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16. Abstract <p>Bonded concrete overlays could provide cost-effective rehabilitation methods for structurally deficient Portland cement concrete (PCC) pavements. Four-inch bonded concrete overlay (BCO) placed in 1986 on Houston's IH 610 North has provided quite satisfactory performance for more than 20 years. Ten test sections were placed as a part of the BCO project during the construction, and after 20 years, they provide invaluable information on the long-term performance of BCO. The variables included in the test sections are reinforcement, coarse aggregate type, and existing pavement condition. The overall performance of 4-in. BCO has been excellent, even though there were a few patches made to address partial depth punchouts. Four-inch BCO over 8-in. continuously reinforced concrete pavement (CRCP) reduced deflections by about one-third, which is good evidence for BCO's ability to enhance the structural capacity of under-designed PCC pavements. Between the two reinforcement types used, welded wire fabric and steel fibers, welded wire fabric provided better performance. It appears that welded wire fabric provided more effective restraint on concrete volume change potential, thus improving bonds between BCO and existing concrete. Two coarse aggregate types were used in the test sections: siliceous river gravel (SRG) and limestone (LS). For the comparable condition, LS provided better performance than SRG. This finding is consistent with the performance in new CRCP, where more spalling and mid-depth horizontal cracking problems occur in sections with SRG. The condition of existing pavement, at least as evaluated with the method adopted in this study, does not appear to have substantial effects on the performance of BCOs. Delaminations and resulting partial depth punchouts were the primary structural distresses. Delaminations were along longitudinal warping joints, as well as under the wheel paths. Those along the longitudinal warping joints appear to be due to environmental loading, while those under the wheel paths were due to wheel load stresses. Full saw cuts through BCO at longitudinal warping joints will minimize delaminations.</p>					
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Table of Contents

Chapter 1. Introduction.....	1
1.1 Background.....	1
1.2 Scope.....	2
Chapter 2. Performance of BCOs in IH 610 in Houston.....	3
2.1 Description of BCO Project in IH 610 North in Houston.....	3
2.2 Factorial Experiment.....	4
2.3 Condition Surveys.....	5
2.3.1 Transverse Crack Spacing.....	5
2.3.2 Longitudinal Cracking	7
2.3.3 Spalled Cracks	8
2.4 Deflection Measurements	10
2.5 Material Properties.....	14
2.5.1 Shear Strength.....	14
2.5.2 Tensile Strength	14
2.6 Summary	15
Chapter 3. In-depth Evaluation of Delamination	17
3.1 Field Evaluations of Delamination	17
Chapter 4. Conclusions and Recommendations.....	21
References.....	23
Appendix A: SPECIAL PROVISION 360---XXX.....	25
Appendix B: Guidelines for the Design and Construction of Bonded Concrete Overlays (BCO).....	29

List of Figures

Figure 2.1: Typical section of BCO project on IH 610 North in Houston.....	3
Figure 2.2: Plan view of test sections	4
Figure 2.3: Transverse crack spacing before and after the overlay	7
Figure 2.4: Dynaflect deflections before and after BCO	11
Figure 2.5: Delaminations and severe spalling near longitudinal construction joint.....	13
Figure 3.1: (a) Location of coring at delaminated longitudinal warping joint.....	18
Figure 3.2: Longitudinal cracks and wide transverse crack.....	19
Figure 3.3: (a) Top of the existing concrete showing delamination	19
Figure 3.4: (a) Face of transverse crack.....	20
Figure B1: Excerpt from the TxDOT Pavement Guide	32

List of Tables

Table 2.1: Factorial experiment setup for BCO test sections	4
Table 2.2: Variations in crack spacing over time	6
Table 2.3: Variations in longitudinal cracking over time	8
Table 2.4: Spalling variations over time	9
Table 2.5: Variations in punchouts and patches	10
Table 2.6: Variations in deflections over time.....	11
Table 2.7: Shear strength values in each section	14
Table 2.8: Tensile strength values in each section.....	15

Chapter 1. Introduction

Bonded concrete overlays could provide cost-effective rehabilitation methods for structurally deficient portland cement concrete (PCC) pavements. Design and construction of bonded concrete overlay are different from those for new pavements, as the behavior and distress mechanisms of bonded overlays are not the same as those of new pavements. The Texas Department of Transportation (TxDOT) is the leader in the use of bonded concrete overlays, and the experience gained during their design, construction, and performance could provide valuable information that will enhance TxDOT's ability to rehabilitate structurally deficient PCC pavements in the most cost-effective manner.

1.1 Background

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, while some of them were under-designed for the traffic they have served, although they were adequately designed at the time of the pavement was built. These under-designed pavements still present valuable assets to TxDOT, and with adequate rehabilitation, these pavements will provide good performance for many years to come. Currently, TxDOT's policy is that continuously reinforced concrete pavement (CRCP) is used when a rigid pavement is selected for a project. This policy was based on the findings that, in Texas, CRCP has provided better performance than plain jointed pavements (JCP)—or CPCD (Concrete Pavement Contraction Design) as it is called in Texas—or jointed reinforced concrete pavements (JRCP) in terms of ride and structural distresses. The most frequent distresses in CPCD or JRCP were slab cracking, faulting, and resulting poor ride, while edge punchouts and severe spalling were the primary distresses in CRCP. While there are no effective rehabilitation methods applicable for CPCD or JRCP, bonded concrete overlays (BCO) present a good rehabilitation method for structurally deficient CRCP. It is because the distresses caused by under-designed CPCD or JRCP are quite destructive from a structural standpoint. On the other hand, distress mechanisms in under-designed CRCP are not quite as destructive for the pavement system. Punchouts can be repaired with full-depth slab replacement method, and structural integrity is relatively easily restored. Punchouts are due to excessive edge deflections, partly caused by under-designed pavements. Properly designed bonded concrete overlay will limit deflections to an acceptable value and make existing, under-designed pavements structurally equivalent to new pavement with adequate design for future traffic.

Over the years, TxDOT has built many miles of BCOs throughout the state. Many of the pavements that received BCOs were built in the 1960s and 1970s, which make them quite old. Concerns were raised regarding the condition of the old slabs under the BCOs. More specifically, concerns were raised as to whether chemical reactions in concrete, such as alkali-silica reaction (ASR), might deteriorate the old concrete even further. Research conducted in this study found no evidence of concrete distresses due to chemical reactions in the old slabs under BCOs (*1*). At the same time, most of the BCO projects provided good performance, extending the lives of under-designed PCC pavement with reasonable cost, even though there were a few projects where premature pavement distresses (PPD) occurred. The experience gained from those BCO

projects could provide valuable information that can be used to improve design, material selection, and construction practices.

1.2 Scope

This research project focused on evaluating the performance of BCO projects in Texas, with two primary objectives: (1) to identify whether any distresses caused by chemical reactions such as alkali-silica reaction are taking place in old pavements that received BCOs, and (2) to improve design, material selection, and construction practices. TxDOT constructed BCOs in 1986 on IH 610 in Houston. To investigate the effects of select variables, a total of 10 test sections were included in the BCO construction project. The sections have provided excellent opportunities to investigate the effects of the variables on the behavior and performance of this BCO pavement. Detailed research study was conducted and this report presents the findings.

Chapter 2 presents the detailed evaluations made on the 10 test sections. Chapter 3 discusses the findings from field study on delaminations. Chapter 4 summarizes the findings made in this study and provides recommendations.

Chapter 2. Performance of BCOs in IH 610 in Houston

In this research project, field studies were conducted to evaluate the performance of BCOs in Texas. Field evaluations provided invaluable information on how the BCOs have performed, including what type of distresses occurred. Most of the findings are included in the previous report (2). After the publication of the report, field evaluations were conducted on BCO section on IH 610 North in Houston District. This section of highway is unique in that a factorial experiment was developed to investigate the effects of three variables. They include (1) the reinforcement type, (2) the coarse aggregate type, and (3) the condition of the existing pavement. A total of 10 test sections were built, and detailed field evaluations were conducted before the overlay, one year after overlay, and 20 years after overlay.

2.1 Description of BCO Project in IH 610 North in Houston

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 test sections were placed in two outside eastbound lanes in January 1986. The original mainlane pavement structure consisted of 8-inch concrete slab over 1-inch bond breaker and 6-inch cement stabilized subbase. The top 6 inches of subgrade was treated with lime. The median and outside shoulders consisted of asphalt concrete pavement on cement stabilized base. Figures 2.1 and 2.2 present a typical cross section and the plan view of the project, respectively. The total length of the overlay project was 3.5 miles, from which 10 test sections were constructed with lengths ranging from 400 to 600 feet.

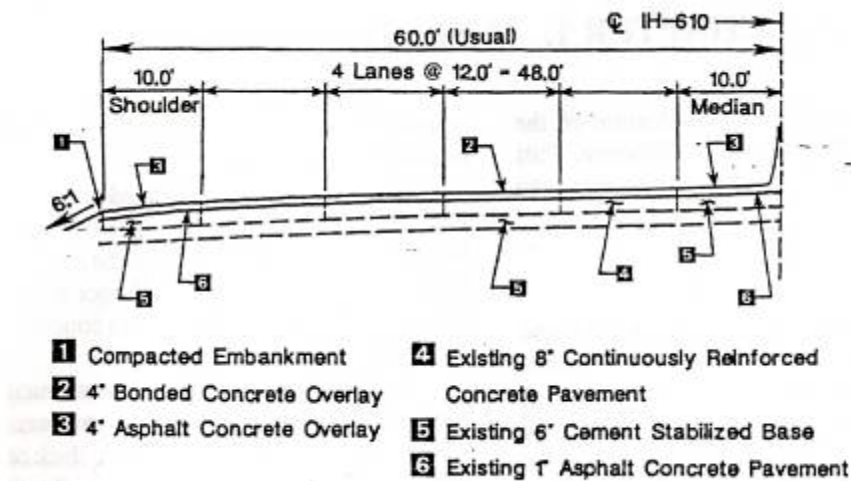


Figure 2.1: Typical section of BCO project on IH 610 North in Houston

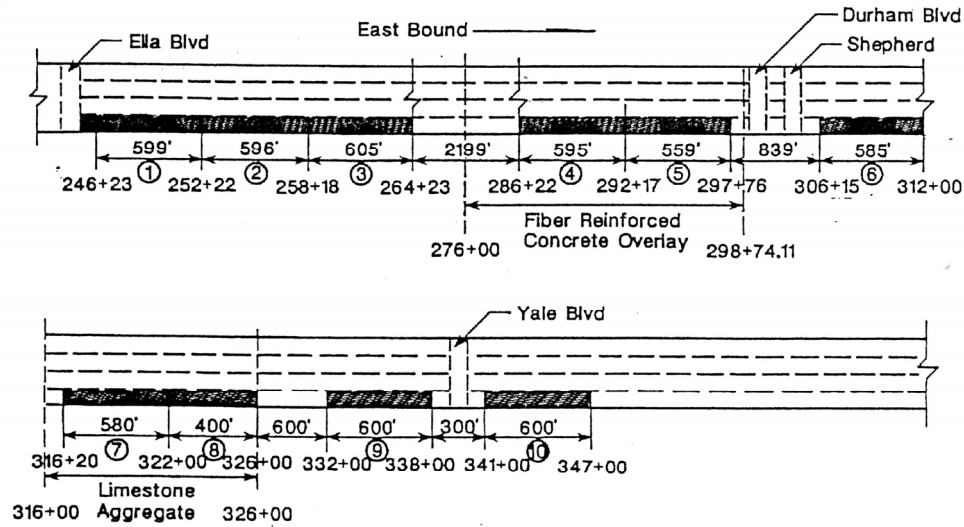


Figure 2.2: Plan view of test sections

2.2 Factorial Experiment

Prior to the overlay, a factorial experiment was developed to investigate the effects of each variable. The variables included in this overlay project are as follows.

- Concrete Coarse Aggregates: crushed limestone (LS), siliceous river gravel (SRG)
- Steel Reinforcement: welded wire fabric (WWF), steel fiber (SF)
- Condition of Existing Pavement: no distress (ND), moderate distress (MD), severe distress (SD)

Table 2.1 presents factorial experiment developed for the test sections. It shows that a total of 10 sections were constructed. Eight sections were built with welded wire fabric, while two sections were built with steel fibers. Also, siliceous river gravel (SRG) was used in eight sections, and crushed limestone (LS) was used in the other two sections.

Table 2.1: Factorial experiment setup for BCO test sections

Reinforcement		Welded Wire			Steel Fiber		
Pavement Condition		ND	MD	SD	ND	MD	SD
Coarse Aggregate	SRG	2 10	1 3	6 9	- -	- -	4 5
	LS	8	-	7	-	-	-

The condition of the existing pavement prior to the overlay was evaluated in accordance with Equation 2.1.

$$Z_c = 1.0 - 0.065FF - 0.015MS - 0.009SS \quad (\text{Equation 2.1})$$

Where, Z_c = distress index,

FF = number of failures per mile (sum of punchouts and patches),

MS = percent minor spalling, and

SS = percent severe spalling.

Equation 2.1 indicates that punchouts and patches have the most significant effect on the distress index, followed by minor spalling and severe spalling. It is not clear why minor spalling has higher coefficient than severe spalling. It appears that the coefficients in Equation 2.1 for minor spalling and severe spalling were accidentally reversed. The classification of the sections was in accordance with the following criteria:

$0.5 < Z_c < 1.0$: no distress

$0.3 < Z_c < 0.5$: medium distress

$Z_c < 0.3$: severe distress

Before and after the bonded overlay construction, under TxDOT research study 0-0920, the conditions of the pavement and the quality of the construction were evaluated. Three tasks were conducted for the evaluations: (1) condition surveys, (2) deflection measurements, and (3) concrete material testing. A brief description of each task, with its findings, is presented.

2.3 Condition Surveys

Condition surveys were carried out before overlay on May 22, 1985, after overlay on January 13, 1987, and about 20 years after the overlay on June 16, 2006. The first two condition surveys were conducted under TxDOT research study 0-0920 (2), and the last one under this research project. The types of distress surveyed included transverse and longitudinal cracks, spalling, punchouts, and patches.

2.3.1 Transverse Crack Spacing

Table 2.2 summarizes the results of the survey for transverse cracking of each test section. It includes the number of transverse cracks, average crack spacing, and percent increase or decrease in the number of cracks. It shows that the average crack spacing in CRCP prior to overlay was very small, with an average spacing of 2.1 ft.

Table 2.2: Variations in crack spacing over time

Test Sec. No.	May 1985 (Before Overlay)		Jan 1987 (After Overlay)		Percent Decrease (%) 1987/ 1985	June 2006 (After Overlay)		Percent Increase (%) 2006/ 1987
	Total No. of Transverse Cracks	Ave. Crack Spacing (ft)	Total No. of Transverse Cracks	Ave. Crack Spacing (ft)		Total No. of Transverse Cracks	Ave. Crack Spacing (ft)	
1	238	2.52	181	3.31	23.9	185	3.24	2.2
2	272	2.19	200	2.98	26.5	252	2.37	26.0
3	322	1.88	135	4.48	58.1	80*	5.64*	-40.7
4	311	1.91	68	8.75	78.1	54†	11.02†	-20.6
5	262	2.13	96	5.82	63.4	71†	7.87†	-26.0
6	319	1.83	75	7.80	76.5	‡	‡	-
7	306	1.90	76	7.63	75.2	220	2.64	189.5
8	179	2.23	23	17.39	87.2	124	3.23	439.1
9	288	2.08	126	4.76	56.3	‡	‡	-
10	259	2.32	68	8.82	73.7	141	4.26	107.4
Ave.		2.10		7.17			3.15	

* 154 ft long section was not included due to traffic control difficulties.

† There were extensive patches in these sections.

‡ Map cracking was observed in these sections and crack spacing was not measured.

One year after the overlay, average spacing for transverse cracks increased from 2.1 ft to 7.2 ft. The examination of the crack spacing before and after BCO for each test section shows poor correlation, as depicted in Figure 2.3. This implies that some of the existing cracks did not reflect through the new overlay at the time of the survey. Alternately, the cracks in the overlay might not have been caused by reflection. Table 2.1 indicates that crack spacing surveyed almost 20 years after overlay is larger than the spacing before overlay. This implies that reflection might not be the primary cause of transverse cracking in BCO.

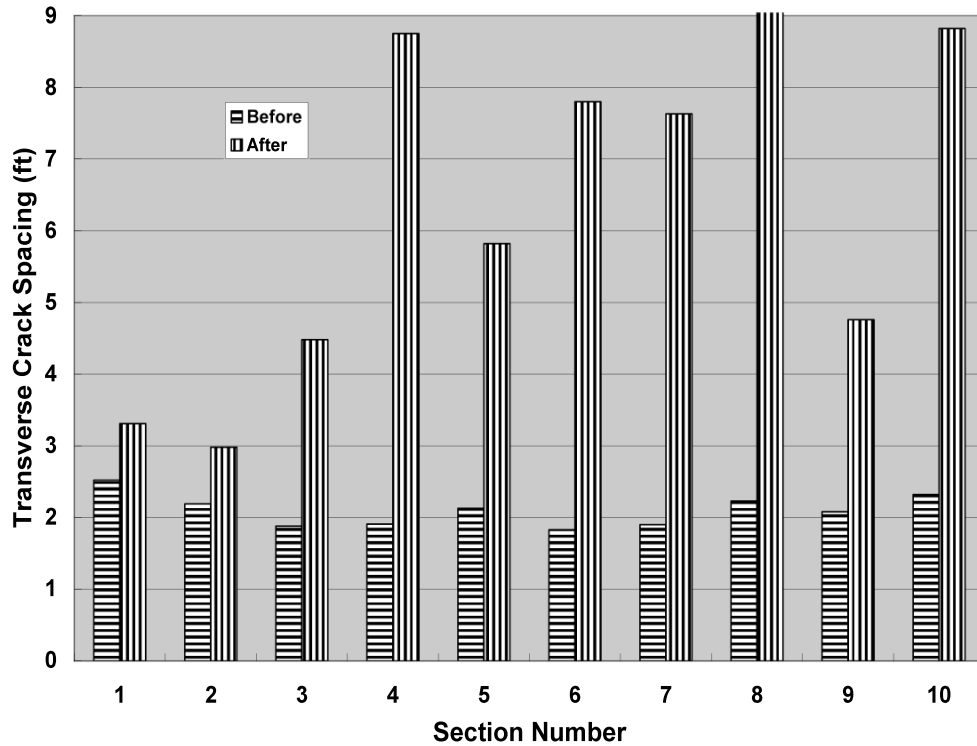


Figure 2.3: Transverse crack spacing before and after the overlay

The condition survey conducted in June 2006 indicates that transverse crack spacing has been stabilized at between 2 ft and 4.5 ft. For example, Sections 7 and 8 had unusually large crack spacing one year after overlay (7.6 ft and 17.4 ft, respectively). After 20 years of service, they were reduced to 2.6 ft and 3.2 ft, respectively. Compared with the after-overlay condition survey (year 1987), in 2006, the total number of cracks actually decreased in Sections 3, 4, and 5. Possible explanation is that some length of Section 3 was not surveyed due to the exit ramp in that section. There were a number of patches in Sections 4 and 5 and it is possible that there were transverse cracks in those patch areas. Also, transverse crack information was not collected on Sections 6 and 9 in the 2006 survey. There was extensive map cracking in those sections, and it was determined that the information on transverse cracking will not provide valid information for comparison.

2.3.2 Longitudinal Cracking

Table 2.3 presents the information on longitudinal cracking. As with transverse cracking, condition survey results in three occasions—before overlay, one year after overlay, and 20 years after overlay—are presented. It is shown that there was extensive longitudinal cracking in the pavement prior to the overlay, except for Section 8. One year after overlay, a few longitudinal cracks took place in Sections 4 and 10. Considering the age of these longitudinal cracks, it is believed that these cracks were induced by environmental loading (temperature and moisture variations) or construction related to joint saw cutting, not by fatigue due to wheel loading applications. There were substantial increases in longitudinal cracking in all sections except for in Sections 1, 7, and 8 between 1987 (one year after overlay) and 2006. Comparisons of the

longitudinal crack lengths before overlay and after 20 years indicate that, prior to overlay, longitudinal cracking was extensive in all the sections except for Section 8. However, after 20 years, only three sections—1, 7, and 8—experienced no longitudinal cracking or patches. All the other sections experienced longitudinal or map cracking. It is noted that LS was used in Sections 7 and 8 (see Table 2.1). This implies that concrete material properties affected by coarse aggregate types, such as coefficient of thermal expansion (CTE) and modulus of elasticity, might have played a role in longitudinal crack development.

Table 2.3: Variations in longitudinal cracking over time

Test Sec. No.	May 1985 (Before Overlay)		Jan 1987 (After Overlay)		June 2006 (After Overlay)	
	total length (ft)	average per 100-ft	total length (ft)	average per 100-ft	total length (ft)	average per 100-ft
1	80.0	13.4	0.0	0.0	0.0	0.0
2	309.0	51.8	0.0	0.0	147.3	24.7
3	447.0	73.9	0.0	0.0	45.0*	10.0*
4	172.0	28.9	42.0	7.0	147.7†	24.8†
5	361.0	64.6	0.0	0.0	0.0†	0.0†
6	233.0	39.8	0.0	0.0	‡	‡
7	192.0	33.1	0.0	0.0	0.0	0.0
8	6.0	1.5	0.0	0.0	0.0	0.0
9	366.0	61.0	0.0	0.0	‡	‡
10	388.0	64.7	11.0	1.8	291.0	48.5

* Condition survey did not include 154 ft due to traffic control difficulties.

† There were extensive patches in these sections.

‡ Map cracking was observed in these sections and crack length was not measured.

2.3.3 Spalled Cracks

In Texas, the frequency of spalling in CRCP has been higher when SRG is used as a coarse aggregate than when other types of coarse aggregate are used. Spalling is not a structural distress; rather, it is a functional distress. Therefore, spalling might not be an applicable performance indicator in determining the effectiveness of the factors under investigation in this study. Table 2.4 shows the minor and severe spalling results observed in three condition surveys. It shows that there were a number of minor spalls in the existing pavement prior to overlay. The coarse aggregate used in the old concrete pavement was siliceous river gravel. Minor or severe spalling was not observed in 1987, one year after overlay. However, after 20 years of service, there were a number of minor spalls in Sections 1, 2, 3, 4, and 5. Also, there were a few severe spalls in Sections 4 and 5. It is noted that the coarse aggregate type used in these five test sections was siliceous river gravel. Both welded wire fabric and steel fibers were used in the five sections. It is concluded that spalling in those five sections was most likely due to the coarse aggregate type used, not by structural deficiency of the overlaid pavement systems. Also,

Sections 4 and 5, where severe spalling formed, are the only sections where steel fiber was used. It appears that steel fiber did not help mitigate spalling problems when SRG was used as a coarse aggregate. Spalling is primarily due to the poor bonding between coarse aggregate surface and surrounding mortar. As steel fiber does not contribute to the bond strength between coarse aggregate and mortar, it follows that steel fiber does not help mitigate spalling problems, as shown in Sections 4 and 5.

Table 2.4: Spalling variations over time

Test Sec. No.	Minor Spalling (ea)			Severe Spalling (ea)		
	May 1985	Jan 1987	June 2006	May 1985	Jan 1987	June 2006
1	26	0	22	2	0	0
2	1	0	20	0	0	0
3	5	0	3	0	0	0
4	15	0	12	0	0	2
5	1	0	12	0	0	4
6	6	0	0	3	0	0
7	8	0	0	2	0	0
8	15	0	0	0	0	0
9	1	0	0	2	0	0
10	2	0	0	1	0	0

Punchouts and Patches

Punchouts are the only and most serious structural distress in CRCP. Punchouts are caused by the fatigue of concrete due to repeated wheel loading applications. Table 2.5 shows the punchout survey results. Prior to overlay, there were a number of minor punchouts in almost all sections, and severe punchouts in Sections 4 and 6. There were no punchouts, minor or severe, in 1987, one year after overlay. After 20 years, there were a number of patches in Sections 4 and 5. There were no punchouts observed in all other sections. It appears that all sections performed very well from a structural standpoint, except for Sections 4 and 5. Sections 4 and 5 have several things in common:

- 1) Prior to overlay, there were most minor punchouts (7 in Section 4, and 17 in Section 5). As for severe punchouts, Section 4 had one, but Section 5 had none.
- 2) The rating of existing pavement was “severe distress.”
- 3) The coarse aggregate type used in the overlay was siliceous river gravel.
- 4) Steel fiber was used as a reinforcement type.
- 5) There were additional longitudinal joints to apparently accommodate stage constructions in these two sections, and it appears that those joints contributed to the debonding and apparent partial depth punchouts.

The latest condition survey indicates severe spalling in these two sections only (see Table 2.4), which strongly suggests that the patches were to repair severe spalling. As discussed later, Rolling Dynamic Deflectometer testing was conducted and deflections on those two sections are not much different from the other sections. It follows that these patches were not due to structural deficiencies of BCOs, but to repair debonding or severe spalling.

Table 2.5: Variations in punchouts and patches

Test Sections No.	Minor Punchout		Severe Punchout		Total Number of Patch (Area [ft ²])
	May 1985	Jan 1987	May 1985	Jan 1987	June 2006
1	1	0	0	0	0
2	1	0	0	0	0
3	1	0	0	0	0
4	7	0	1	0	10 (1,135)
5	17	0	0	0	6 (684)
6	5	0	3	0	0
7	4	0	0	0	0
8	0	0	0	0	0
9	6	0	0	0	0
10	0	0	0	0	0

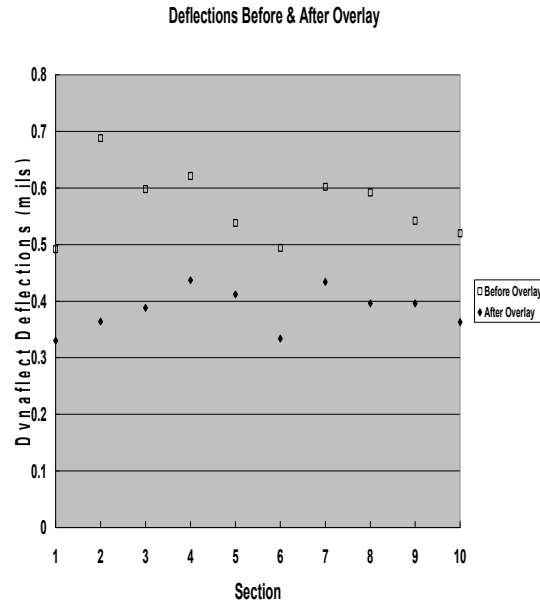
2.4 Deflection Measurements

Structural capacity of the pavement system was evaluated by deflection testing at six different times: twice before the overlay using Dynaflect, three times after overlay using Dynaflect, and once using Rolling Dynamic Deflectometer (RDD) after 20 years of service. The results are presented in Table 2.6.

Table 2.6: Variations in deflections over time

Test Sect. No.	Dynalect										RDD	
	Before Overlay		Before Overlay		After Overlay		After Overlay		After Overlay		After Overlay	
	May 22, 1985		Dec 3, 1985		Feb 4, 1986		Jan 13, 1987		Mar 19, 1987		May 9, 2006	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	0.492	0.113	0.627	0.142	0.33	0.043	-	-	0.283	0.029	4.21	1.17
2	0.688	0.122	0.725	0.082	0.364	0.042	-	-	0.348	0.038	3.75	0.69
3	0.598	0.08	0.785	0.117	0.388	0.071	-	-	0.373	0.101	3.66	0.85
4	0.621	0.048	0.803	0.054	0.437	0.025	-	-	0.43	0.021	3.95	0.69
5	0.538	0.098	0.662	0.128	0.412	0.041	-	-	0.411	0.024	4.04	0.75
6	0.494	0.108	-	-	-	-	0.334	0.081	-	-	3.19	0.88
7	0.602	0.06	-	-	-	-	0.434	0.062	-	-	3.31	0.67
8	0.592	0.1	-	-	-	-	0.396	0.054	-	-	3.49	0.83
9	0.542	0.084	-	-	-	-	0.396	0.051	-	-	3.43	0.94
10	0.52	0.139	-	-	-	-	0.363	0.054	-	-	3.94	1.28

In order to estimate the effect of 4-in. overlay on the increase in structural capacity of the overlaid system, deflections measured before and after overlay (February 1986 and January 1987 measurements) were compared. Figure 2.4 shows the results, illustrating the effect of 4-in. overlay on the reduction in Dynaflect deflections. On average, deflections were reduced by one-third, indicating that 4-in. overlay over 8-in. CRCP increased the structural capacity of the pavement system in proportion to the thicknesses. This is expected from Westergaard's analysis of deflections. Figure 2.4 illustrates a strong correlation between deflections before overlay and after overlay in each section.

*Figure 2.4: Dynaflect deflections before and after BCO*

Sections with larger deflections prior to overlay, such as Sections 4 and 7, also experienced larger deflections after overlay. At the same time, sections with lower deflections prior to the overlay, as in Sections 1, 6, and 10, also had lower deflections after overlay. Because large deflections due to wheel load applications and resulting pumping are the primary causes of distresses in CRCP, the benefits of BCO are clearly shown. Dynaflect is no longer in use at TxDOT; the falling weight deflectometer (FWD) has replaced Dynaflect as a non-destructive pavement evaluation tool. FWD is a powerful tool for structural evaluation of pavement systems, and several data analysis programs have been developed and are in use. However, it requires a stop-and-go operation and would require substantial time for the testing of all the sections for this project. Due to the heavy traffic in this project, it was not feasible to close the sections for an extended period time for FWD testing. As an alternative, RDD testing was conducted. The Rolling Dynamic Deflectometer is a semi-continuous deflection measuring device developed at The University of Texas at Austin. It runs at about one mile per hour and it took only one night of lane closures to complete the testing. The testing was conducted on the night of May 8, 2006. Static force of 13 kips and dynamic p-p force of 5 kips were applied with a loading frequency of 30 Hz. The average deflections from RDD varied between 3.2 and 4.2 mils, indicating excellent structural condition of the pavement. It was noted earlier that there were a number of patches in Sections 4 and 5, but none in the other sections. RDD data indicates that even though the deflections in Sections 4 and 5 are larger than the other sections, except for Section 1, they are still quite low. The patches, therefore, appear to have been to repair distresses due to delaminations.

Delaminations

Debonding or delaminations between new overlay and old concrete slab could cause distresses due to the increased wheel load stress level in new overlay concrete. Delaminations should be avoided in BCO as much as possible. The author of this report participated in the 1987 detailed delamination evaluations in this project. Two methods were used. One method involves dropping steel rebar vertically and evaluating the characteristics of the sound. A solid sound means good bond, while a hollow sound is a good indication of debonding. The other method involved dragging steel chain and using the same sounding criteria. There were quite a large number of areas that debonded, mostly in the areas with steel fibers (Sections 4 and 5). They were all near transverse cracks and longitudinal warping joints. Considering the patches are only in Sections 4 and 5, it appears that early-age delaminations eventually resulted in distresses, requiring repairs. Figure 2.5 illustrates the delaminations near the longitudinal construction joint in Section 4.



Figure 2.5: Delaminations and severe spalling near longitudinal construction joint

To identify delamination mechanisms, field testing was conducted on March 30, 2006, on IH 610 between IH-45 and US-59. The details of the testing and findings are described in the research report 0-4893-2 (3). It identified normal separation (Mode I failure) as the primary mechanism for delamination, not shear failure (Mode II failure). In other words, warping and curling are the primary causes for debonding in BCO. The following measures could minimize warping and curling stresses and resulting debonding:

- 1) The use of coarse aggregate with a low coefficient of thermal expansion (CTE),
- 2) The use of optimized aggregate gradations to minimize CTE and drying shrinkage,
- 3) Efficient curing to minimize drying shrinkage,
- 4) Continuous reinforcement near the bottom of the overlay,
- 5) Minimal use of transverse steel, and
- 6) Achieving adequate durability and strength of concrete while minimizing cement content to control heat of hydration.

Recall that Sections 4 and 5 are the only sections where steel fiber was used as reinforcement and SRG was used as coarse aggregate. Patches were observed in those two sections only. Even though there might have been other contributing factors to delaminations, lack of continuous reinforcement near the bottom of the overlay (Item 4 on the list) and the use of concrete with high CTE (Item 1 on the list) are believed to be the primary contributing factors to delaminations. Even though steel fibers have been used in Houston District with good success on 2-in. thick BCOs, they do not appear to contribute to reducing the amount of warping and curling while promoting good bond. Using continuous rebars near the bottom of the overlay might restrain concrete volume changes in that region resulting from temperature and moisture variations, thus minimizing Mode I failure and promoting better bonds.

2.5 Material Properties

After the completion of bonded overlay, cores were taken from test sections to evaluate bond strength at the interface, and indirect tensile strength of overlaid concrete. Due to the scheduling difficulties, cores were taken at three different times after the overlay was completed.

2.5.1 Shear Strength

Table 2.7 shows the shear strength at the interface between old and new concretes. The strength values are quite satisfactory. However, rather large variations in shear strength values were also observed. It could be that the large variations exist in shear strength from location to location, as the surface texture characteristics in the old slabs could have not been uniform throughout the project. The overlay was constructed in January 1986, and data for Sections 1 and 2 show a minimal increase in shear strength from one month (Feb 1986) to one year (Jan 1987). On the other hand, there was a large increase in shear strength in Sections 4 and 5. It is also noted that the strength values from Section 3 were low. However, the performance of Section 3 has been one of the best. Also, even though delaminations and patches were observed in Sections 4 and 5 after 20 years of service, the shear strength values from those sections from the January 1987 cores were the highest among those from seven sections. From this information, it is construed that shear strength evaluations at a few locations do not provide good quality measures of bond strength, and shear strength testing may not be used as a job control testing during the construction of BCOs.

Table 2.7: Shear strength values in each section

Test Section No.		1	2	3	4	5	6	7	8	9	10
Dates	Feb 1986	205	210	50	136	141					
Cores	Jan 1987	253	300	155	436	429	266	408			
Taken	Aug 1987								523	553	441

2.5.2 Tensile Strength

The average tensile strength values obtained from cores of overlaid concrete are presented in Table 2.8. It is observed that, in general, tensile strength of concrete was more than adequate. It is interesting to note that, even though the performance of Sections 4 and 5 are poor, the strength values from those sections are quite high. It supports that idea that, in BCOs, strength doesn't have to be so high to provide good performance. Rather, as long as durability requirements are satisfied, strength shouldn't be a concern since the concrete is in compression due to wheel load applications and concrete is quite strong in compression. Requiring high strength will result in more cement and larger volume of mortar, which will increase drying shrinkage and the coefficient of thermal expansion of the concrete. Also, requiring unreasonably high strength for overlay slab will force the contractors to use lower water-cement ratio, making the concrete rather dry. Dry concrete will result in poor bond strength, even when the surface of old slabs is kept wet. Delaminations that took place in one project in Texas presents a good lesson on what should be avoided (4). Unreasonably high strength was required for overlay concrete and the water/cement ratios tried were quite low. Extensive delaminations resulted. As long as durability requirements are satisfied, using the smallest volume of cement and mortar will reduce volume change potential of the concrete, thus improving bonding and overall performance.

Table 2.8: Tensile strength values in each section

Test Section No.		1	2	3	4	5	6	7	8	9
Dates	Feb 1986	676	582	422	671	650				
Cores Taken	Aug 1987	615	544	575	625	950	718	638	652	868

2.6 Summary

Major variables considered in the IH 610 BCO project in Houston included overlay reinforcement (welded wire fabric and steel fiber), coarse aggregate type (siliceous river gravel and limestone), and condition of existing CRCP (no distress, moderate distress, and severe distress). A factorial experiment was developed and a total of 10 sections were constructed. Detailed information was collected before, one year after, and 20 years after overlay. The information collected was from condition surveys, material testing, and non-destructive testing. This data presents one of the most comprehensive information available on BCO projects.

The findings can be summarized as follows:

- 1) 4-in. BCO over 8-in. CRCP reduced deflections by one-third from those measured prior to overlay. Deflections measured by RDD after 20 years of service indicate low deflections and might explain excellent performance.
- 2) Sections with LS as coarse aggregate showed no distresses after 20 years of service, even when one section was placed on most distressed pavement. It appears that low CTE and modulus of elasticity of concrete containing LS helped reduce curling and delaminations.
- 3) Sections with steel fibers did not perform as well as those with welded wire fabric. Severe spalling was observed where steel fiber was used. As spalling is due to poor bond strength between coarse aggregate and surrounding mortar, and steel fibers do not enhance bond strength between coarse aggregate and mortar, it is expected that steel fibers do not help reduce spalling. Also, even though steel fibers help improve tensile strength of concrete, they are not as effective as continuous reinforcement in reducing volume changes in concrete near the bottom of the overlay.
- 4) Pavement condition evaluated with the method used in this project does not appear to correlate well with BCO performance. Two sections with most distresses after overlay (Sections 4, and 5) were placed on the most distressed pavement sections. However, three other sections (Sections 6, 7, and 9) also were placed over the most distressed sections, and they did not experience any distresses. It appears that the use of steel fibers was one of the primary reasons for poor performance of Sections 4 and 5, with the use of SRG as another contributing factor. This information is quite important in that proper selection of materials and construction practices will ensure good BCO performance even on moderately distressed CRCP.
- 5) Concrete materials used for overlay were of good quality. Tensile strength was quite high, and bond strength was also in the high range even though rather large variability existed. No strong correlations were identified between concrete material properties and long-term performance. This does not imply the irrelevance of concrete strength for BCO performance. Rather, it emphasizes the fact that, as long as concrete is

durable and meets the minimum quality requirements, concrete strength itself is not determining factor for long-term performance of BCOs. Rather, there appear to be other controlling factors for the performance of BCOs, such as the CTE and modulus of elasticity, and construction practices such as existing concrete surface preparation.

Chapter 3. In-depth Evaluation of Delamination

The previous chapter showed that major structural distress observed in the IH 610 BCO project in Houston was delamination. The premise of BCO is that full bond exists between old and new slabs and, thus the critical wheel load stress that takes place at the bottom of the old slab will decrease. Delamination makes this fundamental premise invalid. Therefore, delamination presents serious issue in BCO, at least from a technical standpoint. There is a report that states delamination does not necessarily result in pavement distresses. Even so, it is evident that delaminations change the locations of neutral axis and critical stresses, thus accelerating the distresses in BCO. To make BCO perform as well as intended, delaminations should be prevented altogether, or minimized.

3.1 Field Evaluations of Delamination

Field evaluations of delaminations were conducted at two locations in IH 610 BCO project on the night of May 8, 2006. Figure 3.1(a) depicts one location selected for coring and detailed study. This location was selected based on the sounding testing, which indicated delamination in this area. This is at the longitudinal warping joint, and it is noted that there are two transverse cracks within a few inches. Figure 3.1(b) shows the condition of concrete in the old slab after a core was taken out and indicates (1) evidence of delamination, (2) no transverse crack in the existing old pavement, which implies that the transverse crack in the overlay was not due to reflection from the slab below, and (3) the existence of longitudinal contraction joint in the old pavement. Delaminations were detected along longitudinal warping joints in other locations as well. Also, they were detected along longitudinal warping joints in other BCO projects. Currently, the saw cut depth requirements for longitudinal warping joints in BCO are the same as those for new PCC pavements, which is one-third of the overlay thickness. This practice of partial saw cutting actually increases normal and shear stresses at the interface, increasing the chances of delaminations in this area. Full-depth saw cut will reduce both normal and shear stresses at the interface, as the overlay and existing slabs will behave together as one monolithic slab. Because most of the transverse cracks in CRCP are top-down cracking due to environmental loading, it's expected that the transverse crack in BCO was not caused by reflection from a crack in the existing slab. Efforts made in this research project to develop mechanistic BCO design algorithms, which will be published later as a separate report, identified both normal and shear stresses at the interface as quite dependent on the relative locations of cracks in existing and BCO slabs. Even though the effects of relative locations of transverse cracks on delamination potential has been identified, from a practical standpoint, there is not much that can be done to control the locations of transverse cracks in BCO relative to those in existing slabs. Rather, the research efforts identified significant effects of CTE in BCO on delamination potential. A report published by FHWA states the importance of "compatibility" of the concrete materials used in BCO and existing slab (5). However, theoretical analysis conducted under this project and field evidence show that concrete materials in BCO should have lower CTE to minimize delamination potential, even when the recommendation of "compatibility" is violated. Minimizing setting temperature of the BCO may also reduce potential for delamination.



Figure 3.1: (a) Location of coring at delaminated longitudinal warping joint



Figure 3.1: (b) Delaminations at the interface between BCO and existing slab

A core was taken in the other location, which was under the inside wheel path. Sound testing revealed delaminations, and Figure 3.2 shows the surface of the core location. Steel fibers are shown on the surface, as well as a relatively wide transverse crack. It is also noted that two longitudinal cracks are not continuous. Rather, they are about one inch apart at the transverse crack. This indicates that the transverse crack occurred first, followed by one longitudinal crack on one side and then the other longitudinal crack on the other side. Based on the characteristics of longitudinal cracks, it is postulated that (1) transverse cracks induced delaminations to some extent to longitudinal direction, and (2) wheel loading stress at the bottom of the delaminated slab caused bottom-up longitudinal cracking. Figure 3.3(a) shows the condition of the interface after a core was taken out. Different colors indicate delaminations and contaminations of the interface by dirt migrated from the surface through cracks. Figure 3.3(b) shows the bottom of the core. It clearly indicates contamination in the middle part of the core surface. It is noted that the contaminated area is along the longitudinal crack and fresh concrete along some part of transverse crack. This provides important information on what caused the delaminations. A fresh cut of concrete along the transverse crack indicates there was full bond in that area. In other words, warping and curling at the transverse crack do not necessarily cause debonding near the transverse cracks. This explains the solid sound or lack of delaminations along many transverse cracks observed in this project. Figure 3.4(a) shows the crack face along the transverse crack. It is quite contaminated with dirt all the way to the bottom. It indicates that the cracks were open and water infiltrated through the depth of the BCO. It also shows that longitudinal crack width varies along the depth of BCO. It is quite tight on the surface, also as shown in Figure 3.4(b); however, it gets wider as it goes down, which is a good indication of bottom-up cracking. Tight longitudinal crack on the surface indicates that steel fibers were able to function as they were supposed to, even though they did not prevent longitudinal cracking in the first place.



Figure 3.2: Longitudinal cracks and wide transverse crack



Figure 3.3: (a) Top of the existing concrete showing delamination

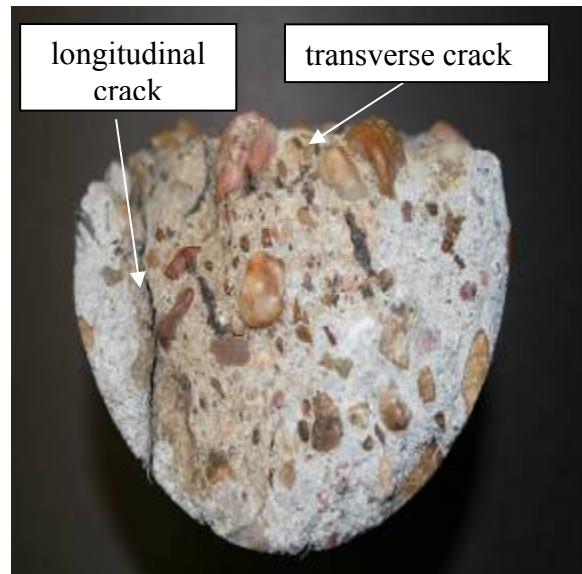
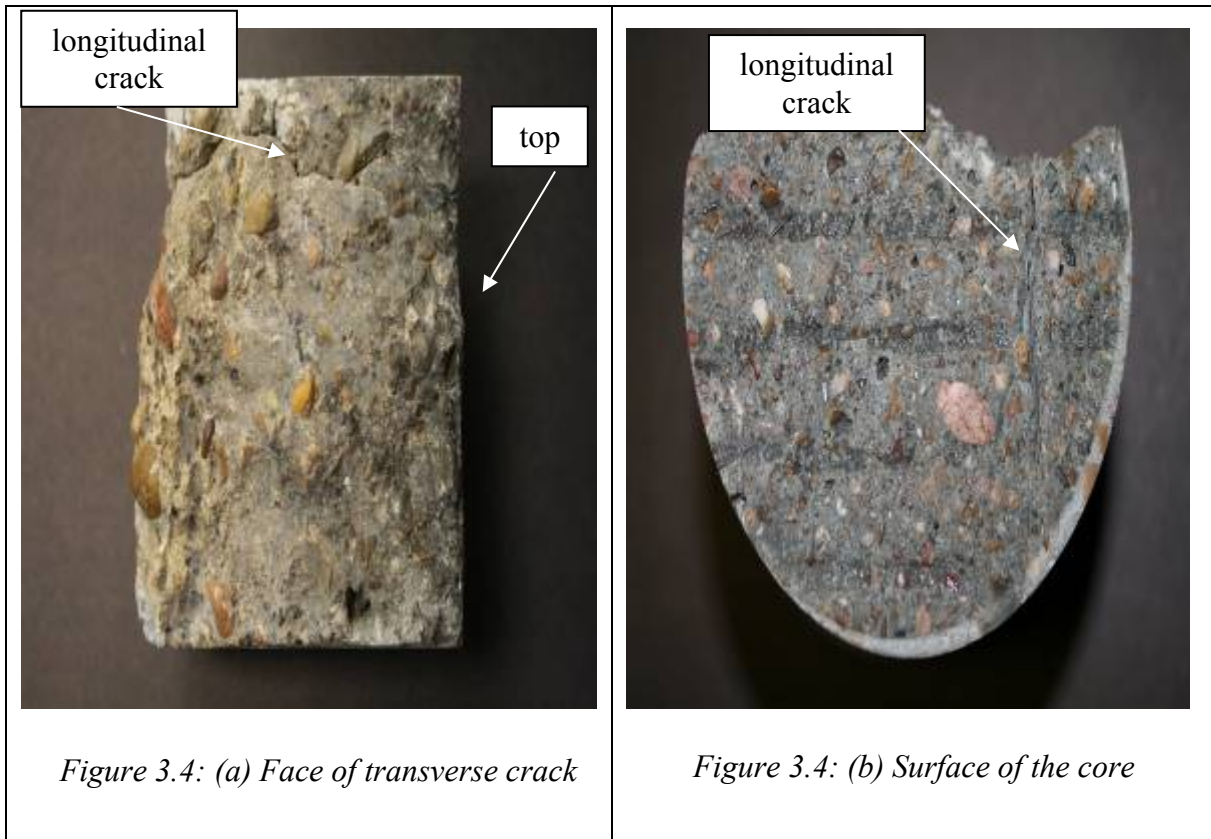


Figure 3.3: (b) Bottom of the core showing delamination



Information obtained from field testing indicates that the longitudinal cracks were bottom-up cracks due to wheel load stresses. When transverse cracks are maintained tight as in Sections 2 and 10, longitudinal cracks did not result in delaminations and punchouts or patches. On the other hand, where steel fibers were used and transverse cracks were not tight, at least at the bottom, longitudinal cracks resulted in delaminations and, in some areas, punchouts/patches. It can be concluded that, in BCOs, longitudinal cracks themselves may not cause premature distresses as long as transverse cracks are kept tight by proper reinforcements.

Chapter 4. Conclusions and Recommendations

Four-inch bonded concrete overlay placed in 1986 in Houston on IH 610 North has provided quite satisfactory performance for more than 20 years. Ten test sections were placed as a part of the BCO project during the construction, and after 20 years, they provide invaluable information on the long-term performance of BCO. This report summarizes the work performed to evaluate the performance of each test section, with the objective of identifying factors that contributed to the excellent performance. The findings can be summarized as follows:

- 1) The overall performance of 4-in. BCO has been excellent, although there were a few patches made to address partial depth punchouts.
- 2) Four-inch bonded concrete overlay over 8-in. CRCP reduced deflections by about one-third, which is a good evidence for BCO's capability in enhancing the structural capacity of under-designed PCC pavements.
- 3) Between the two reinforcement types used, welded wire fabric and steel fibers, welded wire fabric provided better performance. It appears that welded wire fabric provided more effective restraint on concrete volume change potential, thus helping better bonds between BCO and existing concrete.
- 4) Two coarse aggregate types were used in the test sections—siliceous river gravel (SRG) and limestone (LS). For the comparable condition, LS provided better performance than SRG. This finding is consistent with the performance in new continuously reinforced concrete pavement, where more spalling and mid-depth horizontal cracking problems occur in sections with SRG.
- 5) The condition of existing pavement, at least as evaluated in the method adopted in this study, does not appear to have substantial effects on the performance of BCOs.
- 6) Delaminations and resulting partial depth punchouts were the primary structural distresses. Delaminations were along longitudinal warping joints, as well as under the wheel paths. Those along the longitudinal warping joints appear to be due to environmental loading, while those under the wheel paths were due to wheel load stresses. Cores taken from delaminated areas under wheel paths indicate that longitudinal cracks were bottom-up cracks and delaminations were along the longitudinal cracks. As long as transverse cracks are kept tight, longitudinal cracks do not appear to have caused delaminations.

Currently, saw cut depth for BCO is the same as that for new PCC pavement. This requirement appears to have contributed to delaminations along longitudinal warping joints. It is recommended that the saw cut depth should extend to the full depth of the BCO layer.

References

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2. Koesno, K. and B.F. McCullough (1987), “Evaluation of the Performance of the Bonded Concrete Overlay on Interstate Highway 610 North, Houston, Texas” Research Report 920-2, Center for Transportation Research, The University of Texas at Austin.
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4. Delatte, N., Fowler, D., & McCullough, B.F., (1996), “High Early Strength Bonded Concrete Overlay Designs and Construction Methods for Rehabilitation of CRCP,” Research Report 2911-4, Center for Transportation Research, The University of Texas at Austin.
5. Smith K., and Yu, H.T., & Peshkin, D.G. (2002), “Portland Cement Concrete Overlays – State of the Technology Synthesis,” Publication No. FHWA-IF-02-045, Federal Highway Administration, Washington, D.C.

Appendix A: SPECIAL PROVISION 360---XXX

A.1 Concrete Pavement

For this project, Item 360, “Field Evaluations of Delamination,” of the Standard Specifications, is hereby amended with respect to the clauses cited below, and no other clauses or requirements of this Item are waived or changed hereby.

Article 360.1. Description is voided and replaced by the following:

360.1. Description. Construct a bonded concrete overlay (BCO) on previously placed concrete pavement in accordance with the typical sections shown on the plans, the lines and grades established by the Engineer, and the requirements of this specification.

Article 360.2. Materials, Section A. Hydraulic Cement Concrete is voided and replaced by the following:

A. Hydraulic Cement Concrete. Provide hydraulic cement concrete with classification and mix design conforming to Class “CO” concrete as defined in Item 421, “Hydraulic Cement Concrete” except that the design strength should be 600 psi at 7 days when tested in accordance with Tex-448-A. Strength over-design is not required. Type III cement is allowed.

Article 360.3. Equipment is supplemented by the following:

K. Existing Concrete Pavement Surface Preparation Equipment. Provide surface texturing equipment, cold-milling or shot-blasting, capable of providing rough texture on the existing pavement surface. Provide power-operated water blasting equipment capable of removing dirt, oil, paint, membrane curing compound, and other foreign material, as well as any laitance or loose concrete from the surface receiving the new concrete. Dispose of waste material, including water, caused by this operation using a self contained, portable vacuum unit.

Article 360.4. Construction, A. Paving and Quality Control Plan is voided and replaced by the following:

A. Surface Preparation and Paving and Quality Control Plan. Provide a surface texture of the cleaned, blasted concrete pavement with a minimum texture depth of 0.060 in. as measured by Test Method Tex 436-A. The number and location of the tests will be as directed by the Engineer. To minimize contamination, ensure the bonded concrete paving operation follows the hydrocleaning operation unless otherwise directed. If the cleaned surface becomes contaminated, reclean it at no additional cost to the Department.

Submit a paving and quality control plan for approval before beginning pavement construction operations. Include details of all operations in the concrete paving process, including longitudinal construction joint layout, sequencing, curing, lighting, early opening, leave-outs, sawing, inspection, testing, construction methods, other details and description of all equipment.

List certified personnel performing the testing. Submit revisions to the paving and quality control plan for approval.

Article 360.4. Construction, Section G. Concrete Placement, Section 4. Temperature Restrictions the first paragraph is voided and replaced by the following:

Ensure that there is no free water on the surface of the existing concrete when placing the concrete for the bonded concrete overlay.

Place concrete that is between 40°F and 90°F when measured in accordance with Tex-422-A at the time of discharge. Do not allow the temperature of the paving concrete to exceed 90°F when placing. Once the concrete temperature reaches 90°F at the time of discharge at the job site, take immediate corrective action to reduce and control the concrete temperature or stop concrete production. The Contractor is allowed to transport and place concrete produced up to the time of notification of the high concrete temperature. Sample the concrete temperature after it is discharged on grade.

Take special measures when the difference in the ambient temperature following the time of placement versus the expected low temperature in a 24 hour period is expected to exceed 25°F. Place the bonded concrete overlay a minimum of 18 hours prior to the time the maximum temperature difference is expected.

Control the moisture content of the newly placed bonded concrete overlay as directed using polyethylene fabric. Protect the entire day's placement and ensure the protection remains in place for 24 hours or as directed. These measures are in addition to the membrane curing required.

The Contractor may perform paving at night.

Article 360.4. Construction, Section H. Spreading and Finishing, Section 3. Surface Texturing is voided and replaced by the following:

Complete final texturing before the concrete has attained its initial set. Drag the carpet longitudinally along the pavement surface with the carpet contact surface area adjusted to provide a satisfactory coarsely textured surface. Prevent the carpet from getting plugged with grout. Do not perform carpet dragging operations while there is excessive bleed water.

A metal-tine texture finish is required unless otherwise shown on the plans. Immediately following the carpet drag, apply a single coat of evaporation retardant at a rate recommended by the manufacturer. Provide the metal-tine finish immediately after the concrete surface has set enough for consistent tining. Operate the metal-tine device to obtain grooves spaced at 1 in., approximately 3/16 in. deep, with a minimum depth of 1/8 in., and approximately 1/12 in. wide. Do not overlap a previously tined area. Use manual methods for achieving similar results on ramps and other irregular sections of pavements. Repair damage to the edge of the slab and joints immediately after texturing. Do not tine pavement that will be overlaid or that is scheduled for blanket diamond grinding or shot blasting.

When carpet drag is the only surface texture required by the plans, ensure that adequate and consistent micro-texture is achieved by applying sufficient weight to the carpet and keeping the carpet from getting plugged with grout, as directed by the Engineer. For surfaces that do not have adequate texture, the Engineer may require corrective action, including diamond grinding or shot blasting.

Article 360.4. Construction. Section K. Protection of Pavement and Opening to Traffic is voided and replaced by the following:

K. Protection of Pavement and Opening to Traffic. Testing for early opening is the responsibility of the Contractor regardless of job-control testing responsibilities unless otherwise shown in the plans or directed. Testing result interpretation for opening to traffic is subject to the approval of the Engineer.

1. Protection of Pavement. Erect and maintain barricades and other standard and approved devices that will exclude all vehicles and equipment from newly placed pavement for the periods specified. Before opening to traffic, protect the pavement from damage due to crossings using approved methods. Where a detour is not readily available or economically feasible, an occasional crossing of the roadway with overweight equipment may be permitted for relocating the equipment only but not for hauling material. When an occasional crossing of overweight equipment is permitted, temporary matting or other approved methods may be required.

Maintain an adequate supply of sheeting or other material to cover and protect fresh concrete surface from weather damage. Apply as needed to protect the pavement surface from weather.

2. Opening Pavement to All Traffic. Do not open the pavement to traffic, including vehicles of the Contractor, until the last concrete placed is at least 12 hours old and meets a minimum flexural strength of 435 psi.

At the end of this period, the pavement may open for use by vehicles of the Contractor or the public. Such opening, however, in no manner relieves the Contractor of his/her responsibility for the work in accordance with Item 7, "Legal Relations and Responsibilities." Before opening sections of the pavement to traffic, seal the joints and clean the pavement.

Article 360.5. Measurement is supplemented by the following:

C. Bonded Concrete Overlay. Bonded concrete overlay will be measured by the square yard of surface area of the depth specified, completed and accepted work.

Article 360.6. Payment is voided and replaced by the following:

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid as provided under Article 360.5, "Bonded Concrete Overlay" of the depth specified. This price is full compensation for furnishing, loading, unloading, storing, hauling, and handling concrete ingredients, including

freight and royalty involved; for placing and adjusting forms, including supporting material or preparing track grade; for water blasting to prepare concrete surfaces prior to placing the bonded concrete overlay; furnishing and installing reinforcing steel; furnishing materials for sealing joints; for mixing, placing, finishing, curing, and sawing concrete; for cleaning and sealing concrete joints; and for manipulations, labor, tools, equipment, and incidentals necessary to complete the work.

Remove and replace concrete failing to meet the 7 day minimum strength requirements at no expense to the Department, unless otherwise directed.

When surface Test Type B, as specified in Item 585, "Ride Quality for Pavement Surfaces," is used, a bonus or deduction for each 0.10 mile section of each travel lane will be calculated and applied in dollars and cents.

Appendix B: Guidelines for the Design and Construction of Bonded Concrete Overlays (BCO)

This document provides guidelines for the design and construction of bonded concrete overlay over portland cement concrete (PCC) pavement. The Texas Department of Transportation (TxDOT) has many miles of PCC concrete pavements that might need rehabilitation due to the structural deficiencies. Bonded concrete overlay (BCO) provides one of the most cost effective methods to rehabilitate structurally deficient PCC pavements. The success of BCO depends on three factors: (1) proper design, (2) selection of good concrete materials, and (3) quality construction.

B1. Guidelines for the Design of Bonded Concrete Overlay

Design of BCO is quite unique in that it requires proper evaluation of the remaining structural capacity of the existing pavement. There are several design methods available: the PCA (Portland Cement Association) method, the AASHTO (American Association of State Highway and Transportation Officials) method, and the Corps of Engineers method, to name a few. Among these, the AASHTO method is the only one applicable to CRCP overlay. The others are for CPCD (concrete pavement contraction joint) overlay, and not applicable to TxDOT operations.

Before a decision is made to utilize BCO for rehabilitation, several factors need to be evaluated to make sure that the candidate pavement meets the basic requirements, because BCO requires specific conditions for satisfactory performance. In general, BCO is a good candidate for PCC pavements that do not have severe distresses, but are structurally deficient to carry projected future truck traffic. BCO will be able to enhance the structural capacity of the existing pavement, as long as it is designed and constructed properly on a good candidate PCC pavement. At this point, there are no definite criteria that could be used to determine whether an existing PCC pavement is a good candidate for BCO; it is somewhat subjective. However, if the pavement has the following features, it is likely a good candidate for BCO.

- (1) The pavement starts experiencing distresses that are due to structural deficiency, such as punchouts.
- (2) Deflection measurements indicate a deficiency in the pavement's structural capacity. An FWD sensor #1 deflection of 5 mils or more for 9,000 lbs loading is a good indication of structural deficiency.
- (3) There is evidence of onset of structural distresses caused by large deflections, such as pumping and degradation of transverse cracks near the pavement edge.

Once the decision is made that BCO is a good candidate for the rehabilitation of the existing pavement, a BCO design should be developed. Stand-alone BCO design procedures were developed and submitted to TxDOT as Product 7 of Project 0-4893. The 0-4893-P7 program is based on the AASHTO BCO design procedures and quite easy to use. Utilize the program to determine required slab thickness. The other design elements to be determined are the longitudinal and transverse steel designs. If the design thickness is 8 inches or greater, use

reinforcement specified in TxDOT's *CRCP Design Standards CRCP(1)-03*, for both longitudinal and transverse steel. If the thickness is less than 8 inches, which will be usually the case, use the specification shown in Table B1 for longitudinal reinforcement. For transverse steel, use Table 2 in *CRCP Design Standards CRCP(1)-03*.

Table B1: Specifications for Longitudinal Reinforcement

Slab Thickness (in)	Bar Size	Bar Spacing (in)
4	#6	16
5	#6	14
6	#6	12
7	#6	10

B2. Guidelines for the Construction of BCO

The quality of the materials and construction is extremely important to ensure good performance of BCO: BCO performance depends to a large extent on the bonding condition between old and new concrete slabs (interfacial bonding). TxDOT's *Pavement Design Guide* (excerpted in Figure B1 at the end of this appendix) emphasizes this point. A number of factors affect the interfacial bonding. They include (1) the existing pavement's surface condition just before the new concrete is placed, such as roughness and cleanness, (2) the properties of new concrete materials—coefficient of thermal expansion (CTE), modulus of elasticity, and drying shrinkage, and (3) the condition during construction, such as condition of existing pavement surface, temperature condition, and the quality of curing. Considering the importance of these factors, each factor is described separately.

- a) Texture of existing pavement surface: To promote good interfacial bonding, the surface of the existing pavement should be treated so that quite a rough texture is obtained. There are several ways to obtain rough texture, including sand blasting, shot blasting, and cold milling. When cold milling is utilized, special care should be exercised to ensure that all loose concrete pieces are removed.
- b) Cleanness of existing pavement surface: The surface should be clean, free of any dirt. Otherwise, good bond cannot be achieved, because the dirt will act as a bond breaker.
- c) CTE: New concrete will undergo volume changes due to temperature variations. If concrete with a high CTE is used in new concrete, the volume changes will be large and induce debonding at the interface. The requirement of "material compatibility" between old and new concretes, as suggested in some of the research reports, should be disregarded. Field evidence shows that a low CTE is more important than the compatibility requirement.
- d) Modulus of elasticity of concrete: In Texas, coarse aggregate that provides a low CTE in concrete also produces low modulus values. For the same concrete volume changes, concrete with a high modulus will experience higher stress, increasing the potential for debonding. If at all possible, try to find the coarse aggregate source in the district that will give low CTE and modulus values.

- e) Drying shrinkage of concrete: Drying shrinkage of concrete is pretty much a function of water content in the concrete. It's better to use as little water as possible without compromising the workability. However, too little water will make the concrete dry and might hinder the good bonding. It is desirable to use water-cement ratio values between 0.40 and 0.45.
- f) Condition of existing pavement surface: There have been different opinions as to what the condition of existing pavement surface should be, as far as moisture condition is concerned. Based on the research findings in this and other previous TxDOT studies, surface should be in SSD (Saturated Surface Dry) condition, but no standing water on the surface. Do not use bonding agent. Any delay in concrete placement will cause severe debonding problems.
- g) Temperature condition: Concrete volume changes will depend on the temperature differentials from the setting temperature. Therefore, it is desirable to have concrete setting temperature as close to normal average ambient temperature as possible. However, in reality, it is not easy to achieve this. From a practical standpoint, follow the temperature requirements in the Special Provision developed in this study.
- h) Quality of curing: Curing is one of the most important construction elements that have significant effects on BCO performance. The concrete used for BCO is Class CO in Item 421. This concrete has higher strength requirement (600 psi in flexure at 7 days) than normal Class P concrete (520 psi in flexure at 7 days). It will probably have more cement and more mortar volume than those in normal Class P concrete. Consequently, this concrete will have higher drying shrinkage potential compared with Class P concrete. Any volume changes in concrete, whether due to temperature variations or drying shrinkage, will result in a higher potential for debonding. High quality curing will minimize the volume change potential, and keep the moisture for full hydration of cements, improving strength and durability of the concrete. If the project size is not that large, consider using wet-mat curing. It will definitely improve the performance of BCO.

Finally, following the construction specifications requirements as closely as possible will enhance the potential success in BCO.

This chapter describes bonded concrete overlays (BCO) on continuously reinforced concrete pavement (CRCP), not on concrete pavement contraction design (CPCD). BCO is not a good option for the rehabilitation of CPCD.

In the past, concrete pavements were designed and constructed with insufficient thicknesses for today's traffic demand. This insufficient thickness often resulted in pavement distresses such as punchouts for CRCP and mid-slab cracking or joint faulting in CPCD. If the Portland cement concrete (PCC) pavement is structurally sound (in other words, if the slab support is in good condition) except for the deficient thickness, BCO can provide cost-effective rehabilitation strategies to extend the pavement life. In bonded concrete overlays, new concrete layer is applied to the surface of the existing PCC pavement. This increases the total thickness of the concrete slab, thereby reducing the wheel load stresses and extending the pavement life. There are BCO projects in Texas that have provided an additional 20 yr. of service. At the same time, there are BCO projects that did not perform well. The difference between good and poorly performing BCOs is the bond strength between new and old concretes.

The critical requirement for the success of BCO is a good bond between a new and old concrete layers. If a good bond is provided, the new slab consisting of old and new concrete layers will behave monolithically and increased slab thickness. The increased slab thickness will reduce the wheel load stress at the bottom of the slab substantially, prolonging the pavement life. On the other hand, if a sufficient bond is not provided, the wheel load stress level in the new concrete layer will be high and the pavement performance will be compromised.

ded Concrete Overlay (BCO) Procedures

The design and construction of bonded concrete overlay (BCO) involves the following procedures.

1. Evaluate whether the project is a good candidate for BCO.
2. Develop adequate slab thickness and steel designs.
3. Repair distresses in the existing pavement.
4. Prepare surface of existing pavement for overlay.
5. If needed, place steel.
6. Place concrete and provide optimum curing.

Each step is explained in more detail.

1. Evaluate whether the project is a good candidate for BCO.