Technical Report Documentation Page

1. Report No. FHWA/TX-05/0-4398-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle APPLICABILITY OF ASPHALT CONCRETE OVERLAYS ON CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS		5. Report Date March 2003, Revised March 2004 6. Performing Organization Code
7. Author(s) Manuel Trevino, Terry Dossey, B. Frank McCullough, Yetkin Yildirim		8. Performing Organization Report No. 0-4398-1
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705-2650		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0-4398
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080; www.ntis.gov		13. Type of Report and Period Covered Research Report 9/1/2002-3/30/2004 14. Sponsoring Agency Code

15. Supplementary Notes

Project conducted in cooperation with the U.S. Department of Transportation, the Federal Highway Administration, and the Texas Department of Transportation.

16. Abstract

This report presents the research and recommendations on the use of asphalt concrete (AC) overlays to rehabilitate continuously reinforced concrete pavements (CRCP).

A thin bonded AC overlay may be an economical means to restore the riding quality of a CRCP. One of the main benefits of such an overlay is the reduction of dynamic impact loading, which in turn, increases the service life of the pavement structure by delaying its rate of deterioration. To make this possible, the rehabilitation must occur in a timely manner. Additional benefits of this rehabilitation strategy are a reduction in noise levels generated at the interface between vehicle tires and pavement, and a reduction in moisture infiltration into the substrata.

A thin AC overlay on CRCP, however, is incapable of providing any structural load-carrying enhancement to the pavement in question. Therefore, its applicability is limited to those pavements that are structurally sound. Any major distresses in the existing pavement should be repaired, as any unrepaired failures may reflect through the AC overlay.

The most common problems occurring with this type of rehabilitation are debonding of the overlay, reflection of distresses through the overlay and stripping of the asphalt.

A decision tree to be used at the project selection stage is provided as a tool to facilitate the decision of whether to utilize this type of rehabilitation.

17. Key Words	18. Distribution Statement
rehabilitation, asphalt concrete (AC), portland cement concrete pavement (PCCP), bonded concrete overlay (BCO), continuously reinforced concrete pavement (CRCP)	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	86	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Applicability of Asphalt Concrete Overlays on Continuously Reinforced Concrete Pavements

Manuel Trevino
Terry Dossey
B. Frank McCullough
Yetkin Yildirim

CTR Research Report:	4398-1
Report Date:	March 2003
Research Project:	0-4398
Research Project Title:	*Applicability of Asphalt Concrete Overlays on Continuously Reinforced Concrete Pavements*

This research was conducted for the Texas Department of Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration by the Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin.

Center for Transportation Research
The University of Texas at Austin
3208 Red River
Austin, TX 78705

www.utexas.edu/research/ctr

Disclaimers

Engineering Disclaimer

Acknowledgments

The authors express appreciation to Magdy Mikhail, Project Director, as well as the members of the Project Monitoring Committee, Andrew Wimsatt, German Claros, Dar-Hao Chen, Charles Gaskin and Dale Rand.

Table of Contents

List of Figures

List of Tables

1. Introduction

Through 35 years of experience, the Texas Department of Transportation (TxDOT) has found that in many cases a thin AC overlay on CRCP provides excellent performance and extends the life of the original pavement. Project 0-4398 was initiated by TxDOT to formulate the criteria and procedures needed to ensure that the thin AC overlay is used with the conditions that will extend the pavement life.

This first report documents the initial activities of the project relative to developing information through literature surveys, interviews, observation of in-service pavements, and developing a systems approach to establishing the procedures necessary. This chapter provides the background information, objectives, and scope of the report.

1.1 Background

Along the wide spectrum of pavement rehabilitation approaches, the use of thin-bonded asphalt concrete (AC) overlays on existing portland cement concrete pavements (PCCP) is a valuable technique for restoring the riding quality cost-effectively. Since thin AC overlays do not address structural deficiencies, normally a 2-in. thick layer or less is enough to remedy any surface problems and restore the pavement's functional capabilities. It should be acknowledged, however, that an AC overlay is not applicable in all situations and that a set of ideal conditions in the existing PCCP must occur for this rehabilitation to be successful. Furthermore, the purpose of the overlay rehabilitation should be analyzed before proceeding with an AC overlay at the project selection stage.

The primary benefits of applying a thin AC overlay on a continuously reinforced concrete pavement (CRCP) are:

a) restoration of the riding quality
b) reduction of dynamic impact loading
c) increase in the CRCP's service life by delaying its deterioration
d) reduction of moisture intrusion into the pavement structure, performing as a moisture barrier, thus, preserving the structural integrity of the subgrade
e) decrease in noise levels generated by traffic on a tined CRCP

The limitations of this type of rehabilitation are:

a) The thin AC overlay does not add structural capacity to the existing pavement; therefore, the CRCP has to be structurally sound.
b) Unrepaired CRCP distresses may reflect through the AC overlay.

This procedure has been used frequently in Texas, with mixed results. Some districts have had good experiences with these overlays, while others have reported premature failure of their overlays. Debonding is often cited as the primary cause of early failure, but slippage cracks, stripping, and softening of the asphalt are occasional problems.

1.2 Project Objective

The primary purpose of this study is to evaluate the causes for the AC overlays premature failures and ultimately to reduce or eliminate them.

The sub-objectives of the project are:

1. to study the field performance of thin AC overlays on CRCP
2. to summarize the best practices for the utilization of thin AC overlays on CRCP
3. to provide recommendations for preventing the debonding phenomenon
4. to provide recommendations on binder grades and tack coats for thin AC overlays

1.3 Scope

This project studies the applicability, design, and performance of thin AC overlays placed on CRCP. The literature review covers nationwide and international experiences with this type of rehabilitation, but the cases studied are limited to projects in the state of Texas, developed by TxDOT. For this purpose, the Center for Transportation Research (CTR) staff has contacted district offices and has selected tests sections to be studied for this project, the results of which will be presented herein.

1.4 Report Objectives

This first report of Research Project 4398 pursues the following objectives:

a) to present the results of the literature review

b) to discuss the findings from the District visits
c) to present results from selected test sections, and
d) to outline the approach for the development of a decision tree for thin AC overlays on CRCP

1.5 Report Organization

The report is organized as follows:

The introduction to the project research statement, objectives, and scope are presented in Chapter 1.

The literature review, covered in Chapter 2, presents both the conditions of the existing CRCP that are suitable for an AC overlay, and the asphalt characteristics for an AC overlay on CRCP.

Chapter 3 presents a discussion of the major performance issues of a thin AC overlay on CRCP, in light of the results of the literature review and previous research experiences with this kind of rehabilitation.

In Chapter 4 the first part of the Texas experience with this type of rehabilitation is discussed, featuring the TxDOT district contacts established by CTR to study test sections.

Chapter 5 presents the second part of the Texas experience with this rehabilitation strategy, showing the results of the initial field work conducted for the purpose of investigating the sections' performance.

Chapter 6 presents an introduction and a preliminary version of a decision tree, which is intended as a tool for the project selection stage, that will facilitate the assessment of the appropriateness of a thin AC overlay on CRCP projects.

Finally, Chapter 7 first summarizes the material in the report followed by conclusions and recommendations for future research.

2. Literature Review

In this chapter a review of the usage of thin asphalt concrete (AC) overlays on continuously reinforced concrete pavement (CRCP) is presented. This review encompasses the experiences with this type of rehabilitation both in Texas and elsewhere.

A comprehensive review of the literature was conducted in order to determine the experience of Texas and other states with thin asphalt overlays. Specific practices with separate techniques and designs were compared to find out about the overall success rate for each practice. A synthesis of the literature review was prepared, used to guide the investigation proposed in task 2. The literature search encompassed different aspects of AC overlays on CRCP, such as reflection cracking, bonding between layers, structural capacity, moisture damage, and rutting.

2.1 Use of AC Overlays on CRCP

AC overlays are the most common form of rehabilitation for PCC pavements. It is an economical and relatively easy solution for several CRCP upgrading needs.

AC overlays enhance the safety of the roads by improving skid resistance. Some AC mixes improve smoothness and drainage and reduce tire spray. AC allows for swift placement, low labor costs, and reduced drivers' and workers' risk in highway construction zones. Several states have successfully used AC overlays in rehabilitating interstate highways (Fickes 2000).

A study conducted in the 1970s by the Asphalt Institute (1977) demonstrated how a number of old concrete roads in several states have been strengthened and upgraded with AC overlays even when traffic increases, requiring either minimal maintenance or no maintenance at all in subsequent years, providing an extension to the original pavement life.

The following sections present findings and research endeavors that are focused on different aspects of AC overlay performance. The last section of this chapter is focused on the conditions of a CRCP as the substrate for an AC overlay.

2.2 Reflective Cracking

The primary source of distresses on the AC overlay is reflective cracking. A reflection crack is initiated by a discontinuity in the underlying layers that disseminates through the AC surface due to movement of the crack. Reflection cracks may be caused by:

- cracks or joints in an underlying concrete pavement
- low temperature cracks in the old HMA surface
- block cracks induced by the old HMA surface or those induced by subgrade soil cracking due to shrinkage whether stabilized or not
- longitudinal cracks in the old surface
- fatigue cracks in the old surface

Reflective cracking is a well-documented phenomenon. It occurs in pavement overlays that were placed over unprepared PCCP in poor condition. The pavements expand and contract as the concrete slab temperatures increase and decrease. As the cracks or joints open they induce tension on the bottom of the asphalt overlay. When the tensile stress exceeds the strength of the asphalt overlay, a reflective crack is initiated in the AC overlay at the PCCP interface (Figure 2.1). The cracks will ultimately propagate to the surface. Left unsealed, the crack will allow moisture into the aggregate base and subgrade resulting in premature failure.

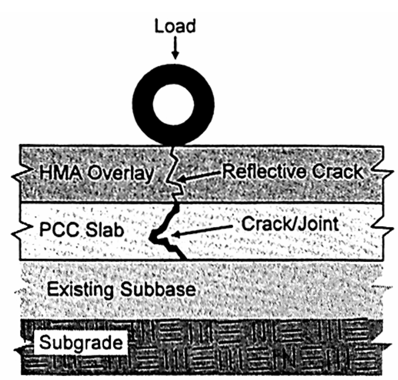

Figure 2.1 Reflective crack distress mechanism

There are many transportation agencies performing reflection cracking tests on some sections, including the ones below:

- Oregon Department of Transportation
- UK Highway Agency
- Missouri Department of Transportation
- North Dakota Department of Transportation
- Arizona Department of Transportation
- Illinois Department of Transportation
- Michigan Department of Transportation

Among these, the Arizona Department of Transportation (ADOT) has distinguished itself as a major leader in the use of AC overlays on CRCP. In one of the studies investigated in this review, a large-scale asphalt rubber (AR, also known as asphalt rubber friction course, ARFC) test project in Flagstaff, Arizona, on the very heavily trafficked Interstate 40, is examined (Way 2000). This section was designed and constructed by ADOT in 1990. The purpose of the test project was to determine whether a relatively thin overlay with AR could reduce reflective cracking. AR is a mixture of 80% hot paving-grade asphalt and 20% ground tire rubber. This mixture is also commonly referred to as the asphalt rubber wet process or McDonald process. The overlay project was built on top of a very badly cracked concrete pavement that was in need of reconstruction. It is reported that the AR overlay has performed beyond original expectations. After nine years of service the overlay was still nearly crack-free, with good ride, virtually no rutting or maintenance, and good skid resistance. The benefits of using AR on this project represent about $18 million in construction savings and four years' less construction time. Strategic Highway Research Program SPS-6 test sections constructed in conjunction with the project further illustrate the very good performance of AR. Results of this project have led to widespread use of AR hot mixes throughout Arizona. On the basis of this work, over 2,000 mi. of successfully performing AR pavements have been constructed since 1990.

The ADOT, in cooperation with the Federal Highway Administration and the private industry designed and constructed numerous experimental paving projects from 1993 through 2001. These were constructed in a variety of different Arizona climatic zones representing hot desert climates and cold snowfall mountainous regions. Traffic truck loading levels also varied from state highways to major interstate freeways. The purpose of all of these projects was to implement new laboratory tests developed as part of the SHRP and the Superpave Models to characterize cracking and rutting of various hot mix asphalt types. The fatigue-cracking test is the four-point bending beam test. The rutting test is the repetitive simple shear test at constant height and the triaxial creep test. As a result of this early experimental work, the ADOT adopted the SHRP asphalt grading system in 1997 for all paving projects. SHRP consensus aggregate properties with regard to a greater degree of crushed coarse, and fine particles and the fine aggregate angularity were adopted as well in 1997. Asphalt rubber open graded friction courses and gap graded mixes continue to be used to complement the structural AC layers as the final wearing surface (Partl 2003).

ADOT, among its experiments with different mixes, has also experimented with Smoothseal, which is a thin overlay, generally between 0.5 and 1.5 in. thick. It comes in two types, A and B, and it is a good example of a thin, dense-graded overlay. It has also been used in Ohio for many years. Asphalt rubber is a blend of liquid asphalt and ground tire rubber, used throughout Arizona. Michigan has developed an ultra-thin overlay as an alternative to micro surfacing, which is similar to a sand asphalt mix (Hansen 2003).

Due to budget constraints, ADOT has sought an alternative to using new asphalt for a roadway rehabilitation project in Yavapai County. By mixing recycled asphalt pavement (RAP) with a polymer-modified asphalt surface sealer (PASS), this RAP/PASS method made use of asphalt millings that had been stockpiled over the years. The method enabled the county to find an inexpensive way to meet the ADOT's minimum stability requirements. In addition, costs were further reduced by adding 6 percent more mixing water while increasing the mixing time. The correct moisture-to- emulsion ratio was maintained and the results of this procedure proved satisfactory (Better Roads 2003).

The use of tire rubber in asphalt pavement materials has been investigated since the 1960s. The main objective of highway engineers was to enhance the properties and performance of conventional bituminous materials and mixtures with the use of rubber from scrap tires. Charles McDonald started his work in the early 1960's developing a highly elastic maintenance surface patch material by using crumb rubber. Asphalt-rubber modified mixtures were used in Sweden since the early 1970's. In 1968, ADOT placed its first stress absorbing membrane (SAM), using an asphalt rubber binder, followed by the placement of a stress absorbing membrane interlayer (SAMI) in 1972, and a hot mix asphalt open graded friction course with an asphalt rubber binder in 1975. The environmental concerns related to the disposal of an estimated 240 million passenger vehicle tires and 40 million truck tires discarded each year in the U.S., and the 1991 ISTEA mandate on the tire rubber use in federally founded projects, generated a significant momentum and interest in the investigation of rubber modified materials (Goulias 1997).

Some studies have demonstrated that the utilization of SAMIs is conducive to a significant reduction of reflective cracking. To gauge the SAMI effectiveness, various types of fabric were analyzed and the bitumen/fabric bond strengths measured using a simple 'Pull-off' test in a study conducted by Arizona University (Woodside 1996). Fabric structure and rate of spray of emulsion tack-coat were found to be the variables that had a most significant effect. In addition, it was found that absorption and retention of water from the tack-coat was a major factor. A series of samples consisting of fabrics sandwiched between asphalt cores were manufactured and sheared by a direct shear mechanism. Additional samples were tested in a creep shear test. The variables considered included emulsion tack-coat rate, fabric type, structure, and fabric orientation. The first two were found to have considerable effect, whilst the latter had virtually no effect. SAMIs have proven to reduce the likelihood of damage and the need for large reconstruction work. The pavement life may be extended by 50% and that of an asphalt overlay by up to 200% (Woodside 1997).

In another study on SAMIs (Dondi 1997), it was found that polymeric interlayers such as geosynthetics appear to be able to delay the surface cracking due to reflection fissures from the underlying layers of damaged bituminous pavements. They are usually laid over a bituminous tack coat prior to the construction of an overlay. The effectiveness of the insertion of geosynthetics in the top asphalt layers is examined by means of the following experiment. A steel box filled in the lower half with rubber simulates the road pavement. In the top half, two bituminous concrete layers with different interlayers were placed. In some specimens, deep grooves were made in order to examine a damaged existing pavement. Fatigue behavior was simulated in the laboratory by applying a maximum of 500,000 cycles of loading at a frequency of 5 Hz. Although there was no improvement in the overall stiffness before the occurrence of a certain degree of cracking, the results of the reinforced specimens showed the advantages of interlayers insertion in terms of reduction of displacements and rut depths. By virtue of the results it is possible to consider insertion of geosynthetics in bituminous pavement as an effective rehabilitation technique.

Open-graded asphalt friction course (OGFC) is a cover aggregate used for seal coats created to improve skid resistance of road surfaces in the United States. OGFC was designed as an open mix with interconnecting voids which contributes to reduced splash, improved wet pavement skid resistance, hydroplaning, improved visibility of pavement markings, and noise reduction. The Federal Highway Administration encouraged testing of OGFC in several states. Some states discontinued use of OGFC because of premature ravelling, stripping of underlying AC course, clogging up of voids by sand, and difficulty in snow and ice control. The majority of states testing OGFC reported positive experiences but concluded that good design and construction practice are necessary for improved performance. OGFC is currently being used by Washington, Oregon, California, Nevada, Arizona, Florida, and Georgia (Kandhal 2001).

On more of the description of research endeavors developed in Arizona on this topic, the following study, related to design applied to reflective crack control, produced an innovative mechanistically based pavement overlay design method that addresses reflective cracking (Sousa 2002). Both dense-graded AC and gap-graded asphalt rubber (wet process) mixes were studied in the laboratory and in the field to derive the necessary mechanistic relationships and statistically based equations. The models proposed are based on a finite element model that closely approximates actual field phenomena. Many field test sections, mainly in Arizona, were studied during the course of the research. Other AC mixes used for overlays may also be calibrated and used through the proposed method, but the relevant mix properties of any additional materials or environmental zones must first be determined. The two mix types studied are mainly used in the desert southwest region of Arizona and California.

A study by Owusu-Antwi et al. (1998) describes the development of a mechanistic-based performance model for predicting the amount of reflective cracks in composite

AC/PCCP structures. Data from the Long-Term Pavement Performance Database were used to develop the model. Using the principles of fracture mechanics, it is illustrated that a mechanistic-based model that closely models the real-life behavior of composite pavements and predicts the amount of reflective cracks can be developed. Because of the mechanistic nature of the model, it is particularly effective for performance prediction for design checks and pavement management. Furthermore, since the model can take into account the relative damaging effect of the actual axle loads in any traffic distribution, it has great potential for application in cost allocation.

Mukhtar and Dempsey studied interlayer stress-absorbing composite (ISAC) for mitigating reflection cracking in AC overlays (1996). To approach the reflection-cracking problem in AC overlays systematically, the properties of the materials to be used in an ISAC system were first identified. Various thermal/structural models and laboratory equipment were used for this purpose. A number of woven and non-woven geotextiles were selected and tested for their engineering properties such as tensile strength, initial modulus, modulus at failure, and thermal coefficient. Several samples of rubber asphalt were prepared by blending different ratios of crumb rubber with various types and ratios of asphalt cements at 400 ºF. These rubber asphalts were tested at different temperatures, and the effects of temperature and rate of deformation on their stiffness were evaluated. An ISAC layer was fabricated in the laboratory using the materials considered appropriate. Testing equipment was developed to evaluate the interfacial shear strength, and laboratory testing was performed to determine the shear strength of the fabricated ISAC layer under an AC overlay. The ISAC layer was evaluated for its effectiveness against reflection cracking. A laboratory pavement section with an AC overlay over a jointed PCC slab was constructed and placed in an environmental chamber. A mechanical device was used to simulate thermal strain in the slab and the joint was opened and closed at an extremely slow rate. The testing was conducted at 30 ºF and deterioration in the overlay was monitored using a sensitive device. The results from the laboratory evaluation-testing program indicated that the ISAC layer was highly effective in preventing reflection cracking in a 2.5-in. AC overlay. When compared to a control test section and a section using a commercially available reflection cracking control material, the ISAC layer provided for superior performance.

A research study entitled "Low-Temperature Stresses and Fracture Analysis of Asphalt Overlays" (Shalaby 1996), used a finite-element method to provide the stress intensity factors caused by temperature in cracked asphalt pavements. The study simulates the thermoelastic response by means of decoupled thermal and stress analyses. The stress intensity factors are obtained using a displacement formula for special crack-tip element or an energy balance principle. These factors are indicative of the crack propagation in thermal cooling cycles and can be used to evaluate pavement surface conditions and predict the service life. The three-dimensional analysis will be implemented to evaluate the severity and progression rate of transverse cracks that do not fully extend across the pavement lane. In this case, the lack of sufficient bonding layers and cracks in the underlayers effectively decreases the overlay service life period. By using the model and method proposed, it is possible to determine the effect of various parameters on low temperature cracking.

The Indiana Department of Transportation's research department evaluated two methods for reducing pavement cracking on asphalt overlays over concrete pavement on IH-74 in Indiana: cracking and seating prior to overlay and fiber reinforcement in the overlay mixture. The project was divided into several experimental sections and control sections. The control sections were overlaid by the conventional method for performance comparison with the experimental sections. Study results are based on seven years of pavement performance data. Results indicate that cracking and seating technique was successful in this project. The majority of the transverse cracks on the cracked and seated sections were thermal cracks, which were narrower and less severe than the reflective cracks on the control section. Fibers improved rutting resistance on both control and cracked and seated sections.

The previous research is presented in Jiang 1993 and 1994. The project was constructed in 1984 and 1985 and divided into several experimental sections and control sections. As a performance comparison with the experimental sections, the control sections were overlaid by the conventional method. The study results based on the seven-year pavement performance data indicated that the cracking and seating technique was successful in this project: it delayed most of the transverse cracks for five years. Most of the transverse cracks on the cracked and seated sections were thermal cracks, which were narrower and less severe than the reflective cracks on the control section. It was also found that the type of hammers used for cracking the concrete slabs had strong effects on pavement performance. The use of fibers in the overlay mixture further reduced transverse cracks on cracked and seated sections but did not improve the cracking resistance of the control sections. Fibers improved rutting resistance on both control and cracked and seated sections. However, the sections with fibers exhibited rapid decreases in pavement strength and rideability. Thicker overlays increased the construction costs significantly but did not reduce the transverse crack intensities. According to the pavement performance and the cost analyses, it is recommended that the thickness of asphalt overlay be determined only by the pavement strength requirement and not be increased as a means of cracking control.

2.3 Rutting

A potential problem with AC overlays is the rutting of the overlay itself. Rutting is a surface depression in the pavement's wheel path due to the traffic loads. Pavement uplift may occur along the sides of the rut. However, in many instances ruts are noticeable only after a rainfall, when the wheel paths are filled with water. Rutting stems from the permanent deformation in any of the pavement layers or the subgrade, usually caused by the consolidation or lateral movement of the materials due to traffic loads. Rutting can be caused by plastic movement of the asphalt mixing in hot weather or by inadequate compaction during construction. Significant rutting can lead to major structural failures and hydroplaning potential. Rutting is measured in square feet or square meters of surface area for a given severity level based on rut depth.

A severe rutting problem was experienced in two sections of an interstate highway in Arkansas in the 1980s. The fault was found to be related to the mix design of the overlay, which had to be removed and replaced (Flowers 1989).

A research study published by the Transportation Research Board (Saraf 1987), focused on AC overlay behavior under the traffic and environmental conditions of Texas by using the rutting history data on AC overlays on rigid pavement collected by the Center for Transportation Research (CTR). The data were collected from the sections that were originally built as CRCP. The results of the data analysis show that the rate of rutting was higher in the first year because of the initial compaction of material in the wheelpath. However, in the second year the pavement in between the wheelpaths gained more compaction than the wheelpaths themselves, and thus, rutting decreased in the second year. Nevertheless, rutting increased again in the years after full compaction of the lanes. The regression analysis developed to characterize the rutting behavior of AC overlays on CRCP indicated that overlay thickness was one of the significant predictors of rutting in overlays. Still, the age of the overlays was not very significant in this regression report. This may be due to the limited history of rutting data available at that time. The geographic location of the overlaid sections had a significant effect on the rutting as well. Obviously, the construction materials and other related items, which may vary by location, influenced the performance of overlays.

Another research study (Chen 2001) shows that, from time to time, TxDOT's districts have reported that the observed rutting on their highways is not reflected in the Pavement Management Information System (PMIS) data. The study provides the opportunity to compare results obtained with the rut-bar device and with those obtained with other devices, and to determine why the rut-bar measurements are different from field observations. Trenching data from ten different pavement locations in Texas were collected; rut depths were measured with several apparatuses before a trench was cut across the traffic lane. Careful measurement of each pavement layer was performed to evaluate the rutting in each layer. Frequently the rut-bar measured no rutting although there might have been 50 mm of rutting as measured with a straightedge. This is mainly because of the limitations of the current rut-bar setup, particularly the sensor spacing and rut-bar length. A profile alone is not enough to determine the layer in which rutting occurred. Material-related problems such as bleeding yielded wide-basin rutting that appears to be base or subgrade rutting when observed from the profile alone. Unless there is a clear dual-wheel rut, the profile alone is not adequate for determining the chief sources of rutting. This is a good indication that rutting occurs only within the AC surface layer. The recommended sensor spacing for routine data collection is 100 mm. The data analysis shows that at this spacing, it is 95 % accurate and capable of capturing dual-tire ruts.

The addition of polypropylene fibers to AC overlays over CRCP was implemented by the Mississippi Department of Transportation in 1986 on IH-59. The performance of this section was monitored for six years and compared to that of a control section without fibers. The test and control sections performed at the same level (Seshadri 1996).

2.4 Bonding

Even in the best existing slabs, in order to achieve the expected quality of bonded overlays, the bond must be maintained in all layers of the overlays to yield a monolithic structure. If the overlay and substrate perform independently, then the useful life of the overlay will be shortened because of the high traffic stress load on the relatively thin overlay. Therefore, the foremost criterion for the successful use of bonded overlays is attaining and maintaining the efficient bond.

There are several techniques used to enhance bond. Among these the most common are power brooming, power brooming with air blast, cement and water grouting, milling, and applying emulsion tack coat. The last two techniques, milling and application of tack coat have been found to be the most beneficial in improving bonding.

Asphalt tack coat is a light application of asphalt, normally asphalt diluted with water, which ensures proper bond between substrate and overlay to accomplish and maintain a monolithic structure that can withstand traffic and environmental loads. A strong tack coat guarantees the bond between pavement layers to transfer radial tensile and shear stresses from the overlay onto the entire pavement structure. Insufficient bond strength causes slippage cracking, debonding, distortion, and reduces the structural capacity, and at the same time, concentrates tensile stresses at the bottom of the wearing course, the overlay. Distortion, which results from asphalt layer instability, can take a number of different manifestations, such as shoving, pushing, corrugation, rutting, etc. The development of slippage cracks, crescent or half-moon shaped, is also a result of poor interfacial bond. The major reasons identified for debonding are (Tayebali 2000):

- Poor condition of the old pavement —presence of debris, dust, oil, rubber, dirt, water or any other non-adhesive materials
- Use of excessive or inadequate tack coat, or a non-uniform application of it
- Highly polished aggregate on the existing pavement, which may be water sensitive and / or use of a tack coat that may not be compatible with the polished aggregates.
- Use of mixture having a high sand content, especially with rounded particles

- Use of improper construction technique and lack of adequate degree of compaction of the AC layer.

The debonding may be caused by any one or by a combination of any of the issues listed above. Additionally, the following conditions may contribute to the occurrence of delaminations:

- Improper consideration of temperature and field conditions
- Excessive load repetitions and dynamic impact loading
- A very thin surface layer thickness

In practice, most of the delamination distresses can be attributed to either improper construction techniques or inadequate choice of tack coat.

Nevertheless, there is no consensus in the available research as to whether tack coats enhance interface strength. Research evaluating the influence of tack coats on interface shear strength reports mixed results.

For instance, the following study (Uzan 1978) evaluated the interface adhesion properties of asphalt layers based on laboratory shear tests. The asphalt used in preparation of the mixture and in the tack coat was Pen 60-70, at various application rates (0, 0.11, 0.22, 0.32, and 0.43 gal/sq. yd). Tests were conducted at two different temperatures, 77 ºF and 131 ºF, and at different stress levels. Tack coats reportedly increased interface strength. The optimum tack coat application rates yielding the maximum shear strength were 0.22 gal/sq. yd at 77 ºF, and 0.11 gal/sq. yd and 0.22 gal/sq. yd for a temperature of 131 ºF.

On the other hand, another similar study (Mrawira 1999) reported no benefit in using tack coats in terms of shear strength, in fact the study suggests tack coats weakened the interface, as the strength obtained was less, when compared to that obtained on non-tacked overlays. This study compared shear strengths of fresh overlays with and without tack coats. The tack coat used for the tests was slow-setting asphalt emulsion grade SS-1, applied at 0.06 gal/sq. yd, and the tests were conducted at 72 ºF, by applying a constant rate shearing load of 0.04 in./min.

Another laboratory study (Mohammad 2002) conducted in Louisiana, evaluated the practice of using tack coats and tested their optimum application rates. It examined various tack coats and test temperatures as well. The tack coats included two types of performance graded AC (PG64-22 and PG 76-22M) and four emulsions —CRS-2P (Cationic Rapid Setting), SS-1, CSS-1 and SS-1h. A Statistical analysis of the results indicated that CRS-2P provided significantly higher interface shear strength, which was therefore identified as the best performer. Its optimum rate of application was found to be 0.02 gal/sq. yd. At the lower testing temperature, increasing the application rate resulted in a decrease in interface shear strength; however, at the higher testing temperature, there was no variation of the strength obtained at different application rates. Even with the best tack coat as it performed during this study, the CRS-2P, applied at the optimum rate, provided only 83% of the monolithic mixture shear strength, which implies that the use of layers introduces weak zones at the interface, as compared to a non-overlaid pavement (single layer).

Studies conducted by the National Center for Asphalt Technology (NCAT) in Alabama, suggest a procedure for overlaying without tack coats. The following report, by the NCAT (Cooley 1999), documents a construction project west of Nashville, Tennessee, on IH-40 that did not use a tack coat during the placement of the AC overlay. This project was constructed in June 1998. For this project, the existing pavement was milled approximately 2 in. with the majority of the millings being used as RAP within the mixture being produced. Instead of sweeping the milled portion clean, the contractor lightly swept the milled surface, leaving a small amount of millings primarily in the bottom of the grooves. The new AC mixture was then placed directly onto the milled surface with no tack coat. The mixture applied is a polymer-modified base mix with a nominal maximum aggregate size of ¾ in. The premise of this methodology was that the grooved pavement in conjunction with the melting of the asphalt within the loose millings by the heat of the placed mixture would result in a bond between the placed mixture and underlying pavement, and a tack coat was not needed. The bond between the overlay and the underlying pavement was strong, and to verify it, core samples were extracted. The cores actually broke in the underlying pavement and not at the interface below the overlay. After this successful experiment, two other rehabilitation projects implementing the same procedure, one in Nashville and the other one in Memphis have shown encouraging results.

A study from North Carolina (Tayebali 2000) investigated the possible improper selection and/or application of tack coats as the cause for the excessive debonding and shoving observed in some pavements managed by NCDOT. Specifically, the use of CRS-2 emulsion versus the PG64-22 asphalt binder was investigated as a tack coat selection for those pavements. The performance test results for the evaluation of the bond strength of the in-situ cores showed that the PG64-22 binder used as tack coat provided a better interfacial bonding compared to the CRS-2 emulsion. Results of this investigation suggest that the delamination and shoving distresses in these pavements could be attributed to the combined effect of intermittent purging of baghouse fines in asphalt mixtures and the use of CRS-2 emulsion as tack coat. Once the moisture-damaged mixture is susceptible to shoving under traffic loading, the CRS-2 emulsion may not provide the tacking strength necessary for the surface layer to remain bonded to the lower layer, leading to delamination.

New technologies have enabled the development of new mixes to serve as tack coats, as the following article shows (Rabiot 1996). The improvement of the rheological properties of bitumens and residual binders provided by the addition of a polymer has resulted in a growing interest in polymer-modified bitumen emulsions. Understanding of the manufacturing process has enabled formulation of polymer-modified bitumen emulsions for various road applications, such as tack coats. One of the major advantages of these emulsions relative to unmodified bitumen emulsions is their applicability as tack coats, providing better interface shear strength, improving the distribution of the stresses, and increasing the resistance to deformation.

2.5 Drainage

Insufficient subsurface drainage is frequently a primary cause of pavement distresses that require reconstruction. The stiffness and shear strength of both the subgrade and foundation layers are adversely influenced by increases in moisture content. Therefore, when considering the causes of pavement distresses, drainage must be investigated thoroughly. Incoming water must be excluded, and an escape route must be provided for water already in the foundation. Unless the subgrade is permeable, a foundation drainage system is needed to ensure that the water table is below the top of the subgrade–ideally at least 300 mm below formation level. If drainage is found to be inadequate, it must be improved as an integral part of the reconstruction project, including structural overlays.

Aggregate base courses or subbases are usually not drained as intended. Some dense-graded granular bases may become saturated with water that cannot drain from the base. Subbases under some old concrete pavements get saturated with subsurface water, and concrete slabs start to pump water through the joints and cracks. If the concrete pavement has an AC overlay, the water under pressure can cause stripping and potholing of the overlays. Asphalt-treated permeable material (ATPM) can be used as a drainage layer between the concrete pavement and AC overlays. Longitudinal drains are needed only along the lower edge of traveled lanes in flat terrain. Lateral drains must be supplied in hilly or rolling terrain to intercept water in the drainage layer, for water is likely to flow longitudinally on steep grades. Reconstruction gives a unique opportunity to improve the existing drainage system, including additional methods such as transverse drains cut into the pavement structure and changes in the drainage pattern.

A collateral problem that commonly develops as a consequence of poor drainage is the corrosion of the reinforcement steel. A study developed by the Wisconsin Department of Transportation (Rutkowski 1994), shows that a significant number of CRCP sections constructed before 1984 are deteriorating prematurely because of the corrosion of the steel. The methods of rehabilitation used were (a) intensive and thorough concrete "super patching," (b) AC overlays of various thicknesses, (c) PCC thin overlay, (d) use of impermeable membranes, (e) reducing the existing CRCP to rubble (rubblize), and (f) placing an AC overlay. After four years of study on CRCP, the investigation showed that the asphalt overlays were the most successful and have become the recommended rehabilitation strategy.

2.6 Existing CRCP Conditions

The following literature findings address the behavior of AC overlays on CRCP from the standpoint of the conditions of the existing rigid pavement layer.

As mentioned earlier, the primary source of distresses on the AC overlay is reflective cracking. Several methods are available to minimize its occurrence regarding the CRCP; those consisting of slab reduction have been reported as the most cost-effective alternative (Thompson 1997), (Rommel 1999). Slab reduction procedures involve fracturing the

PCCP slab, thus reducing the size of the PCCP pieces to minimize differential movements at existing cracks. For AC overlays on CRCP, the slab reduction procedure is called rubblizing. It consists of breaking the slab into pieces less than one foot, reducing the slab to a high-strength granular base, which is then compacted, typically by a 10-ton vibratory roller (AASHTO 1993). There are several pavement-fracturing techniques, according to the equipment being used. In general, the procedure uses readily available construction equipment and no materials are either removed or added, therefore, it is cost-effective and energy efficient. A drawback is the reduction of the PCCP slab structural strength. Also, in some instances, it has been found that rubblization is not a viable option for certain concrete pavements because it may lead to inadequate performance (Niederquell 2000).

If no slab reduction is implemented, a successful AC overlay is still attainable. Rehabilitation should take place before there is significant surface distress (Rutkowski 1994). Otherwise, an AC overlay may not be feasible. If the amount of deteriorated slab cracking and spalling is great, a complete removal and replacement of the existing slab may be needed. For an AC overlay to be placed, a full-depth repair of cracks, spalls, punchouts and deteriorated repairs is necessary. Settlements of the slab should be fixed by AC level-up, slab-jacking or localized reconstruction. Faulting or pumping of the slab should be corrected by edge-drains. The full-depth repairs should be continuously reinforced with steel tied or welded to the existing reinforcement steel to provide load transfer and slab continuity. Existing AC patches in CRCP should be removed and replaced with reinforced PCCP (AASHTO 1993, Thompson 1997).

Another source of distress are the high tensile and shear stresses related to movement of the old concrete slab and the resulting composite nature of the new pavement section (flexible/rigid section). AC overlay layers are also subjected to rutting-type distresses, which are triggered by the increasingly heavy truck gross weights and high tire pressures, often more than 120 psi (Noureldin 1989).

The dynamic behavior under impact of the composite pavement section formed by the existing PCCP and the AC overlay has been analyzed using finite element models. One of these studies investigated the propagation of dynamic displacements induced in the pavement layers under the action of an impact load similar to that utilized in the falling weight deflectometer test. The results revealed the existence of time shifts between the maximum displacements by each layer, independent of the type of bond existing at the interfaces (Shoukry 1997). Another study involving finite element method and fracture mechanics analyzed the effects on reflective of factors cracking such as width of delamination, interface condition, crack length, and thickness of the AC overlay. The results show that it is not economical to prevent reflective cracking only by increasing the overlay thickness (Abd-El-Halim 2000).

AC overlays significantly reduce deflections and extend the pavement life for several years, when the existing CRCP is properly repaired prior to overlaying it. The use of epoxy to bond wide cracks together failed due to large movements of the CRCP. Wide cracks not patched on the existing CRCP appear in the overlay after one year (Barnett 1981).

Other alternatives for reducing reflection cracking have been tested. An experiment in Virginia implemented the use of sand to break the bond at the overlay interface, and the application of a fabric that has a high tensile stress as a stress-relieving layer at the interface. Neither method was effective in reducing the incidence of reflection cracking where differential movements occur (McGhee 1979). However, a similar experiment conducted by the Missouri Department of Transportation using a technology called sand anti-fracture (SAF), accomplished positive preliminary results. SAF is similar to the method used in the Virginia experiment, but besides the fine aggregate a highly polymerized AC was added into the mixture, which was placed between the PCC pavement and the AC overlay. The purpose of the SAF one-inch layer is to retard reflective cracking and reduce PCC repair costs (Blomberg 2000).

AC overlays over CRCP have exhibited good behavior and compared favorably to other means of strengthening CRCP, such as undersealing, subdrains, and concrete shoulder methods. These comparisons refer to deflection measurements, crack counts, and general condition surveys. The tests were conducted on a section of IH-65 south of Indianapolis, Ind. (Virkler 1978). AC overlays also fared better than other procedures implemented as means of restoring CRCP deteriorated by corrosion-related distresses (Rutkowski 1994).

A study in Bowie County, in Texas, analyzed the performance of an AC overlay placed on an old rigid pavement. The overlay restored the riding quality but only slowed, not reversed, the fatigue process on the underlying structure. The research paper is entitled "Case Study of Overlays Performance on Rigid Pavement in Bowie County, Texas" (McCullough 1996). In order to study the overlay's effectiveness, a condition survey, roughness measurements, and deflection measurements were taken before and after the removal of an old flexible overlay and after the removal of the construction of new asphalt overlay. The amounts of deflections on the old and new overlays were approximately equal, both giving approximately equal structural contributions. Comparing the deflections of the old and new overlay and the net effect of the structural overlay, it showed that the thin asphalt overlay does not contribute much to the structural capacity of the pavement. Therefore, the significant reduction in failures that was observed after the initial overlay indicates that it was caused not by reduction of the normal load stresses, but by the impact load stresses developed by the roughness from swelling clays in the substrata.

2.7 Summary

The following statements summarize the literature review:

- A thin AC overlay does not increase the structural capacity.
- Bonding between layers is important.
- Milling and tack coat are the most important factors regarding bond.
- Repetitive thin overlays are cost-effective.
- High moisture content increases the probability of debonding and stripping.
- Using proper materials is important to control rutting.

3. Discussion of AC Overlay

3.1 Behavior and Performance

This chapter discusses the main aspects that affect the behavior of thin asphalt concrete (AC) overlays placed on continuously reinforced concrete pavements (CRCP). These aspects relate to both the rigid part of the structure (i.e., the CRCP) before being rehabilitated, as well as to the composite structure after rehabilitation. Subjects such as dynamic loading and its attenuation by an overlay, debonding problems of the overlay, and other modes of failure are analyzed, all of which have an influence in the performance of the structure.

Preliminary review of the literature and field experience clearly shows that the causes of early failures on an overlaid CRCP can be divided into two categories: (1) uncorrected problems with the existing PCCP, and (2) inadequate design of the AC overlay. PCC problems may be related to such factors as inadequate structural capacity, unrepaired failures and cracks, poor surface preparation, or excessive moisture content. On the asphalt side, proper design of every component of the asphalt must be undertaken with good bonding and water seal in mind. Thus, it is important that the study address both sides of the problem.

Case studies and statewide analyses using the Texas Rigid Pavement Database have shown conclusively that timely application of even a thin AC overlay can extend the useable life of rigid pavements by restoring the riding quality and therefore reducing dynamic loading of the pavement structure. Sealing out water infiltration also has a significant effect in the eastern areas of the state. However, for these overlays to work consistently, a systematic approach must be developed that matches the existing pavement to the design of the AC overlay for optimal effectiveness.

3.2 Underlying Principles

In order to establish sound and comprehensive guidelines for designing and constructing thin AC overlays on CRCP, some basic principles and background information must be fully understood. An in-depth analysis of both the performance of CRCP and key issues associated with thin AC overlays on CRCP is critical to this research.

Accordingly, there are two parts to this problem: (1) assessing the appropriateness of thin AC overlay on a candidate CRCP section, and (2) designing and constructing the AC overlay for maximum effectiveness. CRCP issues will be discussed first, followed by AC issues.

3.2.1 Factors that Affect CRCP Performance

Like other pavements, CRCP deteriorates with the accumulation of traffic loading. However, traffic is not the only factor causing the deterioration of CRCP. There are several other factors that can accelerate the deterioration process if they are not properly addressed (Taute 1980). These factors are briefly discussed below.

1) Dynamic Loading

Vehicles can produce significant dynamic loads on the pavement if they move at high speed on a rough pavement, especially at discontinuities of a rigid pavement such as joints or cracks. The dynamic loads will certainly accelerate the deterioration process of a CRCP if the pavement gets rougher, resulting in increased loading by trucks as their suspensions react to the rough road.

2) Moisture

Rigid pavements, including CRCP, are subjected to various moisture and temperature variations that may result in significant stresses in the pavements. Surface or subsurface moisture may enter the roadbed material supporting a pavement and cause softening of the subgrade, which in turn will increase the stresses in the pavement due to wheel loads. Moisture can also lead to the creation of voids in rigid pavements through pumping, with high pavement stress concentrations subsequently occurring over the voids.

3) Temperature

Temperature changes can increase the tensile stresses in rigid pavements in two ways: one is through volumetric changes of the pavement slab with time, and the other one involves warping stresses in the pavement slab caused by vertical temperature differentials from top to bottom of the slab. Therefore, the larger the temperature differentials by either mechanism, the higher the temperature-induced stresses in the pavement. In other words, temperature change is another factor that accelerates the deterioration process of a rigid pavement. Any effective control or reduction of the stresses induced by the factors described above would slow down the pavement deterioration process and prolong the service life of a rigid pavement.

3.2.2 Discussion of Dynamic Loading

Even though pavements are designed based on static loading conditions, the effects of dynamic loading do accelerate the deterioration of a pavement. In particular, because of the relatively high stiffness of rigid pavement slab, any extra roughness on the pavement slab will produce a significant amount of dynamic loading on the pavement. The dynamic load can go as high as twice that of the applied static load on a pavement, as illustrated by the relationship between pavement profile and dynamic loading in Figure 3.1. Research has shown that even lightly loaded trucks can generate 18 kips of dynamic load; yet they are generally ignored in traffic counts.

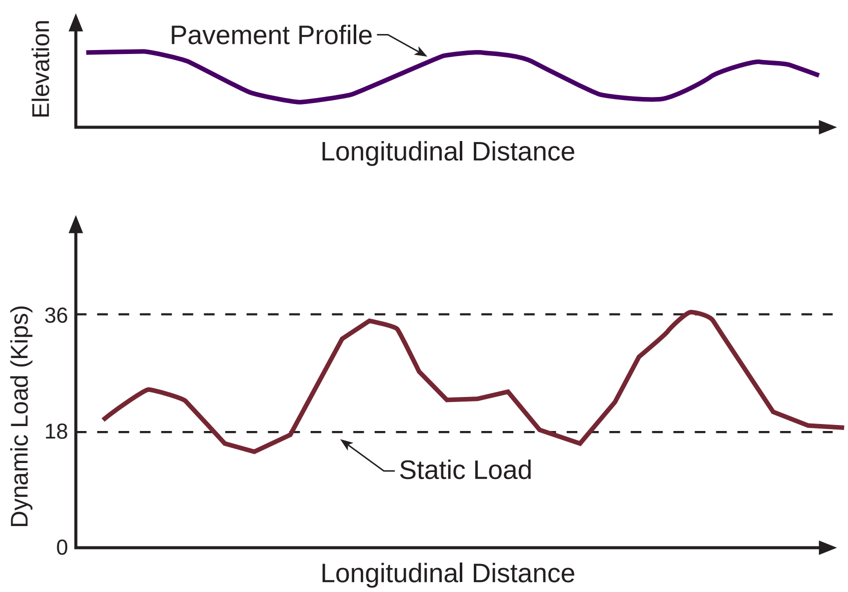

Figure 3.1 The relationship between pavement profile and dynamic loading

The higher dynamic loads definitely produce additional stresses in the pavement that can accelerate the deterioration rate of the pavement. Unfortunately, the deterioration rate is not a linear function, but rather a geometric function to the fourth power or greater, for instance, if the load is doubled, the deterioration would be on the order of sixteen times greater. In order to preserve the service life of a pavement, it is important that the dynamic load be reduced to the minimal level by reducing the pavement roughness.

3.2.3 Functions of Thin AC Overlays

Even though thin AC overlays do not add any extra structural capacity to the original pavement, it has been proven that properly designed and well-constructed thin AC overlays do increase the service life of a pavement. For example, a case study of a 2-inch AC overlay on IH-30 in Bowie County revealed over the seven-year life of the AC overlay, the CRCP deterioration rate went from an excessive rate (greater than 3 failures/mile/yr.) to approximately zero. Because the AC overlay started to get rough, the AC overlay was removed and replaced before the CRCP started to deteriorate again (McCullough 1996).

The increase in rigid pavement life by thin AC overlays may be explained by examining its impact on the factors that affect the performance of rigid pavements. From the earlier discussions it is clear that CRCP is normally at low stress levels. Therefore, stress concentrations in rigid pavements caused by factors discussed in previous sections are one of the primary reasons for accelerated pavement deterioration. Fortunately, many of the factors may be reduced significantly by a thin AC overlay:

- A thin AC overlay may work as an effective barrier to stop moisture from intruding into the pavement structure, thus reducing the potential erosion of the roadbed support resulting from the moisture intrusion.
- The warping stresses in a rigid pavement may be reduced because the thin AC overlay helps reduce the vertical temperature differentials along the depth of the rigid pavement slab. However, AC layers may at times increase the temperature by as much as 10 °C, so this needs to be studied in depth.
- The dynamic loads on rigid pavements may be reduced, because a thin AC overlay can help provide a smoother pavement surface profile. In addition, the relatively low stiffness of the AC material can also contribute to the reduction of the dynamic loads on the pavements.

In other words, thin AC overlays do help to delay the deterioration and to increase the service life of a rigid pavement through the mechanisms explained earlier, even if they do not add any structural capacity to the pavement. Therefore, it is, not difficult to understand that thin AC overlays are effective only if the original rigid pavement still has sufficient structural capacity. Otherwise, a different overlay strategy should be used when the original rigid pavement has deteriorated to a degree where there is not enough structural capacity to carry the traffic load. For example, a thick AC overlay, a BCO, or an unbonded concrete overlay should be used to increase the structural capacity of the pavement. From the point of view of thin AC overlay design and construction, this means that as a minimum, a condition survey must be conducted to ensure that the original pavement has sufficient structural capacity. Otherwise, a thin AC overlay should not be used. It is also worth noting that a thin AC overlay may also have some negative impact on the pavement structure if the overlay is not properly designed and constructed. For example, water may be trapped inside the pavement structure because of the overlay. These issues must be considered when developing the guidelines.

3.2.4 Debonding Problems and Possible Solutions

The primary function of thin AC overlays over CRCP is to improve the surface smoothness of the underlying CRCP. However, to be able to fulfill this function in a sustainable manner, the AC has to remain structurally intact during its service life. This is where the composite system normally fails. To address the problem, it is necessary to understand its nature.

There are at least three possible reasons for this type of phenomenon to occur:

a) lack of bond between layers
b) stripping of the asphalt from the aggregate
c) softening of asphalt binder

These problems might result from factors such as improper design and construction, moisture effect, and incompatibility between materials. The possible mechanisms for and solutions to these problems are summarized in Table 3.1. However, in general, the primary cause of distress in most cases is moisture in some form or other (Marienfeld 1999).

Although the sources of water and the mechanics of how moisture damages a pavement are understood, these principles are often not incorporated into the design. In some cases, it may indeed be difficult to do so, especially in pavement rehabilitation. Often this leads to treatment of the pavement damage, ignoring the root cause of the problem-moisture. Many cases of moisture damage have been reported (Marienfeld 1999).

The primary source of moisture in pavement structures is rainwater, which infiltrates the pavement. Moisture can also enter a pavement from subsurface sources such as:

- cracks in the surface that have not been maintained
- penetration through the surface due to poor density
- poor maintenance, i.e., grass and plants growing on the shoulder acting as a barricade to drainage.

Moisture may also enter a pavement from subsurface flow such as from a spring:

- vertical capillary movement of moisture from the subsurface water table
- lateral seepage from high water in a clogged ditch that has not been properly maintained

It is accepted that distress within the lower pavement structure will be taken care of in the process of evaluation of the integrity of the CRCP structure. The problems caused by the presence of water in its different forms in or near the surface of the pavement structure are many. Presence of water between layers or in the overlaid cracks results in debonding or delamination phenomena. Pore water pressures due to traffic loading cause very high stresses resulting in debonding of layers or even decompaction of the AC.

Stripping is the physical separation of the asphalt cement and aggregate produced by the loss of adhesion between the asphalt cement and aggregate surface, primarily due to the presence of moisture. This is often due to incompatibility between the aggregates and the asphalt. Softening is a general loss of stability of a mixture that is caused by a loss of cohesion due to moisture within the asphalt. These two basic kinds of moisture-induced damage produce various forms of distress at the surface of a flexible pavement, such as shoving, rutting, or bleeding (Lee 1982).

The extent of damage caused by moisture depends on the source and the volume of the water. Pavements are exposed to different levels of moisture damage, with the severity of the damage dependent on how quickly the pavement structure drains after experiencing rainwater infiltration. For a given amount of infiltration, drainage time is a function of the type of stone, the gradation of the base, the thickness of the base, the contamination of the base by subgrade intrusion, and the slope of the base layer (Molenaar 1989).

In general, there are two ways to control moisture in pavement structures: by the use of subsurface drainage or by sealing the pavement to reduce infiltration through the pavement. The following discussion focuses on the infiltration of surface water.

Several methods have been used over the years to limit surface water infiltration through a pavement. These methods include interlayers of modified asphalts, asphalt and fiber, and fabric-reinforced asphalt. Other methods include surface treatments such as chip seals, slurry seals, and various other surface dressings. The effectiveness of the systems varies widely. Surface treatments tend to be short-term solutions, with cracking and infiltration returning quickly. Interlayers are protected by the overlay and as such tend to stay in place and be more effective, provided they do not fail due to entrapped water.

The cost of the systems also varies, which necessitates that a cost-benefit analysis be done to optimize the selection of an appropriate and effective system (Marienfeld 1999); that is, one that is designed and constructed such that there is no possibility of trapping water in the composite pavement structure. To prevent this problem, the source of the moisture should be understood before selection of this kind of moisture control method. The effect of this type of phenomenon was vividly demonstrated in a case study in the Fort Worth District (Walubita 2000).

3.2.5 Other Studies Conducted by CTR

In addition to the considerable insight gained by the MLS accelerated testing program, CTR maintains a rigid pavement database containing, among other things, performance histories for composite pavements (AC over PCCP) across the state over a 27-year period (Dossey 2000). For many PCC pavements, the database contains a complete distress history from construction to AC overlay and beyond. The sort of variables discussed above that may determine the success or failure of the AC overlay (such as ride, condition of the CRCP before overlay, and environmental conditions including rainfall, traffic exposure, and overlay thickness) is present in the database. Condition surveys were then continued on the overlaid sections after overlay, recording the manifestation of distress in the AC until failure and replacement of the overlay. Many such comprehensive histories are contained in the RP database and form the basis for an empirical analysis of AC overlay failure on a large-scale, statewide basis.

An additional analysis tool that has been utilized is the Rolling Dynamic Deflectometer (RDD). CTR has developed software for this device that can estimate not only the structural condition of the pavement and underlying layers, but also the load transfer across cracks and joints, which is important in CRCP and absolutely critical in jointed pavements (Dossey 1998). As discussed above, lack of structural support or poor load transfer in the rigid pavement would be a contraindication for thin AC overlay.

In the subsequent sections a classification of the modes of failure of a thin AC overlay over PCC pavements is presented, followed by a discussion of pertinent reports is presented to familiarize the reader with the extent of material available on the subject. The concluding section is a summary by distress type of the mechanisms producing the distress and techniques for mitigating and/or correcting the distress.

3.3 Modes of Failure

In the following subsection is a listing of the various modes of failure that a thin AC overlay over an existing PCC pavement may experience. A photograph and sketch of each failure mode are included.

Debonding

Definition of the problem: The bond must be maintained in all layers of the overlays to yield a monolithic structure. If the overlay and substrate perform independently, then the useful life of the overlay will be shortened because of the high traffic stress load on the relatively thin overlay.

Factors affecting:

- surface moisture content
- foundation support
- texture of the PCC
- degree of interface bonding

- joint spacing and/or crack spacing

Solutions:

- power brooming
- power brooming with air blast
- heavy shot blast
- milling
- tack coat

Stripping

Definition of the problem: Aggregate base courses or subbases are frequently not drained as intended. Some granular bases may become saturated with water that cannot drain from the base. Subbases under some old concrete pavements get saturated with subsurface water, and concrete slabs start to pump water through the joints and cracks. If the concrete pavement has an AC overlay, the water under pressure can cause stripping and potholing of the overlays.

Factors affecting:

- insufficient subsurface drainage
- aggregates susceptible to stripping

Solutions:

- Incoming water must be excluded, and an escape route must be provided for water already in the foundation.
- Determine the origin of the water, sealing the cracks before placing overlay
- Improve drainage, if possible. Asphalt-treated permeable material (ATPM) can be used as a drainage layer between the concrete pavement and HMA overlays. Longitudinal drains are needed only along the lower edge of traveled lanes in flat terrain. Lateral drains must be supplied in hilly or rolling terrain

to intercept water in the drainage layer, for water is likely to flow longitudinally on steep grades.

- Use proper interlayer.
- Specifications eliminate stripping susceptible aggregates.

Permanent Deformation (Rutting)

Definition of the problem: Rutting stems from the permanent deformation of the AC overlay, usually caused by the densification or lateral movement of the materials, that is, shoving due to traffic loads.

Figure 3.2 Rutting

Factors affecting:

- material properties (mix design)
- inadequate AC stiffness/viscosity
- weak tensile strength
- inadequate compaction of AC during construction
- interface bonding between the overlay and the original surface
- overlay thickness
- excessive periods of hot weather
- large number of heavily loaded trucks

Solutions:

- proper material control during construction

- aggregate with crushed faces
- good density control
- fiber reinforcement in the overlay mixture
- proper mix design
- use higher viscosity asphalt
- produce stiffer mix, i.e., high resilient modulus

Reflection Cracking

Definition of the problem: Reflection cracking is defined as a crack that is initiated by discontinuity such as a joint crack or punchout in the underlying PCC layers, which propagates through the HMA surface due to vertical and/or horizontal movement of the crack.

Figure 3.3 Reflection cracking

Factors affecting:

- cracks, joints, or punchouts in an underlying concrete pavement
- large daily and annual temperature changes
- inadequate load transfer in joints or cracks
- brittle asphalt mixtures
- truck wheel load repetitions

Solutions:

- Improve load transfer capabilities of PCCP.

- Properly repair PCCP to restore continuity of the pavement.
- Use cross-stitching to minimize movement of the cracks.
- Insert dowels at joints in PCC pavements using keyways.
- Replace existing joint with prefabricated joint with dowel bars.
- Use special material combinations to reduce stiffness of AC or reduce stresses between AC and PCCP.
- Apply asphalt rubber (AR) overlay.
- Use polymeric interlayers, such as geosynthetics (they are usually laid over a bituminous tack coat prior to the construction of an overlay).
- Add interlayer stress-absorbing composite (ISAC).
- Use glasgrid blocks

Slippage Cracking

Definition of the problem: Slippage cracks are crescent- or U-shaped cracks with the bottom of the U pointing in the direction of applied force. Cracks are mainly due to poor bond between the surface and the next layer of the pavement structure and/or low strength of the surface mix. They are generally observed on paths where vehicles brake, accelerate, or turn. Cracks can be repaired by removing the slipped part and replacing with new material.

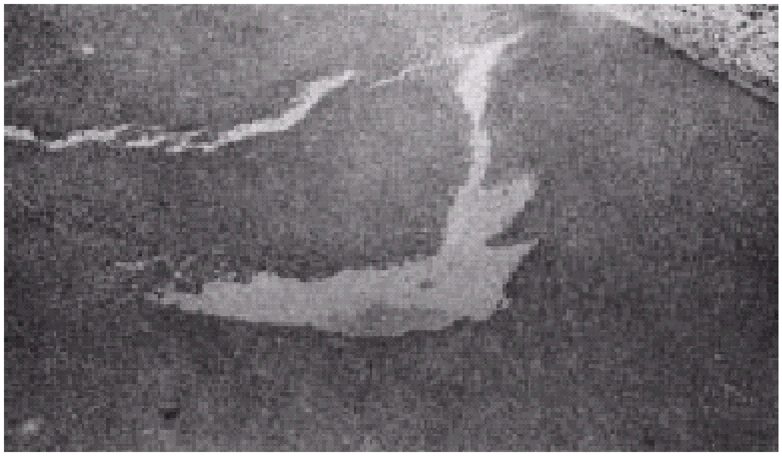

Figure 3.4 Slippage cracking

Factors affecting:

- bonding between overlay and PCC (bonding is affected by dust, oil, dirt, rubber, water, and other non-adhesive material between layers).
- poor overlay surface preparation
- tack coat: over-applied or insufficient tack coat
- poor tack coats
- excessive asphalt binder in mix
- poor stability of asphalt mixture
- high sand content
- moisture

Solution:

- Remove surface layer until good bonding is found, patch with plant-mixed asphalt material, and tuck with an asphalt emulsion.

3.4 Summary

In this chapter a discussion of the factors affecting the behavior and performance of thin AC overlays on CRCP has been presented. It is based on the literature review, shown in the previous chapter, as well as on experiences from other studies. One of the most critical concerns with an overlay of this kind is bonding, because delamination is a frequent cause of failure. The alternatives for addressing this problem, as well as solutions to other failure modes have been discussed in detail.

4. Texas Experience–Staff Interviews

In Chapter 2 an extensive literature review investigating the use of asphalt concrete (AC) overlays on continuously reinforced concrete pavements (CRCP) was presented. The purpose of this study is to identify factors contributing to the failure of thin AC overlays on CRCP, so that a comprehensive decision tree can be developed recommending changes to design and construction practice, in order to reduce the number of these early-age failures. Ultimately, a number of factors must be taken into account, including but not limited to:

1) structural condition of the existing CRCP
2) surface treatment and repairs prior to overlay
3) mix design of the AC overlay
4) construction practice

The discussion of AC overlay behavior and performance, presented in Chapter 3, serves as a background for identifying the problems occurring in Texas, and for understanding the underlying mechanisms causing them.

The next step is to focus on specific, recent experiences with AC overlays of district personnel in Texas, identifying the designs and procedures used in each district, and the successes and failures experienced with each. The investigation of the performance of some of these sections as reported by district personnel is presented in this chapter. The first section of it is dedicated to a discussion of the approach to establish the district contacts in order to enable the researchers to pursue the investigation. The second section summarizes the results from interviews of district representatives as to their experiences with AC overlays of CRCP.

4.1 District Contacts

4.1.1 Interview Approach

In order to achieve the optimal results from the district staff, a systematic approach was developed and then the interview format was prepared. First, a list of district pavement engineers was gathered, including their contact information. At this stage, the information was collected solely by means of interviews. Accordingly, a list of questions was prepared pertaining to the four general areas listed above, and the pavement engineers in each district were contacted via telephone. By this means, the general state of the practice in Texas was determined, with interesting responses noted for follow-up interviews.

Using the information obtained from the districts, projects can be selected to fill the experimental factorial of the study, which can be summarized as well- vs. poor-performing overlays, placed in wet/cold, wet/warm, dry/cold, and dry/warm areas of the state. This will require visiting the district offices, obtaining additional information on the pavement project, and marking the pavement for subsequent condition surveys, if needed. Note that there are three general types of overlay projects to be studied: overlays that are still in place, overlays that have failed and have been replaced, and overlays that are about to be placed. In the case of overlays that have already been replaced, the researchers will rely on district information to determine the probable cause of failure.

4.1.2 Interview Format

District pavement engineers are busy people who are often in the field and difficult to contact in person, but they are even less likely to return a complicated e-mail survey. It was a very high priority to avoid wasting the PE's time, as future contact may be necessary. Accordingly, the questions were broken into tiers and were kept brief. As soon as it became clear from the interview that no further useful information could be obtained, the interview was terminated. With some flexibility given to the interviewer, the basic questions were:

(1) Do you have AC overlays on CRCP in your district? If so, where are they located? If not, thank you for your time.

(2) What type(s) of CRCP distress triggered the decision to overlay?

(3) How successful have your overlays been in restoring the ride quality of your pavements? For how long, in terms of time or traffic loadings? How do your overlays typically fail? What do you suspect to be the cause for these failures?

(4) What is your current practice, and what has been your practice, historically, for overlaying with AC over CRCP? What designs have worked best and worst for you? Why?

(5) Can you point us to some specific sections that (a) have overlays that are failing too soon, (b) have overlays that are performing beyond your expectations, (c) are about to be overlaid, and/or (d) have new designs such as porous friction course (PFC), or are interesting in some other way?

(6) Anything else you would like to tell us about? Thank you very much for your time. We will be happy to share our findings with you later, if you are interested.

4.2 Telephone Survey Summaries by District

Nine districts were contacted, using contact information and suggestions supplied by Gary Graham, Moon Won, and Andrew Wimsatt of TxDOT. The full list of contact information is attached as Appendix A below. All of the persons contacted were the PE of their district, unless otherwise noted. All were very friendly and helpful and agreed to further contact as needed.

4.2.1 Forth Worth District (Andrew Wimsatt, interviewed in person)

Fort Worth District is in the area of the state designated as cold and (relatively) dry. That is, it is located just to the east of the Thornthwaite zero moisture contour and well north of the freeze/thaw line. Heavy traffic loadings occur in this urban district, which has many miles of AC over CRCP, satisfying the first requirement for test section selection.

Fort Worth has a mixture of well- and poor-performing overlays, and a very wide variety of mix designs and overlay procedures are employed. In the Fort Worth District, old CRCP, which is most often eight-inch thick, was most likely to be overlaid due to failures in excess of 15 per mile, and usually overlaid with two-inch type D AC. AC10 mix was used with a 3% latex binder up until 1997. Currently, PG76-22L, PG76-22S, and PG76-22MG are used depending on the project. Fort Worth has also enjoyed success using only Petromat and a tack coat. Table 4.1 identifies some candidate sections for study in Fort Worth.

Table 4.1 Possible test sections in Fort Worth District

Project	*County–District*	*Overlay Type*	*Problem*	*Cause*	*Precautions and Performance*
IH-30	*Tarrant County–Fort Worth*	*SMA*	*Rutting*	*Mix design (multi-grade binder)*	*Replaced inside lane with Type D AC, performing well now*

IH-20	*Palo Pinto and Erath Counties–Fort Worth*	*CMHB*	*Rutting*	*Mix design*	*Replaced with 2 in. of Type D AC in 1996, performing well*
	Fort Worth District	*2" AC Type D*	*None–AC20 Petromat prevents reflective cracks*		*Since the early 1980s, the performance of those overlays have been excellent;, many of them are still in place*
SH-121	*Fort Worth District*	*2" AC Type D*	*None*	*AC 10 w/3% latex, lightweight aggregate*	*Microsurfacing is placed on the AC; performing well*
Conclusion: Based on the experience, 2-in. Type D AC overlays on CRCP were found to be the best overlay types.					

Additionally, during the interview, Mr. Wimsatt informed the research team of two other sections elsewhere, that he has knowledge of, and that he considers good candidates for AC overlay rehabilitation. These are listed in Table 4.2. One section is in Childress and the other one is in Houston.

Table 4.2 Additional possible test sections recommended by Mr. Wimsatt

Project	*County–District*	*Overlay Type*	*Problem*	*Cause*	*Precautions and Performance*
IH-40	*Wheeler County–Childress District*	*SMA*	*Debonding*	*Excessive water–one year's rainfall in a month*	*Crumb rubber seal coat may cause problem bonding to concrete*
IH-45	*Waller County–Houston*	*AC*	*Rutting–Call Larry Buttler*		*No difference between 2" AC overlays and thicker overlays*

4.2.2 Yoakum District (Gerald Freytag)

Yoakum District is located south and east of Austin, in an area of the state considered wet and warm. Because IH-10 and US-59 pass through the district, there are many miles of CRCP overlaid with AC. In fact, all CRCP built prior to the mid-1980s is now covered in AC. Yoakum also has some newer and thicker CRCP sections on SH-71, which are non-overlaid. These sections and others are currently being monitored in the Texas Rigid Pavement Database.

Like the Fort Worth District, Yoakum has had to overlay its primarily eight-inch old CRCP when the number of punchouts per mile had become excessive and the ride score had dropped. The overlays on these sections are almost all two to 3.5 inches AC (Type C and Type D), constructed through the 1990s. SuperPave mix designs are now in use, starting in 2001. A hot rubber seal is used on all projects to prevent water infiltration.

As far as problems with overlays, AC overlays in this district tend to fail by rutting and loss of skid resistance, as would be expected for warm weather and heavy traffic loads. There have also been some problems with delamination of the upper layer when the lower layer had stripped. Mr. Freytag suggested that in these cases the old mix should have been milled off.

4.2.3 San Antonio District (Pat Downey)

San Antonio District does not have a great deal of CRCP, mostly using asphalt. Mr. Downey identified only two projects, one of which is very old (constructed in the late 1970s early 1980s) and located at the intersection of Loop 410 and IH-35, in the northeast area of the city. A newer section of eleven-inch-thick CRCP is located at IH-10 and Loop 410, in the northwest part of the city. Both sections are still non-overlaid, though the older CRCP is scheduled to be overlaid in the near future because of overtining, which has broken out and lost its skid resistance, becoming very noisy as well. This pavement has no structural problems (stable soils) but will be overlaid because of its poor skid resistance and an increased accident rate.

In general, San Antonio has had problems with CRCP due to their use of limestone fines (28% acid insoluble), which tend to polish under traffic application and become too smooth for safety, especially in wet weather. San Antonio now uses SuperPave design. Thus, there is only one candidate section for study in the San Antonio District, which is the overlay to be built on IH-35 later this year. It would be a long-term study project.

4.2.4 Waco District (Billy Pigg)

Waco District is in Central Texas, and is well-known to the researchers due to a great deal of study on the Hillsboro projects on IH-35 and the post-tensioned pavement near the same area. In fact, most of Waco's CRCP is on IH-35, excluding some level-ups near Baylor University. Almost all of the CRCP is 30 to 40 years old, and most has been overlaid. Mr. Pigg suggested we visit a 3.5-in. hot mix overlay on IH-35 in Hill County, north of Hillsboro.

In general, the AC overlays are performing well, the exception being when unrepaired failures in the CRCP have reflected up through the AC. This corresponds to the primary trigger for overlay in this district. There are also some rutting problems on the thicker overlays. Waco has had some debonding problems, but not when thicker lifts (1.5 to 2 in.) are used. They were using Type D mix and then changed to Type C. They are now using SuperPave designs, gap grade. They are also looking at porous friction course but have not actually built any at this time.

Because of Waco's central location, it does not fit clearly into the cold, warm, wet, or dry categories of the factorial experiment. A few test sections with interesting designs may be chosen from this district, but at present no sections have been designated.

4.2.5 Childress District (Danny Brown)

Childress District is located in northwest Texas, in the Panhandle region. It can be considered cold and dry. Unfortunately, there are only 30 miles of CRCP in the district, all on IH-40, in Wheeler County. This pavement is thirteen-inches thick and relatively new, not overlaid now nor likely to be in the near future. Childress District has some overlaid jointed pavement, but no overlaid CRCP.

No test sections from Childress District will be selected for study in this research project.

4.2.6 Bryan District (Darlene Goehl)

Bryan District is located in a section of the state that can be considered wet and warm. Like Houston, which is only 90 miles away, Bryan District has used a great deal of siliceous aggregates in its CRCP, leading to a substantial amount of spalling, close cracking, and punchouts, which in turn have led to many lane miles of AC overlays on CRCP.

Bryan's CRCPs are split between two locations: the SH-6 bypass (formerly a textbook example of severe spalling), which was overlaid with two inches of AC between 1998 and 2000, and a 100-mile section of IH-45 which is entirely AC over CRCP in its entirety. The overlays on IH-45 are four- to eight-inch CMHB, no open-graded. There is some rutting on sections that were 64-22 AC, understandable with the heavy traffic loads. In Ms. Goehl's opinion, the 64-22 mix leads to early rutting.

In Walker County an AC/CRCP had the top lift become unbonded, with the bottom lift still bonded well to the CRCP. Ms. Goehl speculates that this was a tack coat problem, as no emulsion was used-AC only. However, this is the exception, as most of the IH-45 overlays are performing well.

Bryan District is also of interest because a recent forensic study was conducted there on IH-45 through Huntsville, near the Montgomery County line, where a 4-in./2-in. type C overlay debonded, resulting in fatigue cracking and popups. Mr. Joe Leidy of TxDOT supervised this study, the results of which may be very useful to this project. Mr. Dar Hao Chen, of TxDOT subsequently informed the research team that the failure in this case was related to a glass grid placed between AC layers and not to a debonding between CRCP and AC. The district then removed the top AC surface layer as well as the glass grid, and overlaid it with OGFC. He informed that the structure has performed well after one year of service.

4.2.7 Atlanta District (James Joslin and Miles Garrison)

Atlanta District is located in northeast Texas, clearly in the wet and cold section of the State. Because of its location and the large amount of data available from current research in the area, Atlanta is high on the list for potential test sections. Atlanta has many lane miles of AC over CRCP, including the entire length of IH-20 in the district, as well as all of IH-30. In addition, there is a long stretch of new thirteen-inch CRCP (non-overlaid) on US-59, stretching from Atlanta to Texarkana, and from Atlanta to Lyndon.

The decision to overlay these eight- to nine-inch-thick CRCP was primarily due to the need for frequent maintenance. The CRCP was built in the early 1960s, overlaid for the first time in the early 1980s, and is now experiencing the second round of overlays. Thus, the first overlays lasted 20 years with routine maintenance (including hot in-place recycle). They eventually failed due to rutting and stripping in the lower layers. There was no debonding, but there was some cracking which was a secondary reason for the overlay. The district had trouble with gravel aggregates initially, but with the addition of hydrated lime is now achieving a satisfactory result.

Atlanta District is currently using two-inch B + two-inch C plus modifier PG7622 on the top layer. The old design was two-inch Type C + 1.5-inch Type D AC20 without modifier; this was the design for the first overlay. They are not currently using any open graded mixes nor water permeable mixes. Mr. Joslin also reports that some of the old CMHB on IH-20 is still giving good service.

Currently, at least three research projects are underway in Atlanta District: 4185 (CTR), 4126 (TTI, Joe Button), and an IAC (CTR, Ken Stokoe, Mike Murphy, Dar Hao Chen). Data from this research should be very valuable to this research project.

4.2.8 Houston District (Magdy Mikhail)

Houston District is located in southeast Texas, which is classified as warm and wet. There is relatively little mileage of AC over CRCP in Houston, because Houston generally chooses to overlay CRCP with bonded concrete overlays (BCOs). Houston also has a good amount of concrete pavement that has never been overlaid. In any case, it is fair to say that Houston is not having a significant problem with AC overlays over CRCPs. There is an LTPP test section of AC over CRCP on Loop 610, but in general, Houston is not a primary candidate for test section selection. Bryan District is preferable in this temperature/moisture category.

4.2.9 Dallas District (Jim Hunt)

Dallas District is located in northeast Texas, slightly to the west of Atlanta District. Therefore, it is classified as cold and fairly wet. Dallas has many miles of AC over CRCP, including all of IH-35 and IH-35E within the district, plus IH-30 in the downtown area and Loop 635 E. Needless to say, Dallas is a very high-traffic urban area, so the loadings on these overlays are punishing.

Nevertheless, Mr. Hunt reports that Dallas does not have much trouble with overlays, reflection cracking being the eventual mode of failure. Dallas District will be trying a fiber mesh interlayer in an attempt to reduce crack propagation up from the concrete. The newer CRCP in Dallas, which is thirteen inches and was built in the late 1980s, is still in very good condition.

The older CRCP, generally eight-inches, was typically overlaid because of surface distress (including cracking and punchouts) and / or spalling, after giving 25 to 30 years of service with ADTs in the 300,000 + range.

The old procedure for AC overlay was to perform a full-depth repair, if needed, followed by rotomilling, a clean and seal on the joints and cracks, a two-inch strip membrane, seal coat, and a one- to three-inch level up. It was estimated that this procedure would yield 8 to 10 years of additional life under the heavy traffic, but instead it has typically provided 15 years.

The new procedure now includes a latex modifier, SBS, Type C & D mix, and is not open-graded.

4.2.10 El Paso District (Tomas Saenz)

El Paso District is undeniably dry and usually hot. The District has not been contacted at this time because the researchers know that most of the CRCP in El Paso is either non-overlaid or has been rehabilitated with a BCO. It may be deemed advantageous at some time in the future to contact them.

5. Texas Experience–Condition Surveys

Throughout the summer of 2002, several CRCP projects that have been overlaid with AC pavement have been visited and surveyed by the CTR field crew. The purpose of these visits is to investigate and document the performance of AC overlays placed on CRCPs.

This project attempts to conduct diagnostic field studies on selected study sections with AC overlay treatments on CRCP that have resulted in both good and bad performances. In this stage, field data is being collected from the sections to identify important factors that could have affected pavement performance. Further stages will involve testing of the sections for evaluation of moisture problems, evaluation of the AC mixes, tack coat applications, deflection evaluations, etc. Thus, this stage serves as background study for subsequent research activities. In this section, the condition survey evaluation of the pavement segments is documented. The surveys cover selected CRCP sections that have been overlaid with AC in districts 13 (Yoakum), 17 (Bryan), and 19 (Atlanta).

5.1 Results

5.1.1 Yoakum District

Four sections on IH-10 were selected from the Yoakum District, two in Fayette County and two in Colorado County, near Weimar. These sections were surveyed on June 18 and 19, 2002. Table 5.1 illustrates basic information on the sections, such as highway, beginning and end, reference markers, direction, and section identification numbers.

Table 5.1 Yoakum District surveyed sections

Distr.	ID		COUNTY	HWY	RM1	DISPL	RM2	DISPL	DIR	CTRL	SEC
13	13010	1	FAYETTE	IH10	676	0	676	-0.2	W	535	7
13	13010	2	FAYETTE	IH10	675	0	675	-0.2	W	535	7
13	13010	3	COLORADO	IH10	685	0.2	685	0	W	535	8
13	13010	4	COLORADO	IH10	685	0	685	-0.2	W	535	8

Section 13010-1 is in acceptable condition, showing no distresses and only some shallow rutting, especially in the outside lane, as displayed in Figure 5.1. However, Section 13010-2, just down the road, is in poor condition.

The overall condition of sections 13010-2, 13010-3, and 13010-4 exemplifies poor-performing asphalt overlays built on top of CRCP. In some areas the AC overlay has been milled off, and a new AC overlay has been placed as scheduled by TxDOT.

The distressed asphalt overlay shows mainly surface rutting and flushing at both wheel paths of the outside lane. In some cases, both lanes show signs of distress, but the outside lane is considerably more distressed than the inside lane. No cracking was found in the sections. Figures 5.1 to 5.4 display the conditions in which the pavement sections were found during the surveys.

Figure 5.1 Shallow rutting (<0.5 in.) and flushing of asphalt on section 13010-1

Figure 5.2 Image of CRCP underneath the AC layer that was milled off

Figure 5.3 Image of rutted and flushed wheel paths of the outside lane

Figure 5.4 End of distressed asphalt layer area, section 13010-4

After these surveys were completed, the district was contacted to find out background information on these sections on August 22, 2002. Mr. Gerald Freytag, District Pavement Engineer, informed CTR that all four sections would be repaired. The current AC overlays will be removed and replaced with new AC overlays. Some of this construction work has already started.

5.1.2 Bryan District

Nine sections were surveyed in Bryan District on August 14, 2002. Four of them are located in Walker County on IH-45, two in Brazos County on SH 6 and three on US 290 in Washington County as Table 5.2 shows.

Table 5.2 Bryan District surveyed sections

Distr.	ID		COUNTY	HWY	RM1	DISPL	RM2	DISPL	DIR	CTRL	SEC
17	17045	1	WALKER	IH45	118	0	118	0.2	N	675	6
17	17045	2	WALKER	IH45	119	0.3	119	0.5	N	675	6
17	17045	3	WALKER	IH45	116	0	116	-0.2	S	675	7
17	17045	4	WALKER	IH45	113	0.2	113	0	S	675	7
17	17006	1	BRAZOS	SH6	586	0.2	586	0	S	49	12
17	17006	2	BRAZOS	SH6	586	1.1	586	1.3	S	49	12
17	17290	1	WASHINGTON	US290	676	-0.2	676	0	E	114	9
17	17290	2	WASHINGTON	US290	676	-0.2	676	-0.4	W	114	9
17	17290	3	WASHINGTON	US290	674	-1.3	674	-1.5	W	114	9

All of the sections in Walker County on IH-45, except for one section (17045-2), had just been overlaid when the CTR field crew surveyed the pavement. In fact, the traffic control devices were still in place, which facilitated the surveyors' work, and part of the TxDOT crew was at the site. Being a brand new overlay, the condition was excellent, as shown in Figures 5.5, 5.6, and 5.7, where the old overlay on top of the CRCP shoulder has been milled off.

Figure 5.5 Beginning of section 17045-1 on northbound IH-45

Figure 5.6 Section 17045-1, recently overlaid

Figure 5.7 Section 17045-3, still showing non-resurfaced shoulder

Section 17045-2 has not been recently overlaid. Nevertheless it is in very good shape, as shown in Figure 5.8.

Figure 5.8 Beginning of section 17045-2

The two sections on SH 6 south in Brazos County did not exhibit a very good performance, with both presenting several distresses. Section 17006-1 had 25 transverse cracks with 5 spalls, while section 17006-2 had 2 transverse cracks (Figures 5.9 and 5.10).

Figure 5.9 Longitudinal crack next to the shoulder in section 17006-1 on SH 6 in Brazos County

Figure 5.10 Beginning of section 17006-2 with a transverse crack on southbound SH 6

There are three sections in Washington County, all of which are on US290, all of which looked in good shape, showing no distresses. The AC looks relatively new and it offers a good riding surface, as Figures 5.11 and 5.12 illustrate.

Figure 5.11 Section 17290-1 on eastbound US290

Figure 5.12 Section 17290-2

5.1.3 Atlanta District

There are nine sections in the Atlanta District, all of which are on IH-20 in Harrison County. These sections were surveyed on July 8, 2002. The sections are shown in Table 5.3.

Table 5.3 Atlanta District surveyed sections

Distr.	ID		COUNTY	HWY	RM1	DISPL	RM2	DISPL	DIR	CTRL	SEC
19	19020	1	HARRISON	IH20	611	0.1	611	0.3	E	495	8
19	19020	2	HARRISON	IH20	611	0.5	611	0.7	E	495	8
19	19020	3	HARRISON	IH20	612	0	612	0.2	E	495	8
19	19020	4	HARRISON	IH20	612	0.45	612	0.65	E	495	8
19	19020	5	HARRISON	IH20	613	0.1	613	0.3	E	495	8
19	19020	6	HARRISON	IH20	614	-0.2	614	-0.4	W	495	8
19	19020	7	HARRISON	IH20	613	-0.1	613	-0.3	W	495	8
19	19020	8	HARRISON	IH20	613	-0.8	614	0	W	495	8
19	19020	9	HARRISON	IH20	612	-0.7	612	-0.9	W	495	8

In general, the sections are in very good condition with no distresses, rutting, or signs of wear. The AC appears to be fairly new, given the smooth riding surface shown in Figures 5.13 to 5.16. The few minor distresses found in these sections are discussed below.

Figure 5.13 Section 19020-1

Figure 5.14 Section 19020-2

Figure 5.15 Section 19020-7

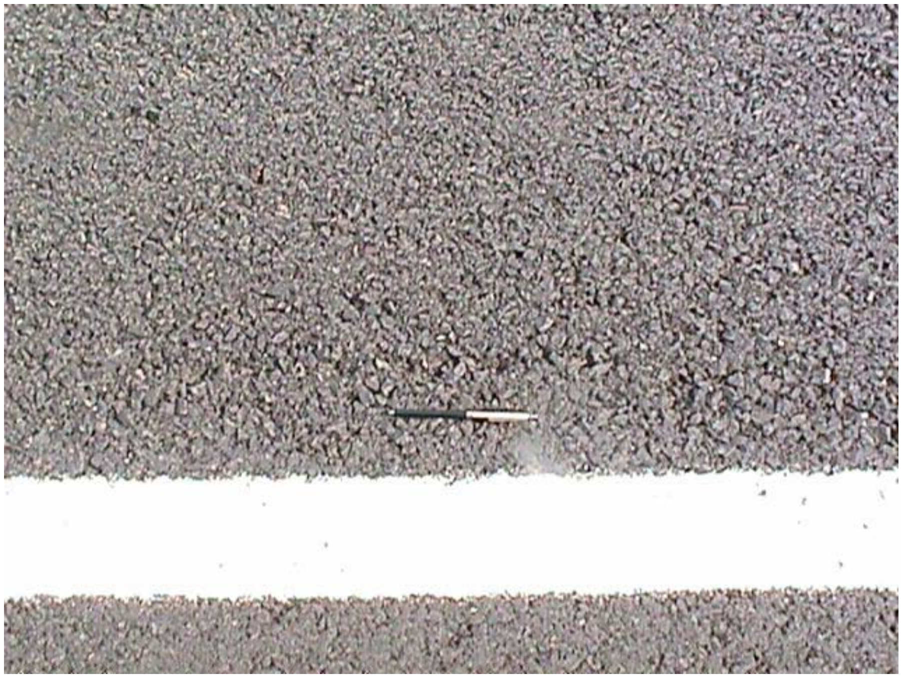

Figure 5.16 Section 19020-8

Section 19020-4 has a few small patches and one transverse crack, while section 19020-5 presents three cracks. None of these distresses is severe. There is a small delaminated area in section 19020-8; the delamination starts at the edge of the lane next to the shoulder, as shown in Figure 5.17.

Figure 5.17 AC overlay delamination in section 19020-8

5.2 Summary of Condition Surveys

Most of the sections surveyed showed good performance. Only the sections in the Yoakum District appear to have some severe problems. However, these sections are already being repaired by new AC overlays, which will be followed up as a useful resource for this investigation. The distresses in the Bryan and Atlanta Districts do not seem to be severe.

5.3 Next Steps

The next stage following the condition survey requires collecting background information on these sections, such as year of CRCP construction, year of AC overlay construction, and layer thicknesses. The district pavement engineers have already been contacted by CTR for this purpose.

With the condition survey information as well as the other field data collected from these and other projects, a decision tree including various criteria for the project selection will be developed. The current draft version of that decision tree is outlined in the following chapter.

6. Decision Tree Approach

This chapter presents the approach to be used in a decision tree for a thin asphalt concrete (AC) overlay to rehabilitate portland cement concrete pavement (PCCP). A decision tree is a tool with a systematic series of steps and decisions involved in the selection of a rehabilitation strategy, which considers both economical and technical factors. Therefore, the decision tree is to be implemented during the project selection stage.

In this chapter a preliminary version of a decision tree for thin AC overlays on continuously reinforced concrete pavement (CRCP) is presented. One of the goals of the development of this decision tree is to evaluate criteria that determine the appropriateness of this kind of rehabilitation. At the current stage of this research project, several criteria have been considered and have been incorporated in this preliminary version. However, as the research progresses, other criteria may be considered, and these will be included in the final version of the decision tree to be presented in a forthcoming report.

6.1 Initial Rehabilitation Decision

The rehabilitation need can be triggered by a number of factors affecting the existing pavement, primarily:

a) increase in traffic
b) pavement approaches the end of its service life
c) appearance of functional and/or structural deficiencies

Before any rehabilitation project decision is evaluated, it is necessary to consider the availability of resources.

6.2 Pavement Evaluation

Once the feasibility of a rehabilitation of any kind is confirmed, the first task is to assess the current condition of the pavement. The first step of this evaluation is to conduct a visual condition survey, recording transverse cracks as well as distresses such as punchouts and spalls. Roughness measurements are also part of the pavement condition assessment. The analysis at this stage may be completed by an estimation of the structural capacity of the pavement, for which deflection tests should be performed. Deflection tests will provide enough information to assess the subgrade support, the load transfer at pavement discontinuities, and to evaluate the overall structural integrity of the CRCP.

6.3 Evaluation of Distress Mechanisms

The distress mechanisms are the causes for the occurrence of failures in the pavement. In order for a rehabilitation procedure to address the cause of the problem it is essential to identify the distress mechanism first.

To identify the distress mechanism, the data from the previous step are analyzed. This includes analyzing the distresses recorded during the condition surveys, analyzing the deflections, backcalculating the pavement properties, and evaluating its structural soundness as well as the pavement profile.

At this point, with this information, it may be useful to analyze some basic statements on the applicability of a thin AC overlay on CRCP to make a preliminary determination of the overlay feasibility in order to continue with the project selection process:

- If the existing structure lacks structural capacity, then an AC overlay will not be the solution to the problem.
- If there is a dynamic impact loading problem due to poor profile, the AC overlay may be a good remedy.
- If the deflections show lack of subgrade support, the AC overlay will reduce roughness only but will not solve the foundation problem.

6.4 Decision Tree Criteria

Three criteria have been identified so far in this research project to establish the feasibility of a thin AC overlay for a CRCP. These are described in the following sections.

6.5 Condition Survey Criterion

This criterion is based on the computation of a pavement distress index (PDI). This index gives an indication of the occurrence and extension of distresses in a pavement section. The concept of the PDI is based on conducting a condition survey of the section, recording types, extension, and severity of the distresses encountered. A value of 100 is assigned initially to the section, from which subtractions are made according to the number of occurrences and severity of the distresses. Several types of distresses are considered along with various classes grouped by degree of severity. The following equation illustrates the concept of the PDI:

$$PDI = 100 - \sum_{i=1}^{n} \sum_{j=1}^{m} D_i \times S_{ij} \times E_{ij}$$

where:

D_i = deducted points for the ith type distress,

S_{ij} = weight of the jth severity class of the ith type of distress,

E_{ij} = extent of the jth severity class of the ith type distress

n = number of distress types,

m = number of severity classes

The purpose of calculating the PDI is to enable the designers to decide whether a section is suited for an AC overlay rehabilitation, in other words, to help discriminate between pavement sections in need of an AC overlay and those that do not need it. Therefore, once the PDI is computed for pavement sections, a discriminant analysis may be conducted to distinguish between those two types of sections, as exemplified in Fig 6.1, where the distributions of both are assumed normal, but with a different mean value, which will be established by a discriminant score based on their PDI.

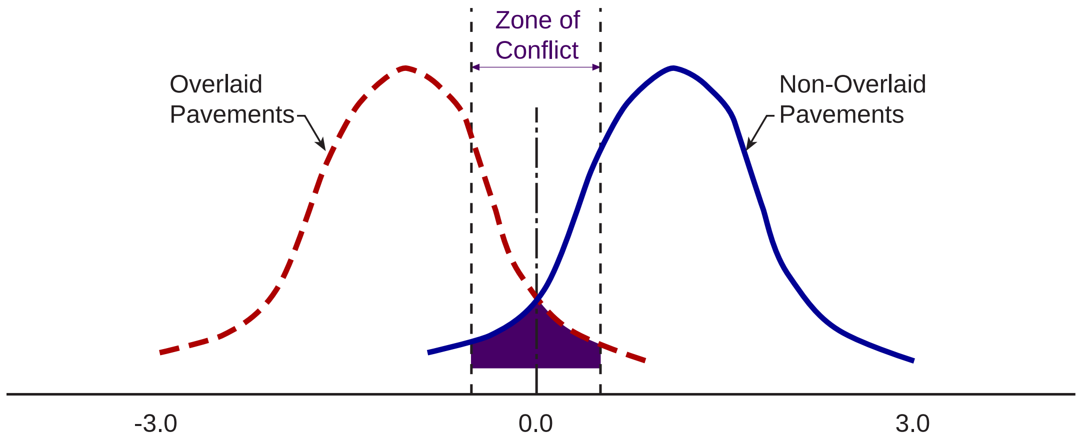

Figure 6.1 Discriminant analysis based on PDI

6.6 Profile Criterion

Improving the pavement profile is one of the areas in which a thin AC overlay may be more beneficial placed on a CRCP. Given that the CRCP is structurally sound and only has profile irregularities, a thin AC overlay may be the ideal rehabilitation, when placed in a timely manner.

However, if the occurrence of failures is extensive and if the failures are severe, the AC overlay may not be feasible, as the overlay placement requires all major failures to be fixed beforehand. Otherwise, in all likelihood, the newly placed overlay will imminently experience reflective cracking.

On the other hand, if the CRCP does not show profile problems, then the thin AC overlay may be unnecessary. The following charts in Fig 6.2 illustrate how the pavement profile affects the attainment of the original design life and the appearance of distresses. A pavement structure with a normal design profile, illustrated by the dashed line, will have a present serviceability index (PSI) of 4.5 and will be able to attain its designed life, carrying the design traffic (W_{18}) before reaching a specified number of distresses. A smoother pavement, such as that represented by the bold line, will be able to withstand a higher number of load applications before reaching that predetermined number of distresses and repairs. Given the smoothness of its profile, this pavement will likely have a PSI of 5. Conversely, rougher pavements like those represented by the thinner dotted lines, probably will not fulfill their design life, reaching the failure level at an earlier stage, before carrying the specified design traffic, and thus, deteriorating at a higher rate. The PSI values for these pavements will be lower than 4.5, unless the structure is rehabilitated. This criterion, which will be developed with experimental field data from selected projects, would be a useful aid in deciding when a thin AC overlay should be placed to provide the maximum benefit to the life of the structure. Overlay placement may occur anytime in the lifespan of the pavement as illustrated in the bottom chart of Fig. 6.2, and the development of this criterion will determine the ideal timing for the rehabilitation.

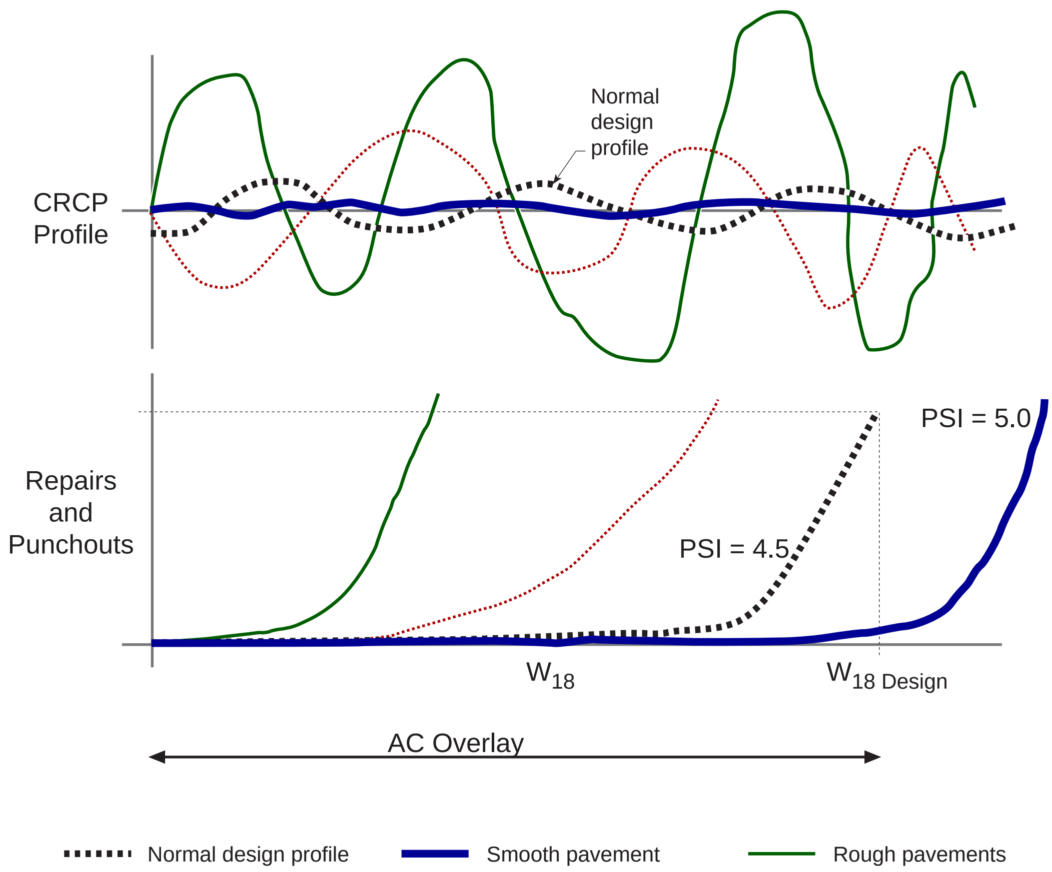

Figure 6.2 Pavement profile, serviceability, and design traffic

6.7 Deflections Criterion

Measurement of deflections on a pavement is a trustworthy indication of its structural capacity. If the deflections are high, the pavement in all likelihood has lost some of its structural integrity, in which case the application of a thin AC overlay may not be a beneficial solution.

If the CRCP has profile problems and high deflections, a thin AC overlay may help to alleviate the dynamic impact loading that occurs as a consequence of an irregular profile, but the overlay may be only a temporary solution, as the structural problem will have to be addressed in the future. However, when there is an irregular profile coupled with low deflections, the application of a thin AC overlay represents an ideal solution, since the low deflections indicate that the pavement is still structurally sound. Of course, if some of the decision criteria are not met, then other rehabilitation alternatives should be considered.

6.8 Decision Tree

This chapter is summarized with the illustration of the decision tree for thin AC overlays on CRCPs, depicted in Fig 6.3. This chart shows every step that has been considered, although new additions may improve the concept as this research project progresses. The establishment of the decision criteria is still in development. Thus, this is a preliminary version.

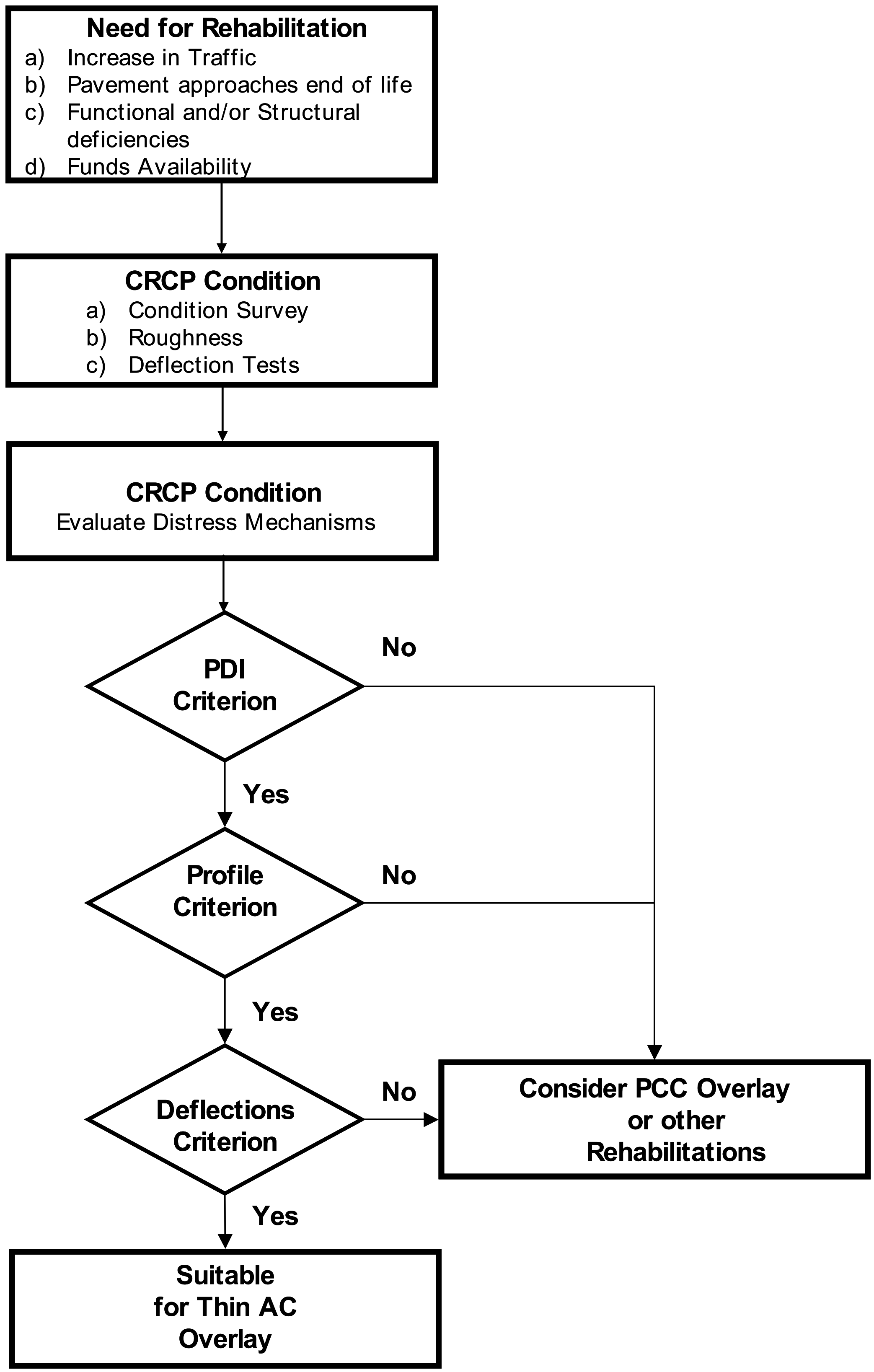

Figure 6.3 Decision tree for AC overlays on CRCP

7. Conclusions and Future Steps

This chapter summarizes this report, along with concluding remarks and the next steps to finalize this research project.

In Chapter 1, project objectives, scope and report objectives were discussed. Chapter 2 presented an extensive literature review on the topic of this report, the usage of thin asphalt concrete (AC) overlays on continuously reinforced concrete pavement (CRCP).

Chapter 3 discussed the main factors affecting the behavior and performance of this type of rehabilitation, both from the perspective of the rigid part of the structure, that is, before rehabilitation, as well as analyzing the composite structure (after the AC overlay has been constructed). These include dynamic loading, debonding, and other modes of failure.

In Chapter 4, the initial results of the contacts established by the research team with the TxDOT districts in regard to this type of rehabilitation and its past and current usage were shown. Chapter 5 presented the results of the field work undertaken in those sections recommended by the districts for study in this project.

In Chapter 6 a preliminary version of a decision tree for thin AC overlays on CRCP was presented, with three proposed criteria to evaluate the feasibility of this kind of rehabilitation.

7.1 Conclusions

The use of thin AC overlays constitutes an economical means of rehabilitation for a CRCP. Even though this restoration alternative does not provide any structural capacity to the original pavement, it is able to increase its service life by providing the following enhancements:

- working as an effective seal coat to prevent the intrusion of moisture into the underlying structure
- reducing warping stresses by diminishing the vertical temperature differentials along the depth of the CRCP slab
- reducing dynamic loads by smoothing the surface profile of the CRCP
- restoring the riding quality as the CRCP surface is smoothed
- delaying the normal CRCP deterioration

A thin AC overlay on a CRCP can be a feasible rehabilitation solution, provided that the following requirements are met:

a) There is a need for a non-structural rehabilitation, i.e., in spite of requiring an upgrade the pavement is still structurally sound.
b) The pavement profile indicates that dynamic impact loading is a cause for distresses.
c) The appearance of functional and/or structural deficiencies is at a stage when repairs are still economically feasible before the overlay placement.

Before any rehabilitation project decision is evaluated, it is necessary to consider the availability of the resources to conduct it.

7.2 Future Steps

The future research activities in this project include the analysis of new overlay projects, the development of a methodology for overlay design, and the investigation of an optimal hot mix design and construction practices.

Some of the new overlay projects have already been identified with the help of the District contacts. Furthermore, data collection activities are already underway for a few of these projects (e.g., the IH-20 project in Marshall, Tex., in Atlanta District). Once the testing activities are concluded on these projects, the data will be analyzed. One of the objectives of the data collection efforts and analyses is to fine-tune the decision criteria for this kind of projects, which will ultimately yield the final version of the decision tree.

The data collection involves condition surveys, deflection tests with both the Falling Weight Deflectometer (FWD) and the Rolling Dynamic Deflectometer (RDD), profile tests, Ground Penetrating Radar (GPR). The analysis includes computation of pavement distress indices (PDI), calculation of spalled areas, backcalculation of layer moduli of elasticity, computation of load transfer efficiencies (LTE), evaluation of present serviceability indices (PSI), and the establishment of decision criteria for their incorporation in the decision tree.

The methodology for overlay design will be based on the field information obtained from those new AC overlay projects and its analysis. An evaluation of tack coat applications is also part of the future research on this project.

Appendix A:

Contact Information
for
TxDOT District Engineers

Table A.1 Contact numbers for District Pavement Engineers

DISTRICT	NAME	PHONE #	FAX #
(01)PARIS	Bernie Holder	**903-737-9282**	903-737-9289
(02)FORT WORTH	Andrew Wimsatt	**817-370-6702**	817-370-3604
(03)WICHITA FALLS	Ralph Self	**940-720-7758**	940-720-7848
(04)AMARILLO	Randy Hochstein	**806-356-3240**	806-356-3263
(05)LUBBOCK	Stacey Young	**806-748-4376**	806-748-4348
(06)ODESSA	Stephen G. Smith	**915-498-4716**	915-498-4689
(07)SAN ANGELO	Karl Bednarz	**915-947-9238**	915-947-9244
(08)ABILENE	Chad Carter	**915-676-6813**	915-676-6902
(09)WACO	Billy Pigg	**254-867-2780**	254-867-2792
(10)TYLER	Bill Willeford	**903-510-9249**	903-510-9165
(11)LUFKIN	Ronald Evers	**936-633-4318**	936-633-4378
(12)HOUSTON	Magdy Mikhail	**713-802-5616**	713-802-5030
(13)YOAKUM	Gerald Freytag	**361-293-4374**	361-293-4372
(14)AUSTIN		**512-832-**	512-832-
(15)SAN ANTONIO	Jerry Carmona	**210-615-5893**	210-615-5851
(16)CORPUS CHRISTI	Pete Stricker	**361-808-2228**	361-808-2407
(17)BRYAN	Darlene Goehl	**979-778-9650**	979-778-9691
(18)DALLAS	Abbas Mehdibeigi	**214-320-6165**	214-320-6625
(19)ATLANTA	Miles Garrison	**903-799-1330**	903-799-1335
(20)BEAUMONT	Susan Chu	**409-898-5794**	409-898-5894
(21)PHARR	Carlos Peralez	**956-702-6162**	956-702-6172
(22)LAREDO	John Tashi	**956-712-7404**	956-712-7401
(23)BROWNWOOD	Elias Rmeili	**915-643-0441**	915-643-0306
(24)EL PASO	Tomas Saenz	**915-790-4350**	915-790-4344
(25)CHILDRESS	Darwin Lankford	**940-937-7186**	940-937-7241

Appendix B:

Fieldwork
in
Yoakum District Sections

FIELDWORK IN YOAKUM DISTRICT SECTIONS

Condition surveys were done on highway IH-10 and four asphalt concrete pavement (AC) sections were selected from locations indicated by TxDOT Yoakum District personnel. The sections are an example of poor-performing asphalt overlays built on top of a continuously reinforced concrete pavement (CRCP). All the sections are located in Fayette County, near Weimar, Tex. on the westbound side lanes. In some areas, the AC overlay has been milled off and a new asphalt overlay is being placed as scheduled by TxDOT.

The distressed AC overlay shows mainly surface rutting and flushing on both wheel paths of the outside lane. In some cases, both lanes show signs of distress, but the outside lane is considerably more distressed than the inside lane. No cracking was found in the sections.

Figs B.1 to B.4 display the conditions in which the pavement sections were found on June 19, 2002, when the condition survey was done.

Figure B.1 Shallow rutting (<0.5 in) and flushing of asphalt on section 13010-1

Figure B.2 Image of CRCP underneath the AC layer that was milled-off

Figure B.3 Image of rutted and flushed wheel paths of the outside lane

Figure B.4 End of a distressed asphalt layer area, section 13010-4

References

Abd-El-Halim 2000 A. O., Taylor, D.A., Mohamed, E., Zhou, F., Sun, L., Mechanistic Analysis of Reflective Cracking and Validation of Field Test, Rilem Publications, France, 2000.

Asphalt Institute 1977 Extending Pavement Life with Asphalt Overlays, Asphalt Institute, Lexington KY, 1977.

Barnett 1981 Barnett, T.L., Darter, M.I., Laybourne, N.R., Evaluation of maintenance/Rehabilitation Alternatives for Continuously Reinforced Concrete Pavement, Report No. FHWA/IL/UI-185 Intrm Rpt., UIUC-ENG-80-2011, Urbana IL, 1981.

Better Roads 2003 "Recycled Sealer Meets Rural Road Resurfacing Requirements," Better Roads, 2003/11 73(11) pp86-87, James Informational Media, Incorporated, 2720 South River Road, Suite 126, Des Plaines, IL, 2003.

Blomberg 2000 Blomberg, J. M., Superpave Overlay of Sand Anti-Fracture Layer Over PCCP, Report No. RDT 00-001Missouri Department of Transportation, Jefferson City MO, 2000.

Chen 2001 Chen, D. H., Bilyeu, J., Deborah, and M. Murphy, "Study of Rut-Depth Measurements," Transportation Research Record, 2001.

Cooley 1999 Cooley, L. A., "No-Tack Inlay on Milled Surface: Project Report," National Center for Asphalt Technology, Auburn University, Report Number: NCAT 99-2, 1999.

Dondi 1997 Dondi, G., "Full Scale Dynamical Testing on Reinforced Bituminous Pavements," Geosynthetics '97, Long Beach, California, 1997.

Dossey 1998 Dossey, Terry, B. F. McCullough, and Tracy Turen, "Benefits of Continuous Deflection Profile Analysis: A Case Study of Runway 17R-35L at Dallas / Fort Worth International Airport using the Rolling Dynamic Deflectometer," Structural Materials Technology III: An NDT Conference, Proceedings of SPIE, Vol 3400, April 1998.

Dossey 2000 Dossey, Terry, B. Frank McCullough, and David Merritt, "Updating the Rigid Pavement Database," Research Report 2952-2, Center for Transportation Research, The University of Texas at Austin, April 2000 (preliminary).

Fickes 2000 Fickes, M., Asphalt Smoothes the Way, HMAT 2000/09, National Asphalt Pavement Association, Lanham, MD, 2000.

Flowers 1989 Flowers, D. Gee, J., Meadors, A., Asphalt Overlays of Concrete Pavements: Case Studies in Arkansas, Transportation Research Record, Issue 1217, Washington DC, 1989.

Goulias 1997	Goulias, D. G., and A. Ali, “Evaluation and Performance Based Mix Design of Rubber Modified Mixtures,” Virginia Polytechnic Institute & State University, Center for Transportation Research, Blacksburg, VA, 24061, USA; Mid-Atlantic Universities Transportation Center, Pennsylvania State University, Research Office Building, University Park, PA, 16802-4710, USA Report Number: 423-087-2F; III-9708, 1997.
Hansen 2003	Hansen, K., “Pavement Preservation with Thin Overlays,” Better Roads, 2003/06 73(6) pp48-50, James Informational Media, Incorporated, 2720 South River Road, Suite 126, Des Plaines, IL, 2003.
Jiang 1993	Jiang, Y., and R. S. McDaniel, “Application of Cracking and Seating and Use of Fibers to Control Reflective Cracking,” Transportation Research Record 1388, 1993.
Jiang 1994	Jiang, Y., and R. S. McDaniel, “Indiana's Study of Cracking and Seating,” Better Roads, 1994.
Kandhal 2001	Kandhal, P., “New Generation Open-Graded Asphalt Friction Courses,” Public Works 2001/12 132(13), pp18-21, Public Works Journal Corporation, Ridgewood, NJ, 2001.
Lee 1982	Lee, K. W., “Prediction and Evaluation of Moisture Effects on Asphalt Concrete Mixtures in Pavement Systems,” Dissertation, The University of Texas at Austin, August 1982.
Marienfeld 1999	Marienfeld, M., Baker, T., “Paving Fabric Interlayer System as a Pavement Moisture Barrier,” Transportation Research Circular, March 1999.
McCullough 1996	McCullough, B.F., Dossey, T., Cho Y-H, Case Study of Overlay Performance on Rigid Pavement in Bowie County, Texas, Transportation Research Record, Washington DC, 1996.
McGhee 1979	McGhee, K.H., Attempts to Reduce Reflection Cracking of Bituminous Concrete Overlays on Portland Cement Concrete Pavements, Transportation Research Record, Issue 700, Washington DC, 1979.
Mohammad 2002	Mohammad, L. N., M. A. Raqib, and B. Huang, “Influence of Asphalt Tack Coat Materials on Interface Shear Strength,” Transportation Research Record, Issue 1789, Washington DC, 2002.
Molenaar 1989	Molenaar, A.A.A., “Effects of Mix Modifications, Membrane Interlayers and Reinforcements on the Prevention of Reflective Cracking of Asphalt,” in Reflective Cracking In Pavements: Assessment and Control, ed. J.M. Rigo, R. Degeimbre, Liege, 1989.
Mukhtar 1996	Mukhtar, M. T., and B. J. Dempsey, “Interlayer Stress Absorbing Composite (ISAC) For Mitigating Reflection Cracking In Asphalt Concrete Overlays,” Illinois Department of Transportation, Bureau of Materials & Physical Research, 1996.

Mrawira 1999 — Mrawira, D., and D. J. Damude, "Revisiting the Effectiveness of Tack Coats in HMA Overlays: The Shear Strength of Tack Coats in Young Overlays," Proceedings 14th Annual Conference, Canadian Technical Asphalt Association, 1999.

Niederquell 2000 — Niederquell, M.G., Baladi, G.Y., Chatti, K., "Rubblization of Concrete Pavements: Field Investigation," Transportation Research Record, Issue 1730, Washington DC, 2000.

Noureldin 1989 — Noureldin, A.S., and R.S.McDaniel, Evaluation of Concrete Pavement Restoration Techniques on I-65, Transportation Research Record, Issue 1215, Washington DC, 1989.

Owusu-Antwi 1998 — Owusu-Antwi, E. B., L. Khazanovich, L. Titus-Glover, "Mechanistic-Based Model For Predicting Reflective Cracking in Asphalt Concrete-Overlaid Pavements," Transportation Research Record, 1998.

Partl 2003 — Partl, M. N., G. B. Way, J. Sousa, and K. Kaloush, "Hot Mix Asphalt Design Prediction and Field Performance, an Arizona Study," Performance Testing and Evaluation of Bituminous Materials PTEBM'03, Proceedings of the 6th International Rilem Symposium, April 2003, pp 543-9, Rilem Publications S.A.R.L, France, 2003.

Rabiot 1996 — Rabiot, D., and M. F. Morizur, "Polymer Modified Bitumen Emulsions an Advantage for the Various Road Applications," Eurasphalt and Eurobitume Congress, Strasbourg, May 1996, Volume 3, European Asphalt Pavement Association, Netherlands, 1996.

Rommel 1999 — Rommel, A., "Rubblization and Asphalt Overlay," HMAT 1999, National Asphalt Pavement Association, Lanham, MD, 1999.

Rutkowski 1994 — Rutkowski, T.S., Preventive Maintenance and Rehabilitation Techniques to Mitigate the Effects of Corrosion-Related Deterioration in Continuously Reinforced Concrete Pavement. Final Report, National Technical Information Service, Springfield VA, 1994.

Saraf 1987 — Saraf, C. L., B. F. McCullough, and M. F. Aslam, "Rutting of Asphalt Concrete Overlays on Continuously Reinforced Concrete Pavement in Texas," Transportation Research Record, 1987.

Seshadri 1996 — Seshadri, M., Evaluation of Bituminous Pavement with Polypropylene Fiber. Final Report, Mississippi Department of Transportation, Report No. MS-DOT-RD-96-67-16, Jackson MS, 1996.

Shalaby 1996 — Shalaby, A., A. O. Abd El Halim, and S. M. Easa, "Low-Temperature Stresses and Fracture Analysis of Asphalt Overlays," Transportation Research Record, 1996.

Shoukry 1997 — Shoukry, S.N., D. R. Martinelli, and O. I. Selezneva, "Dynamic Performance of Composite Pavements Under Impact," Transportation Research Record, Issue 1570, Washington DC, 1997.

Sousa 2002	Sousa, J. B., J. C. Pais, R. Saim, G. B. Way, and R. N. Stubstab, “Mechanistic Empirical Overlay Design Method for Reflective Cracking,” Transportation Research Record No. 1809, Design and Rehabilitation of Pavements 2002, Washington, DC, 2002.
Taute 1980	Taute, Arthur, “Improvements to the Materials Characterization and Fatigue Life Prediction Methods of the Texas Rigid Pavement Overlay Design Procedure,” Thesis, The University of Texas at Austin, Austin, Texas, May 1980.
Tayebali 2000	Tayebali, A. A., M. B. Kulkarni, and H. F. Waller, “Delamination and Shoving of Asphalt Concrete Layers Containing Baghouse Fines,” North Carolina State University, Raleigh, Department of Civil Engineering, North Carolina Department of Transportation, NCDOT Project 1999-03, FHWA/NC/2002-011, 2000.
Thompson 1997	Thompson, M. R., F. R. Van Matre, D. Lippert, and P. Jenkis, “HMA Overlay Construction with One Pass/Lane Width PCCP Rubblization,” National Asphalt Pavement Association, Lanham MD, 1997.
Uzan 1978	Uzan, J., M. Livneh, and Y. Eshed, “Investigation of Adhesion Properties Between Asphaltic Concrete Layers,” Asphalt Paving Technology, Vol. 47., Proceedings of the Association of Asphalt Paving Technologists, Technical Sessions, 1978.
Virkler 1978	Virkler, S.J., Maintenance Methods for Continuously Reinforced Concrete Pavements, Report No. FCP45D2-354, FHWA-RD-78-S0776 Intrm. Rpt., West Lafayette IN, 1978.
Walubita 2000	Walubita, Lubinda F., Fred Hugo, and Amy Epps, “Performance of Rehabilitated Lightweight AC Pavements under Wet and Heated Model MLS Trafficking: A Comparative Study with the TxMLS,” Report 1814-3, Center for Transportation Research, The University of Texas at Austin, March 2000.
Way 2000	Way, G.B., “Flagstaff I-40 Asphalt Rubber Overlay Project: Nine Years of Success,” Transportation Research Record, 2000.
Woodside 1996	Woodside A. R., R. McIlhagger, W. D. H. Woodward, and H. W. Clements, ”Inhibiting Reflective Cracking,” Arizona University, Department of Civil Engineering and Engineering Mechanics, Tucson, AZ, 1996.
Woodside 1997	Woodside A. R., W. D. H. Woodward, H. W. Clements, J. Sikich, and T. Russell, “The Use of Fabrics to Inhibit Reflective Cracking in Porous Asphalt,” European Conference on Porous Asphalt, Madrid, Spain March 1997, Volume I, 1997 pp 271-83, Spain 1997.