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1. Report No. FHWA/TX-12-5-9045-05-1	2. Government Accession No.:	3. Recipient's Catalog No.:	
4. Title and Subtitle: Just in Time Technology Transfer for Portland Cement Concrete Pavement Construction and Rehabilitation		5. Report Date: August 2012	
7. Author(s): Moon C. Won,		8. Performing Organization Report No. 5-9045-05-1	
9. Performing Organization Name and Address: Texas Tech University College of Engineering Box 41023 Lubbock, Texas 79409-1023		10. Work Unit No.(TRAIS):	
		11. Contract or Grant No.: Project 5-9045-05	
12. Sponsoring Agency Name And Address Texas Department Of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Cover: Technical Report 08/2011-08/2012	
		14. Sponsoring Agency Code:	
15. Supplementary Notes: Project performed in cooperation with Texas Department of Transportation and the Federal Highway Administration			
16. Abstract: As of 2010, the total lane mileage of CRCP in Texas accounts for about 5.4 percent of total lane mileage. On the other hand, CRCP carries about 25 percent of total traffic. It is quite important to TxDOT and the State to keep CRCP in good condition. In-depth evaluations of CRCP condition in Texas reveal that the overall condition of CRCP is excellent, with actual performance exceeding intended design lives twice or three times in some projects. On the other hand, distresses do occur in CRCP. TxDOT's "Rigid Pavement Database" research study evaluated the distresses in CRCP, and discovered that most of the distresses were not due to the structural deficiency of the pavement system; rather, they were due to the quality issues in materials and construction. Enhancing the quality of materials and construction operations of CRCP is the most cost-effective way to improve performance, rather than increasing slab thicknesses. This implementation project aimed at enhancing the quality of the materials and construction operations for CRCP by developing training materials and providing training to TxDOT and contractor personnel. Three areas that need the most attention were identified: (1) materials and construction issues of CRCP for optimum performance, (2) full- and partial-depth repairs of CRCP, and (3) prevention and repair lane separations in concrete pavement. For the development of training material, district construction and maintenance staff were consulted along with the review of publications on CRCP construction and rehabilitation. Also, the information gathered over the years under various TxDOT research studies was utilized.			
17. Key Words: CRCP, quality control, pavement performance, training		18. Distribution Statement No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161, www.ntis.gov	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. Of Pages 105	22. Price

**Just in Time Technology Transfer for Portland Cement Concrete Pavement
Construction and Rehabilitation**

by

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Performed in cooperation with the
Texas Department of Transportation
and the Federal Highway Administration

Project Report 5-9045-05-1

Project Number 5-9045-05

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ACKNOWLEDGMENTS

This research study was sponsored by the Texas Department of Transportation in cooperation with the Federal Highway Administration. The author expresses his gratitude to Dr. German Claros for his support throughout the project. In addition, the author acknowledges the support provided by the contractors and TxDOT personnel during the training.

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CHAPTER 1 INTRODUCTION

1.1 Background

Continuously reinforced concrete pavement (CRCP) is the most widely used rigid pavement type by the Texas Department of Transportation (TxDOT), primarily due to its excellent performance. Many miles of CRCP have provided longer performance period or more traffic than design traffic with few distresses. However, this does not mean that CRCP performance has been perfect. Field evaluations conducted on CRCP performance under TxDOT’s “Rigid Pavement Database” research projects 0-5445 and 0-6274 revealed that even though overall distress rates in CRCP are low, there are distresses observed in CRCP. Also discovered is that most of the distresses – more than 85 percent – were related to quality issues on materials and construction. Figure 1 illustrates the classification of CRCP distresses in Texas.

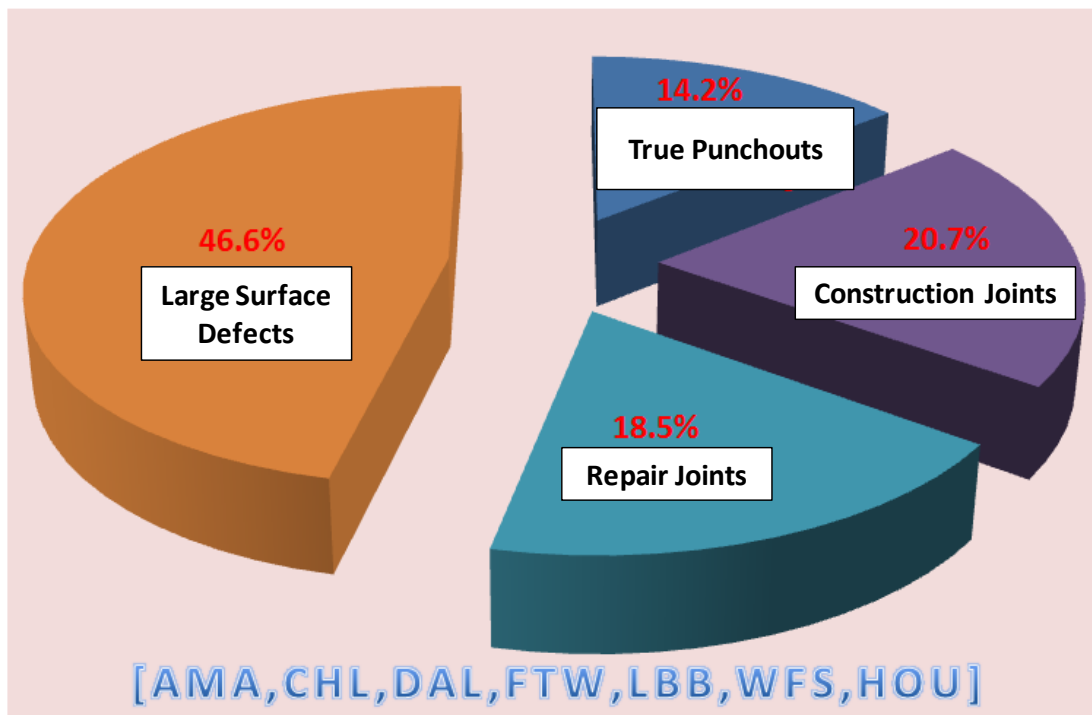


Figure 1 Classification of CRCP distresses in Texas

Figure 1 shows that about half of all the punchouts recorded in TxDOT PMIS are actually large surface defects. These defects, shown in Figure 2, are primarily due to the use of a specific coarse aggregate type, or poor finishing practices. The distress in Figure 2-(a) is due to poor workmanship during the finishing operations. Large spalling and subsequent repairs as shown in Figure 2-(b) are due to the use of a coarse aggregate with high coefficient of thermal expansion (CoTE). Efforts are currently underway in TxDOT to address the coarse aggregate issue.



Figure 2-(a) Large surface defect



Figure 2-(b) Spalling and repairs

About 19 percent of punchouts recorded in TxDOT PMIS are actually distresses related to previously repaired joints. Figure 3 shows the distresses next to the repair joints.



Figure 3-(a) Distress at repair joint



Figure 3-(b) Distress at repair joint

About 21 percent of the punchouts recorded in TxDOT PMIS occur at transverse

construction joints, as shown in Figure 4. This could be due to the materials or construction practices in the joint area. Currently, research efforts are under way to identify the causes of this type of distress.



Figure 4-(a) Distress at transverse construction joint



Figure 4-(b) Distress at transverse construction joint

The distresses presented so far strongly indicate that the performance of CRCP in Texas could be enhanced by improving the quality of materials and construction practices.

Repairs of CRCP are expensive and time-consuming, and the effectiveness of those repairs is not always good. It is best to prevent distresses in CRCP, rather than try to repair the distresses.

There are three general groups of variables that could cause distresses in CRCP. They are (1) deficiency in structural design and imperfections in design details, (2) the use of substandard materials, and (3) deficiencies in construction practices. Over the years, TxDOT sponsored a number of research studies, primarily in the area of pavement design, and the current pavement design procedures and design standards have proven to be effective. Field evaluations also reveal that few distresses are design-related. TxDOT Standard Specifications Item 421, along with Item 360, stipulate the quality of the Portland cement concrete materials to be used in CRCP. Most of the requirements for materials in Item 421 have been adopted from those in the national standards. The material requirements are quite generic for general purposes, and do not necessarily include those responsible for the performance of CRCP. For example, soundness, decant, gradation, and LA abrasion are the material properties included in Item 421 for coarse aggregate. Even though those properties undoubtedly affect

CRCP performance, there are other coarse aggregate properties that have a more significant effect on CRCP performance. Coefficient of thermal expansion (CoTE) and modulus of elasticity of concrete as affected by coarse aggregate are good examples. It is primarily due to the way CRCP responds to temperature and moisture variations. TxDOT recognized the deficiency in the specifications for materials, and took a step to correct this deficiency. Deficiencies in construction quality are responsible for the majority of the distresses in CRCP in Texas. The construction of CRCP is stipulated in the Item 360 of the Standard Specifications. In general, the Item 360 is well structured, and the requirements are reasonable. If CRCP is constructed in accordance with Item 360 and 421, the distress rate of CRCP in Texas would be lower than currently exists. The best way to build quality CRCP is to ensure that it is constructed in the way stipulated in the Items 421 and 360, which is most efficiently achieved by proper inspection during construction. Ensuring proper inspection requires both the inspectors with knowledge and experience and their presence during construction. Over the years, there were two general trends in TxDOT that did not help to improve CRCP. One is the reduction in the number of project inspectors due to the downsizing of the agency. The other is the loss of experienced inspectors through retirement.

There is not much that can be done to address the reduced number of inspectors available, at least in the short term. However, proper training could compensate the adverse effects of the loss of experienced inspectors. This implementation project was aimed at providing just-in-time training for CRCP construction and rehabilitation projects.

1.2 Objectives

The primary objective of this project was to provide training to project inspectors and engineers involved in CRCP construction and rehabilitation. There were three areas of topics covered in this project. They were:

- (1) Key materials and construction issues of CRCP for optimum performance,
- (2) Full- and partial-depth repairs of CRCP, and
- (3) How to prevent and repair lane separations in concrete pavement.

To achieve the objectives more efficiently, training materials were developed in MS Powerpoint and trainings were provided to project personnel who were involved in CRCP construction and rehabilitation projects.

The next chapter describes the development of the training material.

CHAPTER 2 DEVELOPMENT OF TRAINING MATERIAL

To develop effective training materials, the following sources were consulted:

- 1) District construction and maintenance staff
- 2) Publications on CRCP construction and rehabilitation
- 3) In-house materials accumulated from site visits

A list of the items to be included in the training material was developed and sent out to selected experienced district construction and maintenance staff, seeking their input on the appropriateness of the items or any suggested items to be included.

Compared with publications on CPCD, those related to CRCP are quite limited. This is partly due to the limited use of CRCP, especially in other states. Also, most of the publications are authored by students and educators at academic institutions, and they tend to be more theory, modeling, and experiment oriented. They rarely address problems that could occur in real construction projects.

The research team at Texas Tech University, through a number of research studies for TxDOT as well as forensic investigations sponsored by various districts and the Construction Division, accumulated a vast amount of information on CRCP construction and rehabilitation. The information was also utilized for the development of the training material.

Three modules of training materials were developed as described in Chapter 1. The remainder of this chapter provides a general overview of training material for each module. Detailed discussions of the training material contents are not provided in this report, because the discussions are included in the training materials.

2.1 Key Materials and Construction Issues of CRCP for Optimum Performance

The primary objective of this module is to present key issues in the area of materials and construction of CRCP for discussion so that the audience will recognize the issues and how to best resolve the issues during construction. To make the presentation more effective, this module is structured in the following sequence:

- 1) Basic information on the behavior of jointed concrete and continuously reinforced concrete pavement
- 2) General discussion of the basic CRCP responses to environmental (temperature and moisture variations) and wheel loading
- 3) CRCP distress types and potential causes
 - a. Classification of punchouts
 - b. Primary causes of each class of punchout
- 4) Review of TxDOT CRCP Design Standards

- a. Review of general notes
 - i. Tolerance for steel placement
 - ii. Saw cut requirement for slab widths more than 15 ft
 - iii. Saw cut depth requirement
 - iv. Proper installation of single piece tie bars
 - b. Review of drawings
 - i. Transverse construction joint
 - ii. Longitudinal contraction joint
 - iii. Free longitudinal joint detail
- 5) Review of Item 360
- a. Paving and QC plan
 - b. Concrete material strength requirement
 - c. Paving equipment in general
 - d. Job control strength
 - e. Reinforcing steel requirement
 - f. Staggering requirement
 - g. Transverse construction joint in CRCP and CPCD
 - h. Concrete delivery
 - i. Concrete placement
 - j. Concrete consolidation
 - k. Date imprinting
 - l. Temperature restrictions
 - m. Spreading and finishing
 - n. Finished surface
 - o. Maintenance of surface moisture
 - p. Curing
 - q. Sawing joints
 - r. Protection of pavement
 - s. Pavement thickness tolerance
 - t. Payment
- 6) Review of Item 361
- a. Epoxy injection practice
 - b. Experimental results of epoxy grouting tie bars

The above subjects are presented with pictures from actual construction, along with practices that are conforming to specification requirements and those that are not conforming.

2.2 Full- and Partial-Depth Repair of Continuously Reinforced Concrete

Pavement

Compared with CPCD, one of the disadvantages of CRCP is the cost and difficulty of the repairs of distresses. The average cost of CRCP full-depth repairs (FDRs) is in the

range of \$175 to \$200 per square yard, which is quite expensive. In addition, the performance of the repairs has not been always good, quite often requiring repairs of repairs done previously. CRCP is built where traffic is relatively high, and the repairs cause traffic delays. It is desirable to repair CRCP distresses in a correct way, so that the repairs become effective for a long time. Observations made on CRCP repairs in Texas revealed discrepancies between specification requirements and actual practices, resulting in poor performance. In addition, there are deficiencies in Item 361 itself. Many distresses in CRCP are not extended through the slab depth; rather, they are confined in the portion of the slab above the longitudinal steel. In these distresses, longitudinal steel is in good condition, and only the concrete above the longitudinal steel needs to be repaired. Traditionally, TxDOT conducted full-depth repairs for these distresses. FDRs necessarily require cutting the longitudinal steel. Once longitudinal steel is cut in CRCP, it is quite a challenge to restore the continuity of the longitudinal reinforcement. It is best to keep the longitudinal steel intact when possible. Partial-depth repair (PDR) is the best option in this case. In this module, PDR practice is presented in detail, so that this practice can be more prevalent, which will save TxDOT budget while improving the performance of repairs.

This module is structured in the following sequence:

- 1) General CRCP behavior and performance
- 2) General discussion of distresses in CRCP
- 3) Evaluation of the performance of FDRs
- 4) Case study of FDR on IH 40 in Amarillo
- 5) Review of Specification Item 361
 - a. Epoxy grouting of tie bars
 - b. Steel spacing requirement in the design standards
 - c. Grout retention disk requirement
 - d. Base repair requirement
 - e. Preparation of base for CPCD and CRCP repairs
 - f. The use of concrete as base repair material
 - g. Pullout strength of tiebar demonstration requirement
 - h. Epoxy grouting of tiebars
 - i. Acceptable drilling methods
- 6) Partial depth repair
 - a. General description
 - b. Partial depth repair demonstration
 - c. Review of new special specification for partial depth repairs

2.3 How to Prevent and Repair Lane Separations in Concrete Pavements

In Portland cement concrete pavement, lanes are tied together by tiebars and

transverse steel at longitudinal warping joints and by tiebars only at longitudinal construction joints. If the lanes are not tied together, the potential for lane separation increases. Tying lanes together provides two primary benefits: (1) keeping the joint widths tight, which prevents or minimizes the infiltration of water and other non-compressible materials to the joints, and (2) improving load transfer efficiency, which will reduce the stresses in concrete due to wheel loading applications.

Traditionally, tiebar designs were based on so-called subgrade drag theory. The theory was developed in the 1930s when simple assumptions had to be made due to the unavailability of sophisticated computing devices. Simple assumptions made in the development of the subgrade drag theory substantially limited the validity of the theory. In this theory, the amount of tiebars needed is linearly proportional to the widths of the tied lanes. As traffic level increased, more lanes are used and the amount of tiebars and transverse steel also increased. To reduce the amount of transverse steel, at least one district in TxDOT used dowels at longitudinal construction joints. The use of dowels at longitudinal construction joints could lead to lane separations. The limitations of the subgrade drag theory resulted in steel designs that could harm the performance of CRCP. TxDOT Research Study 0-5444 examined the limitations of the theory, and concluded that the use of the theory results in much less conservative designs as the number of lanes tied together increases. The study also evaluated the stresses in transverse steel, and demonstrated that the stress level was quite low. Based on the findings, TxDOT revised its CRCP Design Standards in 2009. The training module developed aims at enhancing the efficiency of tiebars, thus preventing or minimizing the potential for lane separations,

The module is structured in the following sequence:

- 1) General discussion and demonstration of the importance of tying lanes together
- 2) Potential causes of lane separation
 - a. Poor quality tiebar installations
 - b. Improper tiebar/transverse steel design
 - c. Unstable base or subgrade volume changes
- 3) Construction Inspection Items
 - a. Tiebars
 - b. Tiebar spacing
 - c. Single-piece tiebars
 - d. Multi-piece tiebars
- 4) Repair of lane separation
 - a. Cross-stitching
 - b. Slot-stitching

CHAPTER 3 SUMMARY

As of 2010, the total lane mileage of CRCP in Texas accounts for about 5.4 percent of total lane mileage. On the other hand, CRCP carries about 25 percent of total traffic. It is quite important to TxDOT and the State to keep CRCP condition in a good condition. In-depth evaluations of CRCP in Texas reveal that the overall condition of CRCP is excellent, with actual performance exceeding intended design lives twice or three times in some projects. On the other hand, distresses do occur in CRCP. TxDOT's "Rigid Pavement Database" research study evaluated the distresses in CRCP, and discovered that most of the distresses were not due to the structural deficiency of the pavement system; rather, they were due to the quality issues in materials and construction. To further improve CRCP performance, enhancing the quality of materials and construction operations is more cost-effective than increasing slab thicknesses.

This implementation project aimed at enhancing the quality of the materials and construction operations for CRCP by developing training materials and providing training to TxDOT and contractor personnel. Three areas that need the most attention were identified:

- (1) materials and construction issues of CRCP for optimum performance,
- (2) full- and partial-depth repairs of CRCP, and
- (3) prevention and repair lane separations in concrete pavement.

For the development of training material, district construction and maintenance staff were consulted along with the review of publications on CRCP construction and rehabilitation. Also, the information gathered over the years under various TxDOT research studies was utilized.

Three modules of training materials were developed in the areas described above. Training was provided, either face-to-face or by webinar, to districts who were about to construct CRCP or to repair distresses. It is believed that the training provided enhanced the quality of the materials and construction, thus improving the performance of new CRCP or repairs. Since the training materials were developed, it is recommended that TxDOT and contractors routinely review them and, if necessary, further training be provided.