severe” distress level prior to BCO; however, the selection of materials – as a reinforcement and coarse aggregate in concrete – appears to have substantial effects on BCO performance. Figure 2(d) shows a typical condition of Section 9. The combination of SRG and WWF provided excellent performance even when the existing condition was in “severe” distress level.

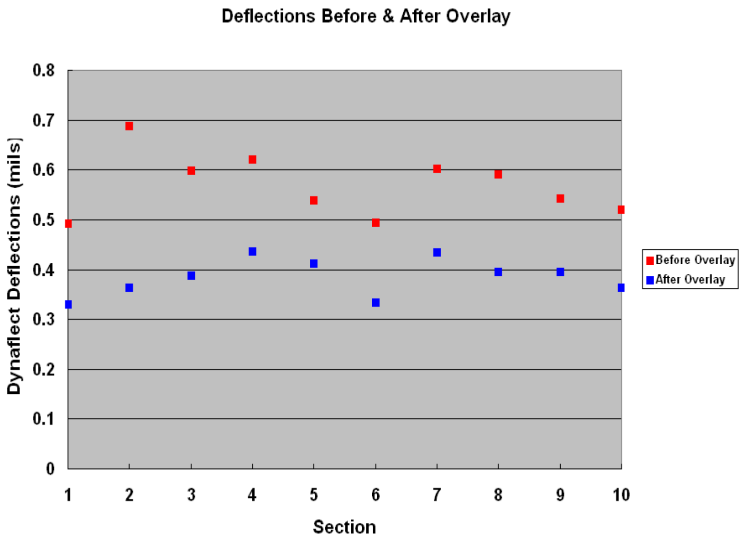

Figure 1 Deflections before and after overlay

Figure 2(a) Tight transverse crack, Section 1

Figure 2(b) Severe spalling, Section 4

Figure 2(c) Tight transverse crack, Section 7

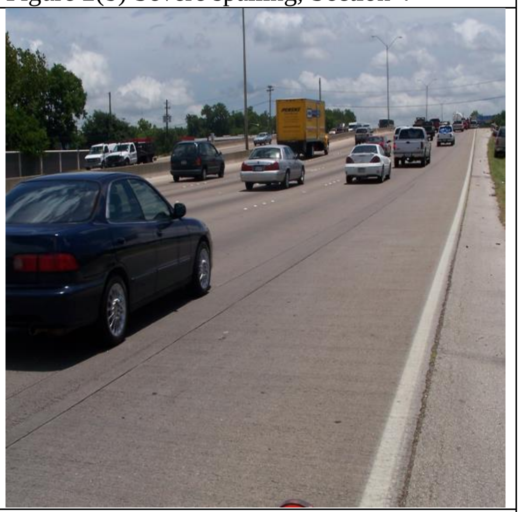

Figure 2(d) Condition of BCO, Section 9

Overall, the performance of this section has been excellent, with very few distresses observed after more than 20 years of service. The section was removed in 2012, after more than 26 years of service. It was not due to the poor performance of the BCO; rather, the whole section was removed and replaced as a part of the reconstruction of Loop 610. The condition of the pavement at the time of removal was still quite good.

(2) BCO projects on US 75 in the Paris District

The 10-in JCP (CPCD) section on US 75 in the Paris District was completed in 1984. The pavement has 15-ft joint spacing with dowels at transverse contraction joints on a 6-in flexible base and lime treated subgrade. Originally, shoulders were 1-in AC layer on 8-in flexible base. In 1998, tied concrete shoulders were retrofitted with 10-in JCP with matching 15-ft joint spacing on a 6-in flexible base. When the pavement design was developed in the early 1980s for this section, the average daily traffic (ADT) was 11,000 and 20-year projected ADT (in 2004) was 16,200. The pavement was designed with 20-year design life and the above projected traffic. Actual ADT in 2010 was 51,000, which is more than 3-fold the projected design traffic for 2004. Since 2002, the District has spent on average between half a million and one million dollars per year for routine maintenance of this JCP section. Major distresses included mid-slab cracking and longitudinal cracking. However, faulting was quite minimal primarily due to the use of dowels. Repairs on this section required various lane closures for an average of 3 months per year. With the assumption that the same level of repairs will be needed for the next 20 years, the cost of maintenance was projected to be 10 to 20 million dollars, even without adjustments for inflation. Road user cost due to lane closures at the current ADT and project ADT for the next 20 years was estimated at over 70 million dollars. It was determined that a different approach must be taken than routine repairs, and CRCP overlay was suggested. CRCP overlay on JCP is not a typical overlay system used. No design procedures for this overlay system did not exist. To investigate the viability of CRCP overlay on deteriorated JCP, a half-mile section of JCP with the worst condition was selected for CRCP overlay. The logic was that, if CRCP BCO on JCP with the worst condition works, the overlay system should work in the remaining areas of this project. To evaluate the structural condition of the JCP, deflection testing was conducted. Figure 3 illustrates deflections at 9,000 lbs loading throughout the project. It shows that deflections were more than 30 mils at some joints. The poor condition of the pavement made it quite difficult to come up with a good CRCP overlay design. The concept in the AASHOT method was considered in the thickness design. However, the performance of 14-in CRCP section on IH 35, where horizontal cracking at the depth of longitudinal steel developed soon after concrete placement prior to the traffic applications, provided valuable information. The section, with delamination at the depth of 7-in from the concrete surface in many areas, survived 10 years of service under heavy truck traffic. Based on the information from the AASHTO method, the performance of afore-mentioned CRCP, and engineering judgement, 7-in CRCP overlay was developed.

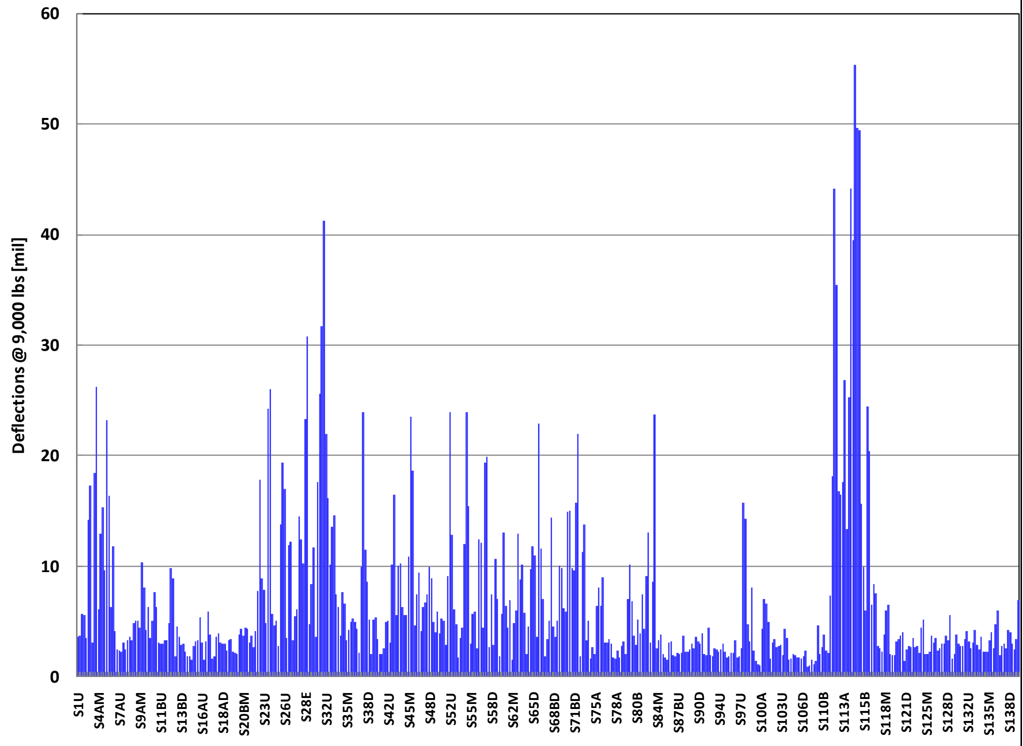

Figure 3 FWD deflections at 9,000 lbs along the 0.5-mile project

Longitudinal steel selected was 0.7 %, which is a little higher than steel percentages used for normal CRCP in Texas. The reason was to provide more restraint on concrete volume changes to enhance bonding at the interface. Since the deflections at transverse joints are quite large, potential for debonding, reflection cracking and distresses could be quite high. To reduce the potential for reflection cracking, non-woven fabric was placed on the top of the transverse contraction joints. For more information on the use of non-woven fabric in this project, please refer to the report by SW Ryu, et al (Ryu, et al, 2011).

Construction was completed in two phases. In Phase 1, concrete was placed in the inside lane and inside shoulder on May 24, 2010. In Phase 2, concrete was placed in the outside lane and outside shoulder on June 21, 2010. In Phase 1, concrete surface in the existing JCP was cleaned with pressurized air and water, just prior to concrete placement. However, in Phase 2, concrete surface in the existing JCP was prepared with cold milling, followed by cleaning with pressurized water. Curing compounds were applied in accordance with TxDOT specification requirements (two applications with not to exceed 180 sq. ft. per gallon of curing compound, within 10 and 30 minutes after concrete finishing) and after concrete was set, cotton mat was placed, followed by water spraying and vinyl sheet placement on top of the mats, as shown in Figure 4(a). The wet mat curing system continued until June 1, 2010. In Phase 2, there were issues with concrete supply in a timely manner, and 600-ft of concrete had to be removed and new concrete was placed. For the details of the construction aspects of this project, refer to the report by SW Ryu, et al (Ryu, et al, 2011).

The performance of this project varied. The performance of inside lane has been perfect, with no single distress. However, distresses developed in the outside lane, at the locations of transverse joints, as shown in Figure 4(b). As of August 13, 2015, distresses occurred at a total 24 locations, all in transverse contraction joints in the existing JCP. Truck traffic in this section is quite heavy, and it appears that heavy truck traffic caused large deflections in the BCO system, inducing separations of overlay from JCP, and resulting distresses. 24 distresses out of 140 total joints in this section represent 17 percent of joints. In other words, BCO at 83 percent of joints survived under heavy truck traffic loading for more than 5 years. It appears that the CRCP BCO system on deteriorated JCP could work with minor adjustments in design, as long as joint deflections in the existing JCP are not excessive. Further performance evaluations in this section need to be conducted to establish a threshold value for joint deflections for CRCP BCO on JCP.

Figure 4(a) Wet-mat curing

Figure 4(b) Distress in outside lane

(3) BCO projects on US 287 Southbound in the Wichita Falls District

8-in CRCP was constructed in 1972 on US 287 in the Wichita Falls District. By late 2000s, distresses were observed in the form of punchouts. Figure 5 shows a condition of the existing CRCP in this section. Evidence for poor pavement support, as shown in Figure 5(a), (b), and (c) and resulting edge punchout as shown in Figure 5(d), was observed in a number of places. In 2012, a decision was made to rehabilitate this section. Two alternatives were considered: one was asphalt overlay and the other CRCP BCO. Life cycle cost analysis was conducted, and based on the analysis result, CRCP BCO was selected. The thickness design was performed in accordance with the AASHTO method. Based on the design inputs, 4-in slab thickness was selected. For the evaluation of the condition of existing CRCP, FWD testing was conducted at a selected 1000-ft long section.

Figure 6 shows deflections at 9,000 lbs from FWD testing. Localized large deflections were observed at several locations due to poor slab support condition. Evidence for pumping was also observed during the field survey, which indicated possible loss of base materials. Texas statewide average deflection for 8-in CRCP is 3.6 mils according to the TxDOT rigid pavement database project (Choi et al. 2013). However, in the section evaluated with FWD, there are a number of locations with much larger than the average deflection of 3.6 mils, an indication of poor slab support at those locations.

	
Figure 5(a) Half-moon shape cracks	Figure 5(b) Longitudinal cracks
	
Figure 5(c) Fatigue cracking at pavement edge	Figure 5(d) Edge punchouts

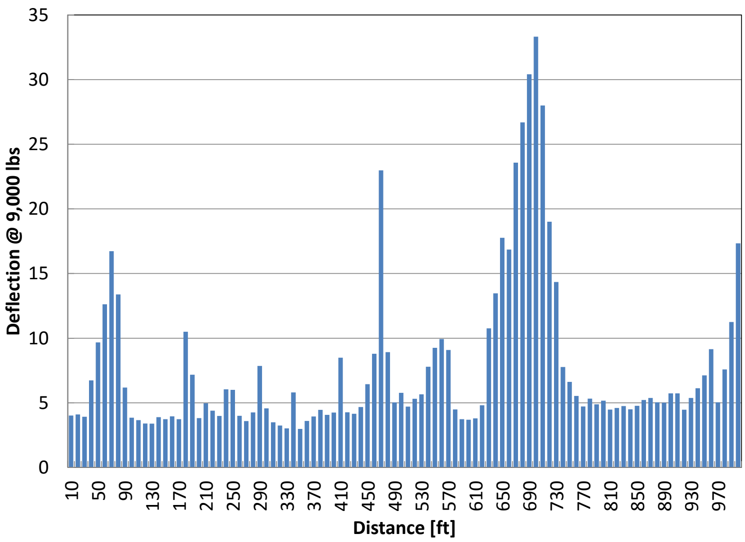

Figure 6 Deflection at 9,000 lbs

Continuous deflection testing using TPAD (Total Pavement Acceptance Device) was also conducted along 5.0 miles on April 25, 2012. Overall, the variations in deflection along the 5-mile section were rather large, confirming the FWD testing results in Figure 6 and indicating that slab support is not uniform throughout the project. However, in the AASHTO method for slab thickness design, design input for the condition of existing pavement is in terms of the number of distresses per mile, not structural capacity. Based on the AASHTO method, 4-in slab thickness was derived. This section, which is 5-mile long, was overlaid with 4-in BCO on Nov 5, 2012.

The bond strength was evaluated between existing concrete and the BCO to verify whether the both CRCPs will behave monolithically in accordance with the ASTM C1583/C1583M-13 (ASTM International 2013). The testing was conducted in 14 locations. Figure 7(a) illustrates a schematic of pull off test. The ultrasonic shear-wave tomography was applied to locate rebar before concrete coring (Bishko et al. 2008; Kozlov et al. 2006). Figure 7(b) shows the analyzed images of the ultrasonic testing at the bond strength test locations. The longitudinal steels are clearly identified for both the BCO and old CRCP. The thickness of the old CRCP is 8-in and the BCO thickness is 4-in.

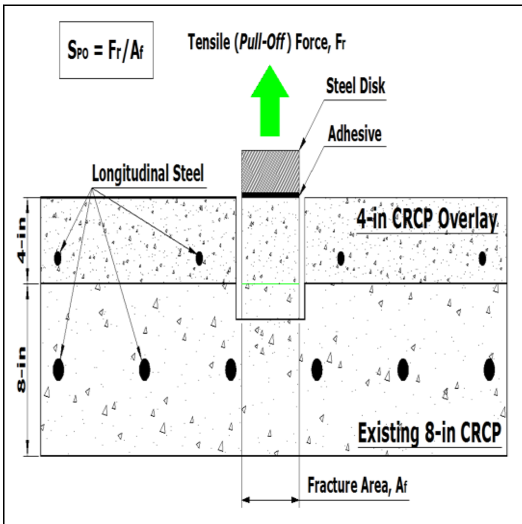

Figure 7(a) Schematic of pull-off testing

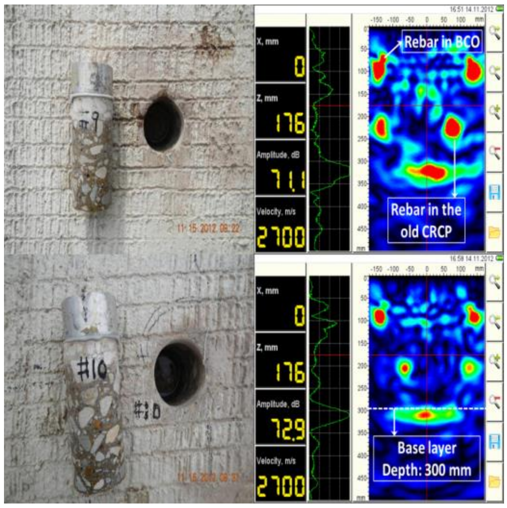

Figure 7(b) Rebar location

Figure 8(a) shows the test locations for the bond strength test. Figure 8(b) illustrates the bond strength test result. Among the testing at 14 locations, concrete was broken at 2 locations and concrete was broken at the interface at one location during coring. Test results illustrate that the bond strengths are larger than 150 psi at 9 out of 11 locations, which is an indication of quality construction.

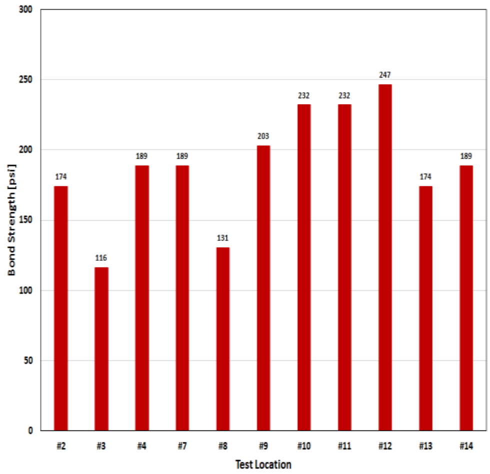

Figure 8(a) Pull-out test location	Figure 8(b) Bond strength test result

Figure 9 shows an example of pavement condition before and after the BCO in the full-depth repair (FDR) area. The FDR was done prior to BCO as shown in Figure 9(b) to address longitudinal cracks and large deflections in the location shown in Figure 9(a). However, distress occurred again in the FDR section before the BCO construction as shown in Figure 9(b).

This location includes all types of distress and mechanism in CRCP - edge punchouts, longitudinal crack due to a poor base support, and pumping at the longitudinal joint. Figure 9(c) shows reflected cracks in BCO at the location of distresses in the existing pavement. Figure 9(d) is a close-up view of distress in the BCO. The edge punchouts in the old CRCP seem to be reflected through in the newly constructed BCO slab. This strongly indicates the need for sound repairs of CRCP distresses prior to BCO placement.

Figure 9(a) Pavement condition, 12/03/2010	Figure 9(b) Distress at FDR, 04/25/2012

	
Figure 9(c) Distress in BCO, 08/13/2013	Figure 9(d) Close-up view of BCO distress

Figure 10(a) illustrates well performing BCO area, with no wide or meandering cracks. Figure 10(b) shows reflected cracking from the existing CRCP. In this area, the overall deflection was measured at lower than 7.0 mils at 10,000 lbs and resulting in good BCO. However, at a location of the reflection cracking, deflection measured prior to BCO was larger than other nearby areas, with about 8 mils at 10,000 lbs. Figures 10(c) and (d) show captured picture from TPAD video image and the measured TPAD deflection. Both GPS coordinates in TPAD image and surveyed picture were nearly identical, which means the reflective cracking was at the location of the larger deflection. Although the pavement condition shown in Figure 10(b) is not classified as a distress at the time the picture was taken, there is a high potential for further deterioration. The fundamental mechanisms leading to the development of reflective cracking are differential movements from the supporting pavement structure in asphalt concrete overlay over JCP (Chen et al. 2007). On the other hand, movement of transverse crack in CRCP is negligible when the base support condition is adequate. Accordingly, the transverse crack behavior in CRCP is completely different from that of contraction joint in JCP. However, the pavement survey result shows that once the base support condition is degraded, reflection cracks might develop in BCO. The condition of this BCO project deteriorated at a number of locations. There was a good correlation between deflection level in the existing CRCP and distresses in BCO. Unfortunately, the area and the rate of deterioration in BCO became excessive and a decision was made to overlay with asphalt for entire 5-mile project. Even though bond strength was quite adequate in this project with good quality construction, poor slab support in the existing pavement resulted in larger deflections and distresses in BCO. The performance of BCO in this section indicates that a threshold value for deflections should be developed and applied when BCO is considered as a rehabilitation method of CRCP.

Figure 10(a) Good BCO condition

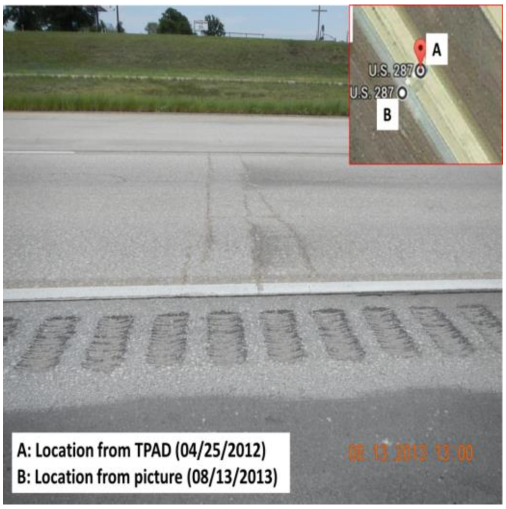

Figure 10(b) Reflection crack

Figure 10(c) Transverse crack before BCO

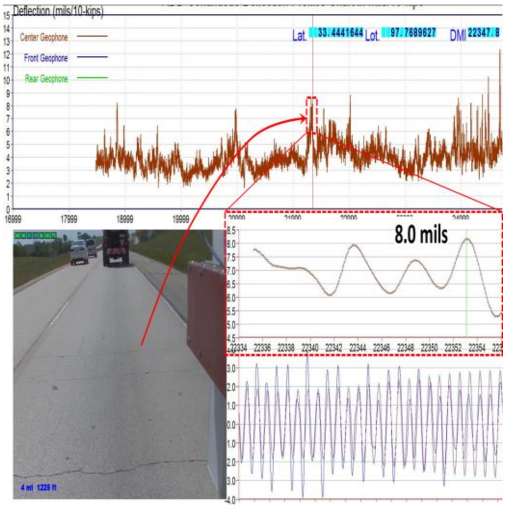

Figure 10(d) Large deflection, 8.0 mils

Conclusions

There are many miles of Portland cement concrete (PCC) pavements in Texas that have provided satisfactory performance for much longer than their original design lives. These pavements still present valuable assets to TxDOT, and bonded concrete overlays (BCO) could provide cost-effective rehabilitation methods for structurally deficient PCC pavements. Over the years, TxDOT built a number of BCO projects and their performance varied, from poor to excellent. In this paper, the performance of 3 BCO projects, along with technical significance in each project, was discussed. The findings from 3 BCO projects can be can be summarized as follows:

(1) 4-in BCO on 8-in CRCP reduced slab deflections by about 40 percent, confirming the capability of BCO system in enhancing structural capacity of under-designed CRCP.
(2) Welded wire fabric provided better performance than steel fibers. Steel fibers did not prevent spalling in concrete containing siliceous river gravel. This

indicates that continuous steel reinforcement is beneficial in CRCP BCO on CRCP.

(3) Longitudinal reinforcement is recommended in BCO with overlay slab thickness greater or equal to 4-in when BCO is placed on CRCP. Also, for 4-in BCO, longitudinal steel should be placed closer to the surface of existing CRCP.

(4) Desirable concrete properties for BCO include adequate strength and lower modulus and coefficient of thermal expansion, which should be achieved by use of crushed limestone.

(5) CRCP BCO is a viable option to rehabilitate jointed concrete pavement. Further performance evaluations in the US 75 Section need to be conducted to establish a threshold value for joint deflections for CRCP BCO on JCP.

(6) Even when good bond is provided at the interface between old and new concrete pavements, if slab support condition under the existing concrete pavement is deficient, BCO performance can be compromised. A threshold value for deflections should be developed and applied when BCO is considered as a rehabilitation method of CRCP.

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