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16. Abstract

This report analyzes and evaluates new information collected in 1998 for the jointed concrete pavement (JCP) database, which currently comprises information on 137 test sections. An updated demographic description of the sampled test sections and a quantitative analysis of different distresses are presented. The relevance of environmental factors that influence the early age performance of the structures is highlighted and related climatic data are incorporated into the database. Finally, improvements achieved through this study, along with future challenges, are addressed here. In terms of implementation, this report demonstrates the relevance of maintaining the rigid pavement database (RPDB).

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THE TEXAS RIGID PAVEMENT DATABASE ANNUAL REPORT, 1999

Cesar Medina
Terry Dossey
B. Frank McCullough

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Report Date:	July 1999 (Revised November 2003)
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Center for Transportation Research
The University of Texas at Austin
3208 Red River
Austin, TX 78705

www.utexas.edu/research/ctr

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Project Engineer: Dr. B. Frank McCullough
Professional Engineer License State and Number: Texas No. 19914
P. E. Designation: Research Supervisor

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1. Introduction

1.1 Background

This is the first report related to Research Project 0-1778 "The Rigid Pavement Database", conducted by the Center for Transportation Research (CTR) of the University of Texas at Austin and funded by the Texas Department of Transportation (TxDOT). The Rigid Pavement Database (RPDB) project manages lots of information of hundreds of portland cement concrete pavement (PCCP) test sections that represent part of the highway network in Texas. Condition surveys have been conducted for the last 26 years, and this information has aided in the understanding of pavements' performance and the effect of different variables on them. This report documents the tasks that have been conducted by the Center for Transportation Research to maintain the RPDB. CTR's series reports 1908, 1342, 1244, and 472 contain prior information related to the RPDB as well.

1.2 Objectives

This report documents and provides information about activities related to the RPDB. Ongoing activities that need to be continuously pursued are highlighted throughout the different chapters. In the same manner, activities that might improve the quality of the research conducted for the project are stated here.

1.3 Methodology

To carry out the goal of this report, the chapters contained herein describe different tasks as follows:

Chapter 2 contains the demographics of the data collected up to date. The demographics description is explained throughout the display of charts that summarize the current status of the RPDB database. If changes were made in the population of sections contained the database, then, the reasons for those changes are stated here.

Chapter 3 lists all the components of the database. A description of the two main components of the RPDB, the Inventory Data and Performance Data is provided. Likewise, there is a description of the accomplished tasks and the tasks that have yielded considering improvements to the RPDB. Finally, there is a list of climatic variables that have been incorporated into the database and that have a great impact on pavements' performance.

Chapter 4 describes the criteria adopted for addition of new pavement sections in the RPDB. It shows the layout of a new revised condition survey form that is already in use and that provides a better way to collect field data. The step-by-step process of a typical condition survey and problems encountered when in the field are described. Incorporation of global positioning system (GPS) technology and its justification is analyzed. Finally electronic data processing and summary reports preparation are described.

Chapter 5 describes in detail the five climatic variables incorporated into the RPDB. These are the most influential climatic parameters that affect pavements' performance, and therefore, have been added to the database. It is believed that further analysis of the sections in the RPDB will consider these important variables.

Chapter 6 shows a comprehensive analysis of various distresses found in a selected group of sections located in Dallas Texas. Crack and joint spacing distributions and the influence of concrete coarse aggregate type are highlighted in the analysis.

Chapter 7 summarizes the findings of research activities and provides concise conclusions and recommendations.

This report includes 6 appendices summarized as follows:

Appendix A contains the detailed instructions to be followed to configure the GPS equipment used for data collection.

Appendix B displays a map of Texas showing the coverage of GPS differential correction.

Appendix C lists the JCP sections contained in the database and provides brief inventory data (e.g., section number, highway, county, etc).

Appendix D lists the five climatic variables recently incorporated into the RPDB. The conditions for all the JCP sections in the database are displayed in the list.

Appendix E serves as a catalog of the various distresses commonly found in JCP pavements. This section includes photographs of the distresses and their description.

Finally, Appendix F describes the step-by-step process followed to collect the information of every section in the database.

2. Demographics of the Database

2.1 Evolution of the Database

Table 2.1 summarizes the evolution of the jointed concrete pavement (JCP) condition surveys from 1982 to date. For the major distress types on the JCP, the intensity of the distress type was divided into two levels — minor and severe. On the right side, the years when the surveys were conducted are shown and an x in the cell means the condition survey covered that type of distress. For example, corner breaks were collected for each condition survey year, whereas D-Cracking data were only collected for two years.

Table 2.1 Data collection history for JCP sections

Distress	Type	Severity/ Extent	1982	1984	1993	1998
Cracking	Transverse [1,2,3]	Spacing	x	x	x	x
	Longitudinal [1,2,3]	Length			x	x
	Spalling [1,2]	Minor	x	x	x	x
		Severe	x	x	x	x
	Alligator [3]	Minor			x	x
		Severe			x	x
	Block [3]	Minor			x	x
		Severe			x	x
	Faulting [2]	Minor			x	x
		Severe			x	x
Corner Break [2]			x	x	x	x
D-Cracking [2]					x	x
Rutting [3]		Shallow				x
		Deep				x
Patching	AC [1,2,3]	0-50 ft^2	x	x	x	x
		51-150 ft^2			x	x
		>150 ft^2			x	x
	PCC [1,2]	0-50 ft^2	x	x	x	x
		51-150 ft^2			x	x
		>150 ft^2			x	x
Punchout [1]		Minor			x	x
		Severe			x	x
GPS coordinates [1,2,3]						x

[1] Collected for CRCPs
[2] Collected for JCPs
[3] Collected for Overlaid Pavements

As shown in Table 2.1, the type of information collected has varied for some years. The first data collection was performed in 1982 and the latest collection was conducted in 1998. It was not until the late '90s that global positioning system (GPS) coordinates were incorporated into the database. As for the number of sections surveyed each time, the criterion has varied because of different reasons, being the most important the reliability of the collected information.

Figure 2.1 presents the number of sections that have been surveyed each year and displays information about both JCP and continuously reinforced concrete pavement (CRCP) sections. As mentioned before, the number of sections surveyed each year has differed depending on the level of funding and reliability of the collected data, among other factors.

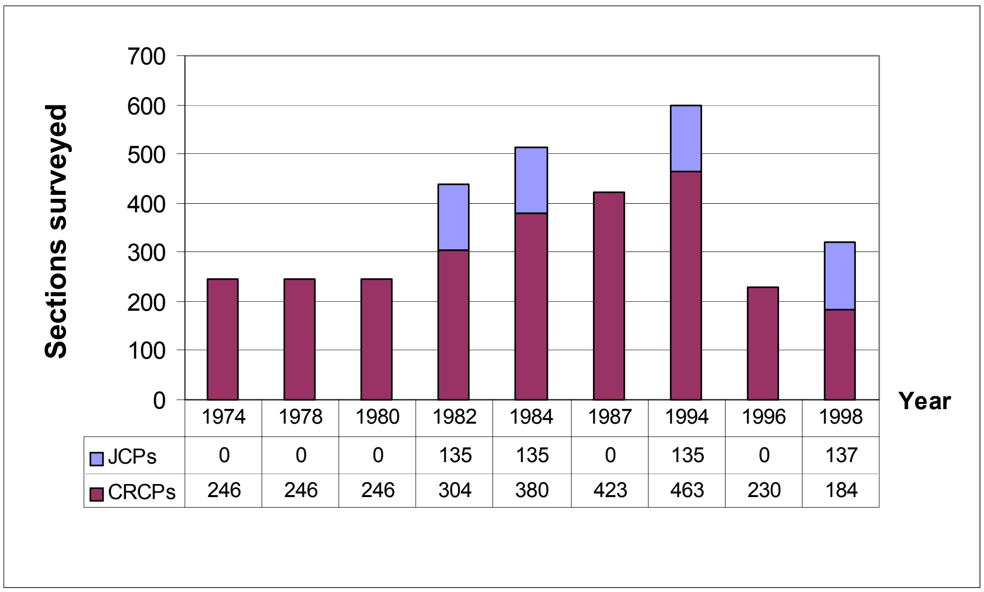

Figure 2.1 Condition surveys conducted from 1974 to 2000

2.2 Demographics

The following charts show the demographics of the JCP sections. The charts show the results obtained from the information collected in 1993, and also the most recent information from the condition survey performed in 1998. In 1993, 135 sections were surveyed; in the most recent survey a total of 137 sections were included. Throughout this chapter, the charts present information from these two years. The numbers obtained in 1993 are represented in small italicized font; a normal font represents the numbers obtained in 1998. If italics do not appear in a chart, it means that the chart contains only information from the 1998 survey.

The demographics show information about the performance data (e.g., the number of sections per construction project and overlaid and nonoverlaid sections) and the inventory data (e.g., distribution of projects through districts, highway functional classification, and age distribution of the sections.) The demographics of the inventory data usually remain the same, except for the aging of the sections and the addition of new sections to the database.

2.2.1 Project Characteristics' Analysis

This preliminary project characteristics' analysis is provided to give an initial understanding of the JCP database. The distribution of projects by district is first presented, followed by a distribution of project test sections. Next, the distributions by highway classification and age are shown.

Project Distribution by District

Figure 2.2 shows the distribution of the projects in the different districts. Note that the Houston district contains nearly 40 percent of the sections included in the database. The reason for this is that most of the JCP pavements placed in Texas are located in the Houston area. The Beaumont and Dallas districts are the second and third, respectively, in the number of sections.

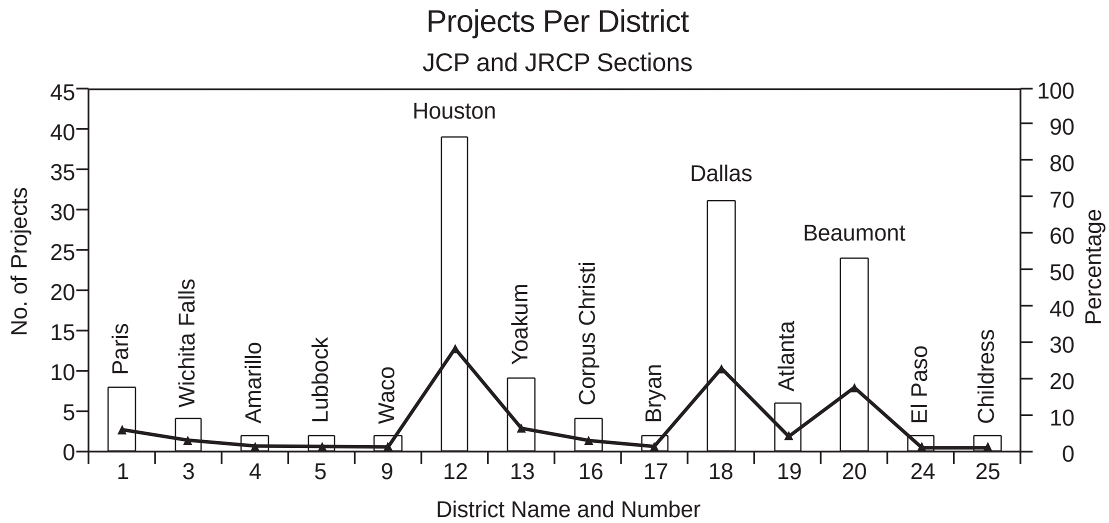

Figure 2.2 Distribution of projects within districts

Test Sections per Construction Project

Figure 2.3 shows the density and cumulative distribution for the number of test sections existing in a given project. Note that 51 percent of the projects have two sections, 31 percent have three sections, and there are no projects with more than four sections. This explains that when a project is fewer than 3 miles long, two or three sections will sufficiently represent the characteristics of the entire project.

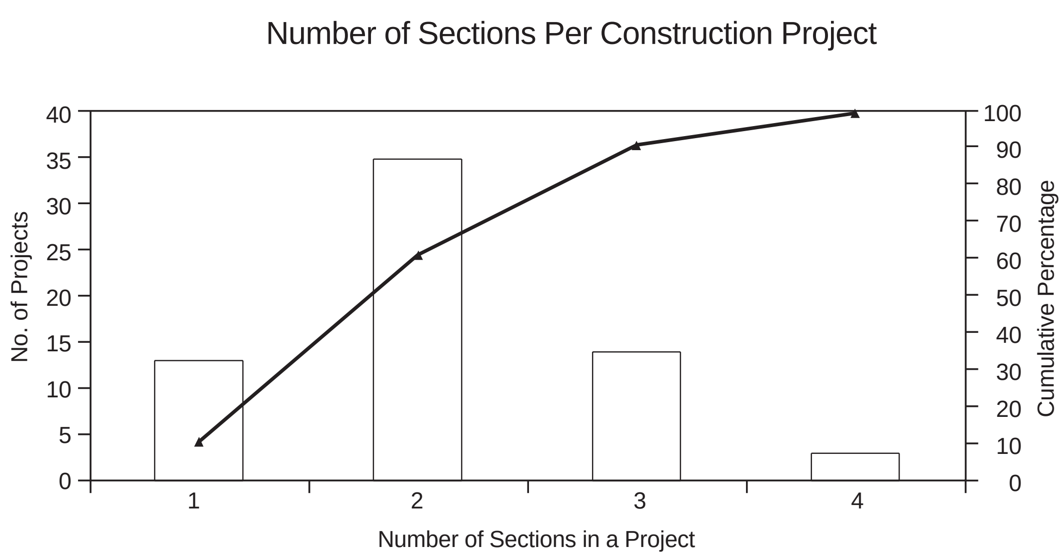

Figure 2.3 Distribution of test sections existing in a project

Highway Functional Classification Distribution of the Sections

Figure 2.4 shows that a substantial percentage of the JCP sections are located on the interstate highway network, as would be expected due to load magnitude and numbers leading to selection of portland cement concrete pavement (PCCP). U.S. highways (US) and state highways (SH) also comprise a substantial number of sections. At first glance, the 10 percent of test sections for farm-to-market (FM) highways appears to be large, but most of these are in or near major urban areas where the traffic volumes are high.

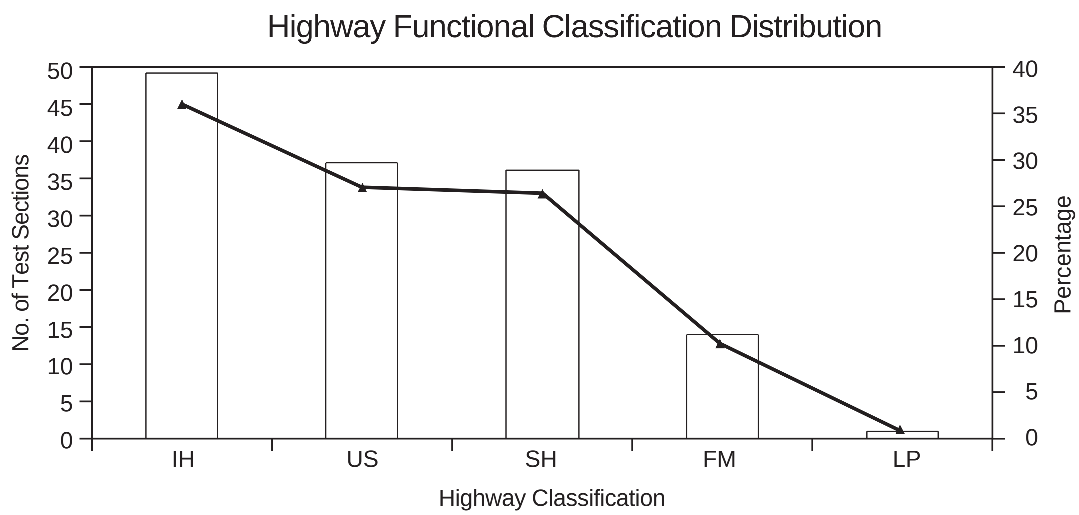

Figure 2.4 Highway functional classification distribution of test sections

Age Distribution of the Sections

Figure 2.5 shows that only a small number of sections are fewer than 5 years old. Most of the sections are between 25 and 45 years old and some sections are older than 55 years. The apparent perturbation exists due to the major shift from jointed concrete pavement (JCP) to continuously reinforced concrete pavement (CRCP) in the late 1950s and early 1960s that was made during the important construction years for the interstate highway system. Most of the older sections have received major maintenance and rehabilitation through time, but it should be recognized that they have served well beyond the normal design life of 20 years. At the other extreme, one should not assume that the cumulative percentage greater than 45 years implies the same percentage of today's JCP-constructed highways will serve as long.

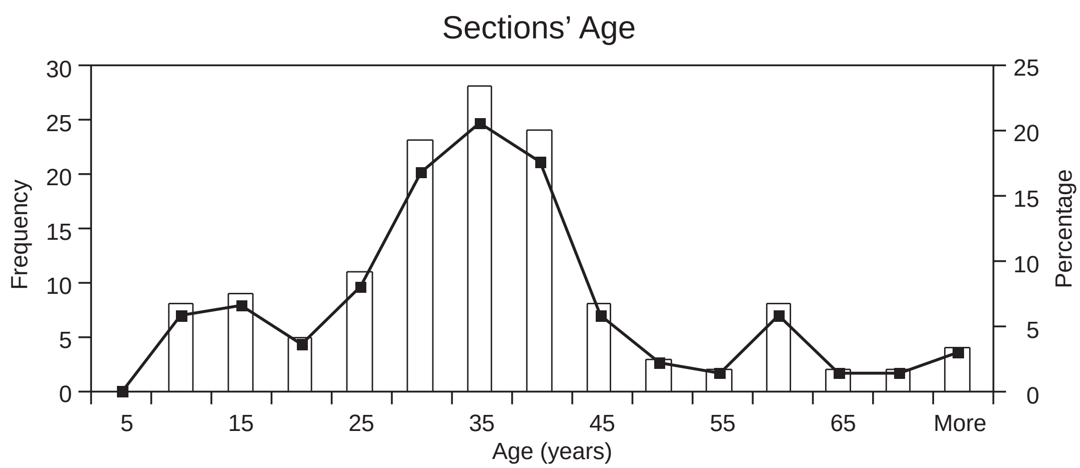

Figure 2.5 Age distribution of the test sections

2.3 Pavement Type Characteristics Analysis

In this section, the test sections are first examined as to overlaid or nonoverlaid sections and then by jointed pavement type. Next, the in-situ conditions for coarse aggregate type (CAT) and pavement thickness are presented.

2.3.1 Overlaid and Nonoverlaid Sections

Figure 2.6 shows that 40 percent of the JCP sections are overlaid, thus 60 percent are nonoverlaid sections. This issue requires special attention because according to Figure 2.4, most of the sections are between 25 and 45 years old. Some of these nonoverlaid sections may have been recently overlaid.

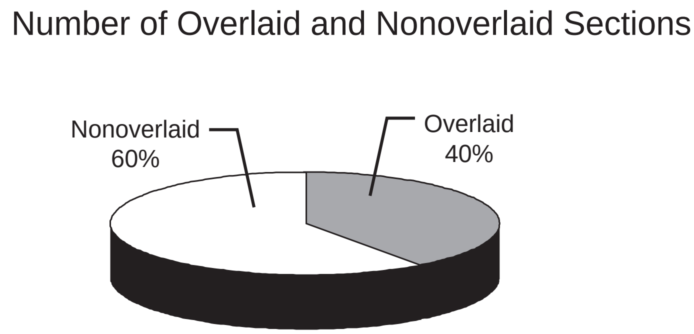

Figure 2.6 Number of overlaid and nonoverlaid sections

2.3.2 Pavement Type Distribution

Figure 2.7 shows the distribution of the jointed plain concrete (JPC) sections and the jointed reinforced concrete (JRC) sections in the database. As can be seen, the distributions from 1993 and 1998 differ in one unit. This difference is the result of the cleaning process performed on the database and one of the objectives of this study. A few sections were removed from the JCP database because they were CRCP sections, and this also caused the percentages to change.

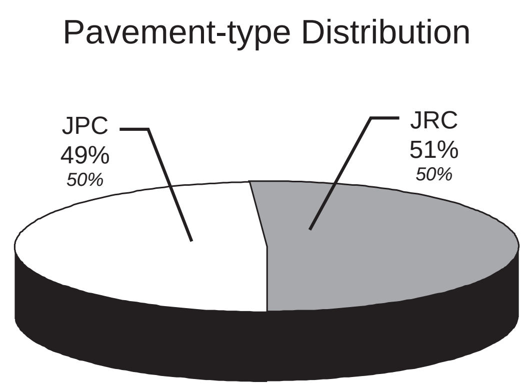

Figure 2.7 Pavement type distribution

2.3.3 Coarse Aggregate Type (CAT)

In Texas, the most commonly used coarse aggregate types are limestone (LS), siliceous river gravel (SRG), or a combination of both. Research studies have shown that thermal properties of the coarse aggregate make its use more or less suitable for pavement construction. It can be seen in Figure 2.8 that most of the JCP sections in the database (68 percent) contain SRG as coarse aggregate and almost one-third (31 percent) of the overall sections contain LS. Only 1 percent of the sections were built with a combination of the two aggregates or something different. This distribution of aggregate types is not typical of current or future distributions. Prior to the 1970s, LS aggregates were not available or cost competitive in the eastern part of the state. Again, the differences between the 1993 and 1998 results are due to the cleaning and checking processes of the JCP database contents.

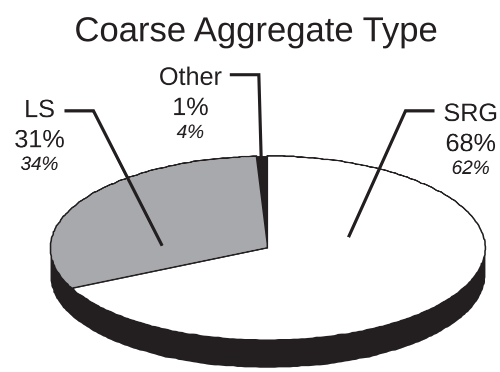

Figure 2.8 Coarse aggregate type distribution

2.3.4 Slab Thickness Distribution

Figure 2.9 shows that nearly 35 percent of the JCP sections in the database have a thickness of 10 inches; 25 percent of the sections have a thickness of 8 or 9 inches; and the remaining 40 percent are as thin as 6 inches and as thick as 13 inches. The bulk of the sections range between 6 and 10 inches. Again, this anomaly exists because the Federal Highway Administration (FHWA) had a policy that did not permit JCP constructions to be thicker than 10 inches.

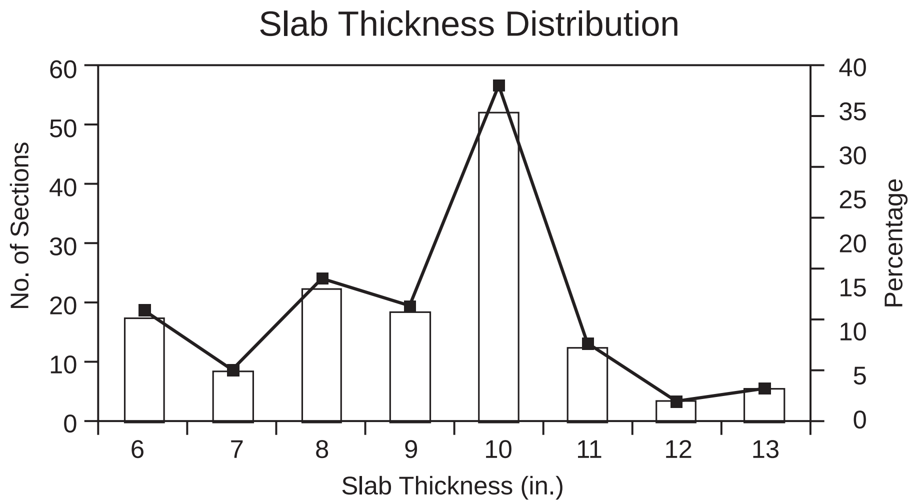

Figure 2.9 Slab thickness distribution of pavement sections

2.4 Analysis According to Geometry

This section provides an overview of distributions by number of lanes in one direction and location of the test sections.

2.4.1 Number of Lanes per Section Distribution

Figure 2.10 shows that 70 percent of the sections have two lanes in each direction, and only 2 percent of the sections have four lanes in each direction. This distribution is consistent with the information provided in Figure 2.3 because a large number of the sections are located in the interstate highway network. Those sections with four lanes per direction are usually located in urban areas. In this case, no difference was found between the results from 1993 and 1998.

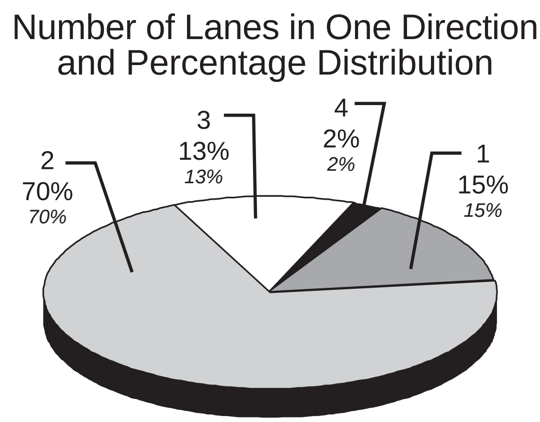

Figure 2.10 Number of lanes per section

2.4.2 Location of the Sections

Figure 2.11 shows the roadbed type distribution of the sections in terms of cut, fill, transition, and at-grade configuration. As expected, more than 50 percent of the sections are at grade because of the flat topography that predominates in the state of Texas.

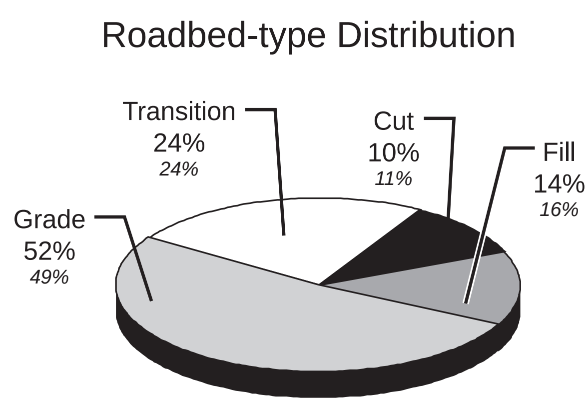

Figure 2.11 Roadbed type distribution of the section

Again, in this case the differences between the 1993 and 1998 results reflect the cleaning tasks performed in the database in the latest study.

3. Description of Current Data and Recent Additions

3.1 Jointed Concrete Pavement (JCP) Database

In 1982, the CTR jointed concrete pavement (JCP) database contained 4,019 pavement test sections, each one approximately 0.2 miles in length (Singh et al. 1993). A unique number called Center for Transportation Research (CFTR), was used to identify those sections, and is still being used for continuity purposes. Because of the impossibility of maintaining such an extensive database (budgeting and other time-consuming factors), the number of sections in the database has been reduced through the years, but the preserved sections represent the statewide characteristics regarding design, construction, materials, traffic, and environmental conditions. There are currently 137 test sections that contain updated information.

3.2 Structure of the JCP Database

The two components of the database are (1) the inventory data and (2) the performance-related data. The primary difference between the two components is that the inventory data usually does not vary through time; they always remain the same. On the other hand, the performance-related data evolve through time, and contain a history of the data for the different distresses collected during each field visit.

3.2.1 The Inventory Data

The inventory data contained in the database include: the district number, the county name, the highway functional classification, the starting reference marker station, the ending reference marker station, the geographic global positioning system (GPS) coordinates (latitude and longitude), the number of lanes, the roadbed characteristics, the geometric characteristics, the coarse aggregate type in the pavement, the construction date, the thickness, the overlaid and nonoverlaid characteristics, and in the most recent updating process, detailed climatic information.

3.2.2 Performance-Related Data

In order to establish the historical performance of a pavement structure, data must be added on a regular basis, i.e., annually or biannually, if a pattern is to be established. The performance-related information contained in the database is the number of asphalt concrete (ACP) and portland cement concrete (PCC) patches, the number of punchouts, D-cracking, corner breaks, number of cracked slabs, and the total number of cracks in the 0.2 mile section[1]. Additionally in the database, the cumulative crack spacing distribution is contained for the first 200 ft. of the section.

Table 3.1 summarizes and briefly describes some of the fields used in the electronic format of the database for the different inventory and performance-related data. As indicated previously, the inventory data will have only one set of numbers that remain constant over time, whereas the performance-related data will have entries for each time a condition survey is performed. Appendix C presents the inventory and performance data for the JCP sections surveyed during 1998.

[1] Most of the sections have a length of 0.2 miles or 1,000 ft. Some sections are shorter than the standard length for different reasons. The exact length of a particular section may be found in the electronic format of the database.

Table 3.1 Inventory and performance data included in the database

Field in Database	Description
Inventory Data	
DIS	District number
CFTR	Identification number of the section
COUNTY	County name
HWY	Highway functional classification and name
RM_1 *	Beginning reference marker and displacement of the section
RM_2 *	Ending reference marker and displacement of the section
GPSLON	Geographic coordinate (longitude W)
GPSLAT	Geographic coordinate (latitude N)
LANES *	Number of lanes in the surveyed direction
RBD	Roadbed type (cut, fill, at grade, or transition)
CURVE	Geometric Alignment (T=tangent, L=left curve, R=right curve)
OVER	Overlaid characteristics (Y=overlaid, N=nonoverlaid)
CAT	Coarse aggregate type (L=LS=limestone, SRG=siliceous river gravel, M=mixture)
CDATE	Construction date
D	Pavement thickness
AMAT	Average minimum annual temperature (°F)
AARF	Average annual rainfall (in.)
AMER	Average monthly evaporation rate (lb/ft^2/hr)
LTAC	Low temperature after construction (°F)
HTDC	High temperature during construction (°F)
Performance-Related Data	
AC	Asphalt concrete patches
PCC	Portland cement concrete patches
PUNCH	Number of punchouts
DCRACK	D-cracking
CORBREA	Corner breaks
SLABS	Number of cracked slabs
CRACK	Total number of cracks in the section
* According to the current TxDOT PMIS rater's manual	

3.3 JCP Database Revisions

The JCP database began in the early 1980s. In 1982, provisions were made to store only routine condition survey data for thousands of sections. No provision was made at that time for collecting data on climate, traffic, materials, pavement design characteristics, or maintenance and rehabilitation histories. The 1984 study contained considerably fewer sections and the same distress types as in 1982 were recorded for the remaining sections.

Again, no effort was made for the collection of climatic data or for maintenance and rehabilitation tasks.

In 1993, in an effort of Project 1908, "Performance Prediction Models for Concrete Pavements in Texas," and due to lack of information on maintenance and rehabilitation activities, a maintenance and rehabilitation (M&R) survey form was sent to twenty-three Texas Department of Transportation (TxDOT) district offices. The survey requested M&R history for various pavement sections located in those districts. The history of the sections was requested for the period from 1983 to 1990, and it included information such as construction date, coarse aggregate type used in the pavement, and M&R activities and dates for different categories (Singh et al. 1993). From the twenty-three surveyed districts, responses were received from only eighteen. Six districts out of the eighteen reported that rigid pavement sections did not exist within the district.

Additionally, in 1993 the study under Project 1342, "Development of a Jointed Concrete Pavement Database for the State of Texas," developed a new collection factorial for the RPDB that would include jointed reinforced concrete (JRC) and jointed plain concrete (JPC) pavements for the first time. The purpose of the factorial was to include in the database recently designed sections and constructions containing double-steel mat and pavement of thicknesses greater than 10 inches. Moreover, factors such as coarse aggregate type and slab length were included. Condition surveys were performed on 135 sections, and the different distress types were collected and stored.

In this current study, which began in 1998 with the field data gathering process, some major tasks have been achieved and some are currently being updated and expanded. These tasks include the following:

1. Extensive quality control activities were performed on the database to eliminate inconsistencies. These activities included inputting all the data collected in the 1993 survey in the same format as the 1998 data, the

introduction of the new simplified condition survey form, a comprehensive review of the type of pavement in the database, among others.

2. A new and more effective condition survey form was designed to expedite field data gathering. This form is presented in Chapter 4.
3. A method to permanently and accurately mark the sections in the field has been adopted, and efforts were made to relocate sections, where necessary.
4. Incorporation of GPS technology for precise relocating of the sections has been achieved. The GPS data are now a part of the inventory data as shown in Table 3.1.
5. Improved and easier access to the database is now possible by using different software packages.
6. Detailed climatic and environmental information that influences pavement behavior has been partially incorporated.

In 1998, raters walking on the shoulder of the road conducted the condition surveys. The collected information included various types of cracking, spalling, corner breaks, punchouts, asphalt concrete and portland cement concrete patches, crack spacing, reflected cracks, block and alligator cracking, overlays, and GPS coordinates. The cumulative crack spacing was collected for the first 200 ft. of the section, and the number of cracks was counted for the remaining length.

3.4 Current and Future Improvements

The anticipated improvements to this study are the full implementation of expanded climatic data and the incorporation of mapping capabilities to the database. At present, several climatic indicators have been added to the database; now the challenge is to correlate the performance-related data with the new climatic information. To collect this climatic information, data from the National Oceanic and Atmospheric Organization (NOAA) were retrieved and merged into different components or fields in the database. Appendix D contains detailed climatic information for various JCP sections. The following climatic factors were included:

1. Average minimum annual temperature (AMAT)
2. Average annual rainfall (AARF)
3. Average monthly evaporation rate (AMER)
4. Low temperature after construction (LTAC)
5. High temperature during construction (HTDC)

This climatic information is a significant addition to the database due to its applicability in research studies. More information about these parameters is contained in Chapter 5. Finally, several other improvements considered for the database include:

1. Updating inventory data related to maintenance and rehabilitation activities, such as date of overlays.
2. Revising process of compatibility with the CTR database, now that access to the PMIS database has been achieved.
3. Updating traffic model information previously derived from the database.
4. Merging the two existing databases, CRCP and JCP, into one database.
5. Creation of a new numbering system for the sections when the two databases are merged.

4. Data Collection Activities

4.1 Criteria for New Sections

In the past, a policy of collecting information on up to six test sections per construction project was followed. That policy is still current, although fewer sections may be included if the nature of the site allows this criterion or if additional projects with similar characteristics are located nearby.

When a new project is considered for inclusion in the database, the procedure for determining the number of sections to be included is based on the following factors:

1. An important issue is the length of the project, which ranges from a few hundred feet to several miles. The length of a project provides a clue to the number of test sections to be selected. Usually for projects of 3 miles or less in length, one cut, one fill, one at-grade, and one transition section may be selected. For projects longer than 3 miles, two cut, two fill, one at-grade, and one transition section may be selected. The different types of locations from which test sections may be selected are conceptually presented in Figure 4.1. For condition survey purposes, a section is classified within one of the four categories. A "cut" exists when the highway profile at the centerline of the roadway is 5 ft. below the natural ground line. A "fill" is designated when the highway profile at the centerline of the roadway is 5 ft. above the level of the natural ground line. The cases where the roadbed changes from cut to transition or to fill, or vice versa, are designated "transition test sections." Finally, when the level of the highway profile at the centerline of the road and the natural ground line differ fewer than 5 ft., the test section is categorized as "at grade."
2. The roadbed soil support characteristics affect the pavement's performance, thus a section cannot be excessively long. It has been found that the average length of a uniform roadbed construction is about 1,000 ft., which is one of the reasons this standard length has been adopted.

3. Recommendations from TxDOT and CTR staff.

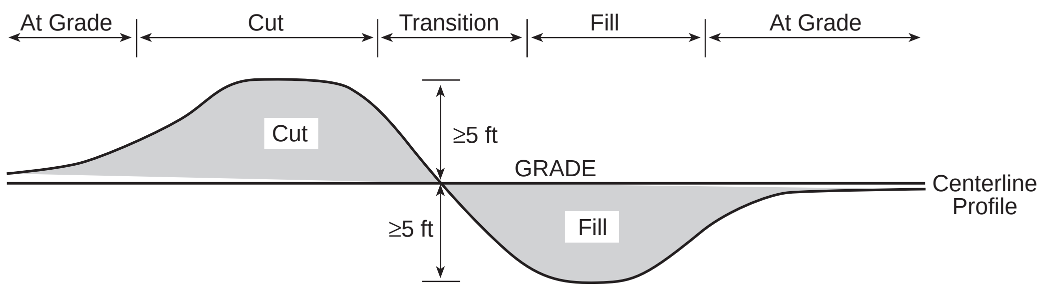

Figure 4.1 Classification of a transverse section

4.2 Revised Condition Survey Form

Since 1974, very few changes were made in the condition survey form. Three different forms were used from 1974 to 1993, with only minor changes from time to time. Initially one form was used to survey both CRCP and JCP sections; later additional forms were developed for each one of the two different pavement types, CRCP and JCP. These forms may be found in various references (Ruiz 1994).

In connection with this study, a new condition survey form was developed. The purposes of implementing the new form were to expedite fieldwork tasks and also to reduce the paperwork used by the field crews. Figure 4.2 is a layout of the new condition survey form adopted for this project. This form may be used for both CRCP and JCP sections because it includes all the necessary information to be collected in the field.

CFTR No.	Direction	Highway	Date	Surveyor	GPS Location
					Lat N ° ' "
Reference Marker Start RM_1 to End RM_2		**County**	**JCP** / **CRCP**	*Overlaid* / *Non-overlaid*	*Long W* ° ' " *Elevation (ft)*

Number of Lanes / Surveyed Lane / CAT:	Cracking %: Alligator (% of total lane area) Minor & Severe — M	S	Cracking %: Block (% of total lane area) Minor & Severe — M	S	Rutting%: Shallow 1/2"-1" (% of the wheel path)	Rutting%: Deep 1"-3" (% of the wheel path)	Patches: size in square feet — AC 0-50 ft^2	AC 51-150 ft^2	AC >150 ft^2	PCC 0-50 ft^2	PCC 51-150 ft^2	PCC >150 ft^2	Number of Punchouts Minor & Severe — M	S	No. of D-Cracks	No. of Corner Breaks	No. of Faulted Joints	Slabs with longitudinal cracks	Number of Spalled Joints/cracks Minor & Severe — M	S	Total No. of Cracks
0 ft - 200 ft																					
200 ft - 400 ft																					
400 ft - 600 ft																					
600 ft - 800 ft																					
800 ft - end																					

Vertical Alignment	Cut / Fill / Grade / Transition	**Fill or cut (in feet)**	**Horizontal Alignment** Curve Left / Tangent / Curve Right	*Crack locations for the 0 -200 ft span. Circle all the joints*
Comments:				

Figure 4.2 Layout of the new condition survey form

4.3 Reference Markers/PMIS Database

As previously mentioned, a priority for this study, was to assign accurate reference markers to the sections. All new and existing sections were assigned a starting (RM_1) and ending (RM_2) reference marker. This procedure is fully described in the Pavement Management Information System (PMIS) Rater's Manual (TxDOT 1998) and summarized in the following paragraphs.

A section is usually located by using a physical milepost (mile marker). This milepost may be located before or after the starting point of the section, but the first case is always preferable. When the section does not begin or end exactly on a milepost, then the displacement must be recorded. To better illustrate this concept, the following example is given.

Assume a section has a starting reference marker (RM_1) of 554+0.3. This means the section begins 0.3 miles after milepost No. 554. In this case, the recorded displacement should be +0.3 miles. Now assume that the ending reference marker (RM_2) of a section is 235-0.25. This means that the section ends 0.25 miles before milepost No. 235, and it begins 0.45 miles before milepost No. 235. In this case, the recorded displacements are –0.25 and –0.45 miles for the ending and starting points of the section, respectively.

4.4 Field Activities

When conducting the field tasks, the field crew gave special consideration to the following:

1. Reference markers: As previously mentioned, this was considered one of the priorities for this study. A complete review of the precise field location was performed for all new and existing test sections. Reference markers have been assigned to every section according to the procedure described in the PMIS Rater's Manual (TxDOT 1998).
2. GPS coordinates: A GPS location was assigned to every surveyed section. The procedure for collecting the information is discussed later in this chapter.
3. Designation of rated lane: The location of the rated lane was derived from the nomenclature system used in the PMIS Rater's Manual (TxDOT 1998).

4.4.1 Locating Sections in the Field

To successfully locate a section in the field, several sources of information were used, such as road maps, the previous condition survey forms, and SAS reports. Once the sections were listed in a spreadsheet, they were sorted in ascending order according to the road number, direction, and mileposts. Everything was then set for visiting the sections.

Survey Procedure

Once a list of sections to be surveyed is sorted according to mileposts, the next step is to go to the field and collect the current information about the pavement regarding distresses and general conditions. The condition survey is performed in the field according to the following steps:

1. Identification of the section. The vehicle is parked at the beginning of the section, and it is used as a barrier for the protection of the crew member(s) against traffic. The hazard lights and headlights are turned on, and then the crew is able to perform a preliminary inspection of the section. The GPS equipment is configured and fixed on the dashboard of the vehicle. It should stay there for a few minutes in order to stabilize and obtain a reliable reading.
2. The GPS coordinates are recorded, usually for the starting point of the section. If no reading is available, then the coordinates are recorded for the ending point of the section.
3. The inventory data of the section are recorded in the survey form, and then the surveyors are ready to begin the collection of distress data. If the CFTR section number paint is not clearly visible, new paint is applied. The crew walks from the starting point toward the end of the test section and records all the necessary information regarding distresses and general conditions of the pavement and its shoulder. At the end of the section, another visible paint mark should be applied indicating with an arrow the direction of the surveyed section, along with its CFTR number. The paint mark may begin on the edge of the shoulder and extend to the interior.
4. Usually, one lane is surveyed and its position is recorded in the survey form according to the PMIS Rater's Manual (TxDOT 1998).
5. To record the crack spacing distribution, a measuring wheel or rolatape is set to zero and placed on the starting point. While walking through the section, a 1 ft. stripe is marked every 200 ft. showing the cumulative distance from the starting point recorded above or below the stripe, usually in hundreds of feet.

6. Using the measuring wheel for the first 200 ft. of the section, the cumulative distance from the starting point to each transverse crack is recorded on the survey form.
7. As previously mentioned, the distresses are recorded on the survey form. For a nonoverlaid section one surveyor measures distances and marks the pavement, while the other counts and records the number of punchouts, D-cracks, corner breaks, spalled joints and cracks, faulted joints, repaired patches, and cracks. For an overlaid section, asphalt concrete patches, cracks, ruts, repaired patches, punchouts, and reflected cracks are recorded. Shoulder conditions and any relevant comments are also recorded.
8. Photographs are taken with a digital camera. At least two pictures are taken for a section. One picture showing the first 200 ft. of the test section is taken and the milepost is included, if possible.

The equipment used to collect field information includes the following:

1. Condition survey forms
2. Spray paint, usually yellow or red
3. Rolatape or measuring wheel
4. Digital camera and floppy diskettes
5. Highway maps and county maps to locate the projects and sections to be surveyed
6. List of projects with precise location information
7. Safety vests and hard hats
8. GPS equipment and accessories

Data Inconsistencies

During fieldwork a variety of inconveniences come up, including loss of time due to unforeseen events and problems encountered when discrepancies exist between what is stored in the database and the in situ conditions of a section. Several examples are:

1. Certain test sections fell short of the initial target of 1000 ft. length.
2. The heavy traffic in urban areas did not permit the surveying of certain test sections.
3. JCP distresses could not be recorded on recently overlaid sections.
4. In only a few cases the test sections in the field did not correspond to already-existing sections in the database, and this caused some problems in locating the correct test sections. Three sections believed to be JCP turned out to be CRCP. Those errors were most likely the result of information incorrectly updated in previous surveys.
5. Where new sections were incorporated into the database, a very common and time-consuming problem was that the available information on the location of the sections was given in "construction plan stations," instead of mileposts. As a result, an adequate correlation between both referencing systems was difficult to obtain. Usually, TxDOT staff provides linear equations for particular projects, but in some cases those do not work appropriately.

4.5 Measurement of Distresses

As part of the condition survey process, the identification, classification, and quantification of various distresses are performed. Appendix E describes the most common distresses found in overlaid and nonoverlaid pavements, with the latter being the case when a concrete pavement has a layer of asphalt concrete placed over it. Causes of the manifestations and how the distresses are rated are also described.

4.6 GPS Technology Application

Global positioning system (GPS) is a satellite navigation system that is funded and controlled by the U.S. Department of Defense (DOD). Although there are thousands of civilian users of GPS worldwide, this system was originally designed for military purposes. GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity, and time. Extensive GPS concepts may be found in some of the references listed at the end of this report.

4.6.1 Current Equipment

For this project, the survey crew used two GPS units. From left to right, Figure 4.3 displays the Trimble® Scout receiver, the DCI® differential receiver, and the GeoExplorer® receiver. Because the Scout has no capability of receiving differential correction data, it was used alone; the GeoExplorer® has a port that can be used to either connect the FM differential receiver or a personal computer.

The receivers shown in Figure 4.3 were used in a field test in order to determine the accuracy and repeatability of the two units. The test procedure was a simple factorial design using two different operators visiting three different locations in Houston and San Antonio. The factors to be determined were the ability of the two units to accurately obtain and relocate a test section at a later time, and the limitations of the equipment regarding the expected error when relocating a section. Table 4.1 shows the obtained repeatability of the two devices.

Figure 4.3 The GPS Scout®, the DCI® and the GeoExplorer® receivers

Table 4.1 Repeatability of the GPS receivers

Location	Scout Error (ft.)	GeoExplorer® Error (ft.)
1	506.9	8.5
2	382.8	12.7
3	105.0	21.0
Average	331.6	14.1

4.6.2 Actual Coverage and Needs

It is estimated that more than 90 percent of the surveyed sections are located in an area where differential correction is provided. Only those sections located in the Amarillo and Wichita Falls districts were not differentially located, even though those sections still have geographic coordinates. Appendix B shows the areas in Texas where differential correction is available from DCI®, the current provider.

A pertinent observation can be made from the experience: Any operator can obtain accurate, repeatable results at any location using the differentially corrected receiver (GeoExplorer®). To relocate a section within 15 ft. of accuracy, the results obtained with the available equipment are good enough for building a reasonable history of pavement performance. The GPS technology was found worthwhile and better than the previous system in which nearly 20 percent of the sections were not precisely located each year a condition survey was done.

One aspect that should be considered when using the GeoExplorer® is that the correct configuration parameters must be set every time it is used in the field. Appendix A shows the step-by-step procedure to configure the device. Failure to reconfigure the receiver would result in defective real-time reading positions.

4.7 Processing Data

Once the collection of field data is completed, the next step consists of the incorporation of the information into the electronic format of the database. At the same time, the completed condition surveys are photocopied and stored in appropriate files to avoid losing the information. Next, as described in the following sections, the data are incorporated into an electronic format, quality control is exercised, and software compatibility is ensured.

4.7.1 Incorporation of the Data into Electronic Format

In order to begin with the incorporation of the field data into electronic format, the survey form must be previously checked to corroborate that the contained information belongs to the correct location, district, or highway.

Once the information is reviewed, it is ready to be input. The incorporation process in this study was adopted as a standard for different purposes. This standard methodology begins with the use of Microsoft Excel, which is the software used to routinely prepare charts and graphs to show outcomes of different distresses and demographics of the sections.

Taking advantage of the compatibility of Microsoft Access and Excel, the tables prepared in Excel are then imported from Access and stored in *.mdb format, which is the default Access format for databases. This Access format is useful to prepare summary reports and to facilitate communication with SAS.

Finally, the tables imported to Access may be imported again from SAS. The use of SAS is fundamental for the database because it provides very complete reports and statistical analysis of the information. Figure 4.4 shows a typical report of a section generated by SAS. Similar reports can be prepared using Access.

SECTION ID

CFTR:	18164-01	DISTRICT:	18	HWY:	SH352
CTRL:	430	COUNTY:	DALLAS	LOC:	592+0.0
SEC:	1				592+0.2

CONSTRUCTION

CONST. DATE:	1965.8
RATED LANE:	RI
THICKNESS:	8
SUBBASE:	1
COARSE AGG:	L
LENGTH:	1000
AMAT:	12.80
AARF:	32.80
AMER:	0.08
LTAC:	10.00
HTDC:	78.80

TRAFFIC

YR	ADT	% TRUCK	ATHWL	% TAND	ESALs ($x10^6$)
1994	---	---	---	---	14.3595

CONDITION SURVEY

SEC	YR	RBD	CURVE	OVR	LEN	ACP	PCP	DCRACK	CRACKS
18164-01	1994	G	R	N	1000	0	0	0	55
	1998	G	R	N	1000	0	0	1	55

DEFLECTIONS

SEC	LOC	DF1	DF2	DF3	DF4	DF5	DF6	OVR	CONF

***** NO DEFLECTIONS AVAILABLE IN DATABASE *****

Figure 4.4 Summary report for a typical section

4.7.2 QC/QA Activities

These activities are performed in various ways. While in the field, the basic QC/QA procedure is to check that all the information has been collected. Special attention is given to the reading of the correct GPS coordinates and the adequate location of the section with respect to mileposts by using the PMIS Rater's Manual criterion.

With regard of the processing of data, QC/QA procedures are usually done by reviewing the correct input of data to the electronic format. This process can be easily performed when some basic skills have been developed. Special attention is given in this case to revising the correct CFTR number, location, and distress types for a particular section.

4.7.3 Software Compatibility of the Database

As previously mentioned, different software packages are used in the management of the database. This policy has been adopted as the standard because it has provided an effective way to prepare diverse analysis and reports. Another reason for maintaining this software variety is because TxDOT's Pavement Management Information System (PMIS) database also combines SAS and Access software.

5. Influence of Climatic Factors on Pavement Performance

5.1 Environmental Effects

Environmental conditions play an important role in pavement performance. Owing to relevance of the climatic factors affecting the early age pavement performance, the researchers felt it was essential to incorporate extensive climatic information in the existing database, which in the past contained only two climatic indicators: average lowest annual temperature and average annual rainfall amount. Having only these two parameters, it was not possible to calculate evaporation rate, a parameter that is fundamental in the early and long-term performance of concrete pavement. For this reason, the evaporation rate, the low winter temperature after concrete placement, and the high ambient temperature during placement are additional climatic parameters that are being included in the database, as described in the following paragraphs.

Information from the National Oceanic and Atmospheric Administration (NOAA) has been retrieved, transformed, and merged into the database. Most of these data can be obtained from the National Climatic Data Center (NCDC) Solar and Meteorological Surface Observation Network (SAMSON), which contains among other variables, hourly temperature, relative humidity, wind speed, and precipitation. Rainfall amounts were obtained from the NCDC Internet site. Statistical analysis software (SAS) programs were used to extract data and compute the following five weather variables.

5.1.1 Average Minimum Annual Temperature (AMAT)

This study updated the information from 1987 currently in the database. The lowest temperature for each year was obtained and averaged for the twenty-year period from 1971 to 1990. The computed values have been incorporated into the database.

5.1.2 Average Annual Rainfall (AARF)

Special research studies using the database have demonstrated the potential for swelling damage by correlating swelling soils with high rainfall. This study is updating the rainfall information from the 1987 values currently in the database. From the NCDC information, the total annual rainfall was retrieved and calculated for each year and averaged for the period from 1970 to 1990, depending on the available data from the NCDC Internet site.

5.1.3 Average Monthly Evaporation Rate (AMER)

The mean evaporation rate was obtained for each month averaged over ten years, by county, and matching the existing construction projects. Of the climatic data that are being incorporated into the database, this is the most difficult parameter to calculate. The reason is the need for additional temperature parameters that are considered in the evaporation rate equation (Eq. 5.1). A predicted evaporation rate can be calculated when climatic data are available, as well as concrete temperature, at placement time.

The evaporation rate calculation is based on an equation published by the Portland Cement Association (PCA 1966):

$$E = 0.0638 * \left(e_c - \frac{RH * e_o}{100} \right) * (0.253 + 0.0960 * ws) \qquad \text{(Eq. 5.1)}$$

where

$$e_c = 0.611 * e^{\left[17.269 * \frac{(t_c - 32)/1.8}{[(t_c - 32)/1.8] + 237.3} \right]}$$

$$e_o = 0.611 * e^{\left[17.269 * \frac{(t_a - 32)/1.8}{[(t_a - 32)/1.8] + 237.3} \right]}$$

E = *Evaporation rate (lb/ft^2/hr)*

RH = *Relative humidity (%)*

ws = *Wind speed (mph)*

tc = *Concrete temperature (°F)*

$tc=20.2+0.758\ ta$

ta = *Ambient temperature (°F)*

This equation is valid for a free surface of water, similar to a concrete pavement when no curing compound has been applied to the surface.

The evaporation rate parameter has been found to be a fundamental factor influencing the early age performance of new pavements. Gräter (1996) documented research done on the effect of different curing methods and evaporation rates of concrete. He also obtained evaporation rates for test sections located in Dallas and El Paso and showed the effects of different climatic conditions on the evaporation rates.

Evaporation rates were calculated for each section in the JCP database using the previous equation (Eq. 5.1). This evaporation rate was computed daily for a period of 3 months (one month prior to construction, through construction, and one month after the construction). The average of these daily evaporation rates was considered the final value for the average monthly evaporation rate.

5.1.4 Low Temperature After Construction (LTAC)

Temperature variation through time causes cyclical variations in the geometry of the slab. Expansion, contraction, curling, and warping are commonly known negative effects of temperature on pavement. A slab has disproportionate dimensions and its surface is commonly exposed to drastic environmental changes in comparison to the other five faces. These factors cause considerable temperature gradient changes in the shortest dimension of the slab (thickness) and large displacements on the longest dimension.

The combination of these factors, as well as the varying material properties, induces volumetric changes to the slab, which when restrained can cause unwanted behavior in the structure. Low temperatures after construction relate to the freezing and thawing cycles of pavement and underlying stratums. The contraction and expansion of the concrete slab cause tensile distresses in the structure, which are undesirable.

These cited reasons explain why this climatic factor is being included in the database. This parameter was derived from the lowest temperature recorded over a period of 13 months (one month before construction through twelve months after construction) and has now been calculated for all the JCP sections in the database.

5.1.5 High Temperature During Construction (HTDC)

As previously explained, the ambient temperature influences the early age performance of pavement. The temperature effect during construction has been a topic of various studies at CTR. Several reports contain valuable information on this topic and most of them are focused on the differences observed in cracking pattern and evolution of concrete mixtures prepared with limestone and siliceous materials.

As was previously discussed, temperature changes cause slab movement, and the restraint of movement exerted by the subbase to the slab due to those cyclical variations is transformed into stresses in the slab. The distribution and magnitude of these stresses depend on the setting temperature.

Results of Projects 1244 and 422 showed that concrete placement time significantly affects crack distribution at early ages. Results reflect that there is a great difference in the crack distribution of the pavement slab when concrete is placed in opposed seasons like summer and winter. Differences were also found between day and night paving results. These differences are stressed by the use of different aggregate types, such as limestone (LS) and siliceous river gravel (SRG). Figure 5.1 shows the temperature fluctuations of an early age concrete slab for summer and winter seasons and through time of day.

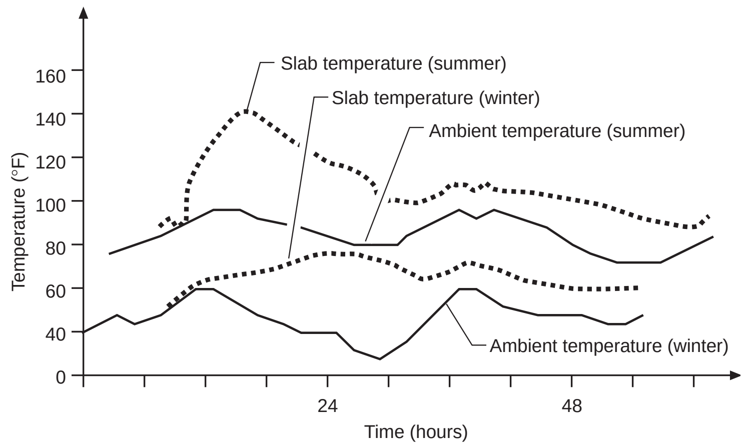

Figure 5.1 Early age concrete slab temperature fluctuations over time and season

For the JCP sections in the database, the high temperature during construction was computed as the average of the highest temperatures for 3 months surrounding the construction date (one month before construction, one month during construction, and one month after construction).

In summary, environmental conditions have an influence on the short-term performance of pavement and may have an effect on the long-term performance. Appendix D lists all these climatic variables for all the JCP sections in the database.

6. Distress Analysis of the Sections

This chapter presents the analysis of the test sections using the information obtained during condition surveys conducted in 1994 and 1998. The analysis presented here corresponds only to the JCP sections located in the Dallas District. This district was selected for the analysis because the distribution of the test sections provides an excellent representation of the Texas JCP highway network in terms of traffic, weather conditions, concrete pavement's coarse aggregate, and other characteristics.

The analysis shows the historical evolution of distresses through time for twenty-eight test sections, all of them located in the Dallas area and distributed through interstate highways, state highways, U.S. highways, loops, and farm-to-market roads.

6.1 Development of the Analysis Plan

Figure 6.1 shows the analysis plan that was followed in this chapter to analyze different distresses found on the pavement sections.

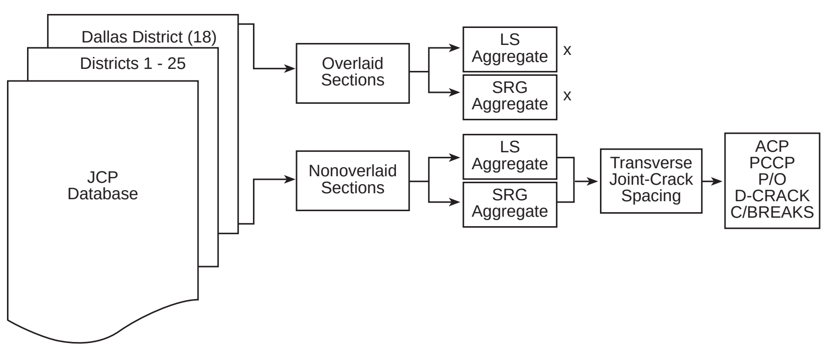

Figure 6.1 Sequence of the analysis plan for the JCP sections

First of all, the entire JCP database containing test sections from fourteen districts was revised district by district, and then it was decided that the Dallas District fairly represented the overall JCP database. Having selected the sections in Dallas, the next step was to decide if both the overlaid and the nonoverlaid sections were to be included in the analysis. After consideration, it was decided not to include the overlaid sections for two reasons:

1. There were only three overlaid JCP sections in the district: one section contains limestone (LS) as coarse aggregate, one contains siliceous river gravel (SRG), and the third contains a mixture of both aggregates. Including these sections in the analysis would not fairly represent the behavior of the overlaid pavement sections because of the small sample.
2. Additionally, it was decided not to consider the overlaid sections because the observed distresses in this type of section would not be the only ones existing in the pavement. Other distresses could be hidden under the asphalt overlay and may not be noticed at certain times of day and at ambient temperatures.

Once it was decided to analyze the nonoverlaid sections, the next step was to test the sections based on the two different coarse aggregates. Therefore, the analysis shows the results of distresses for the sections containing LS and also the results of distresses for the sections containing SRG. Finally, the two scenarios were compared to show the performance of concrete pavement containing two different aggregates under similar conditions.

6.2 Typical Example of Distresses Analysis

The following sections present the analysis of the distresses of twenty-eight test sections with 50 percent of them containing each aggregate type. This is an ideal condition because it is not necessary to compute weighting factors when comparing the results of the two aggregates.

The analysis begins with the observation of different distresses in the pavement sections and then continues with a crack-joint spacing analysis.

6.2.1 Coarse Aggregate Type (CAT) Consideration

To analyze the effect of coarse aggregate type on the behavior of pavement, different common distresses are considered and listed in Table 6.1, which shows the sections that were considered for the analysis and their distresses for the 1994 and 1998 condition surveys. The first half of the sections contains LS as coarse aggregate and the second half contains SRG. Note that this table contains only basic information needed for analysis. Further information on the sections, such as reference markers, GPS location, and so forth, may be found at the appropriate table in Appendix C. Climatic information prevailing in the area where the sections are located may be found in Appendix D. The values displayed in Table 6.1 correspond to the number of distresses found in the overall length of the sections, commonly 1000 ft.

Table 6.1 Basic information for JCP sections containing LS and SRG in the Dallas District for the 1994 and 1998 surveys

				1994					1998				
CFTR	HWY	OVER	CAT	ACP	PCCP	P/O	D-CRACK	C/BREAK	ACP	PCCP	P/O	D-CRACK	C/BREAK
1816401	SH0352	N	L	1	0	0	0	0	0	0	0	1	0
1816402	SH0352	N	L	0	0	0	0	1	0	0	0	0	0
1816403	SH0352	N	L	2	0	0	1	1	4	0	0	0	1
1817001	LP0244	N	L	1	1	0	0	0	1	1	0	0	0
1860201	IH0035E	N	L	0	0	0	0	0	0	0	0	0	0
1860202	IH0035E	N	L	0	0	0	0	0	0	0	0	0	0
1860203	IH0035E	N	L	0	0	0	0	0	0	0	0	0	0
1860501	SH0034	N	L	0	0	0	0	0	6	0	1	1	3
1860502	SH0034	N	L	0	0	0	0	0	1	0	0	0	1
1860901	SH0121	N	L	0	0	0	0	0	0	0	0	0	0
1860902	SH0121	N	L	0	0	0	0	0	0	0	0	0	0
1861001	IH0035	N	L	0	0	0	0	0	0	0	0	0	0
1861002	IH0035	N	L	0	0	0	0	0	0	0	0	0	0
1861003	IH0035	N	L	0	0	0	0	0	0	0	0	0	0
1812001	SH0342	N	S	7	0	0	7	4	8	3	0	1	2
1812002	SH0342	N	S	5	0	0	11	0	6	1	0	11	0
1860101	US0067	N	S	1	0	0	1	0	0	0	0	0	0
1860101	US0067	N	S	0	0	0	0	0	0	0	0	0	0
1860301	FM0546	N	S	0	5	0	0	0	0	7	0	5	5
1860302	FM0546	N	S	1	0	3	0	1	3	0	0	4	1
1860401	FM3038	N	S	0	0	0	0	0	0	0	0	0	0
1860402	FM3038	N	S	0	0	0	0	0	0	0	0	0	0
1860601	IH0020	N	S	0	0	0	0	0	0	0	0	0	0
1860602	IH0020	N	S	0	0	0	0	0	1	0	1	0	0
1860603	IH0020	N	S	0	0	0	0	0	0	0	0	0	0
1860701	IH0030	N	S	0	0	0	0	0	0	0	0	0	0
1860702	IH0030	N	S	0	0	0	0	0	0	0	0	0	0
1860703	IH0030	N	S	0	0	0	0	0	0	0	0	0	0

The overall and mean for each distress type is summarized in Table 6.2. The first two columns show the number of distresses for the fourteen LS sections and the fourteen SRG sections, respectively. The next two columns show the computed mean value of distress per 1,000 ft. section based on the first two columns. The last two columns show the normalized mean number of distresses per mile (DPM) of pavement.

Table 6.2 Summary of distresses for LS and SRG test sections in the Dallas District

DISTRESS	Overall (LS)	Overall (SRG)	Mean (LS)	Mean (SRG)	DPM (LS)	DPM (SRG)
			1994			
ACP	4	14	0.286	1.000	1.429	5.000
PCCP	1	5	0.071	0.357	0.357	1.786
P/O	0	3	0.000	0.214	0.000	1.071
D-CRACK	1	19	0.071	1.357	0.357	6.786
C/BREAK	2	5	0.143	0.357	0.714	1.786
			1998			
ACP	12	12	0.857	0.857	4.286	4.286
PCCP	1	10	0.071	0.714	0.357	3.571
P/O	1	1	0.071	0.071	0.357	0.357
D-CRACK	2	10	0.143	0.714	0.714	3.571
C/BREAK	5	8	0.357	0.571	1.786	2.857

Figure 6.2 presents the number of distresses per mile (DPM) for each distress type according to the 1994 condition survey results and for the two aggregate types (LS and SRG). Figure 6.3 shows the same parameters obtained in the 1998 condition survey. Note that for both survey years, the number of occurrences per mile for the SRG is generally greater than the number for LS. This is similar to the results for continuously reinforced concrete pavement (CRCP) that have been reported over the years. Thus this observation should be studied on a statewide basis in the near future.

Figure 6.4 compares the distresses found in the two condition surveys, but for the LS sections only. Figure 6.5 also compares the results of the two years for the SRG test sections. For the LS test sections, the number of all types of distress occurrences increases with age as expected. This is not the case for the SRG test sections for ACP patches, punchouts, and D-cracking. This does not imply the data are inconsistent because they may have decreased due to their replacement by portland cement concrete patches (PCP). To ascertain the correct implication, one needs to examine the detailed survey.

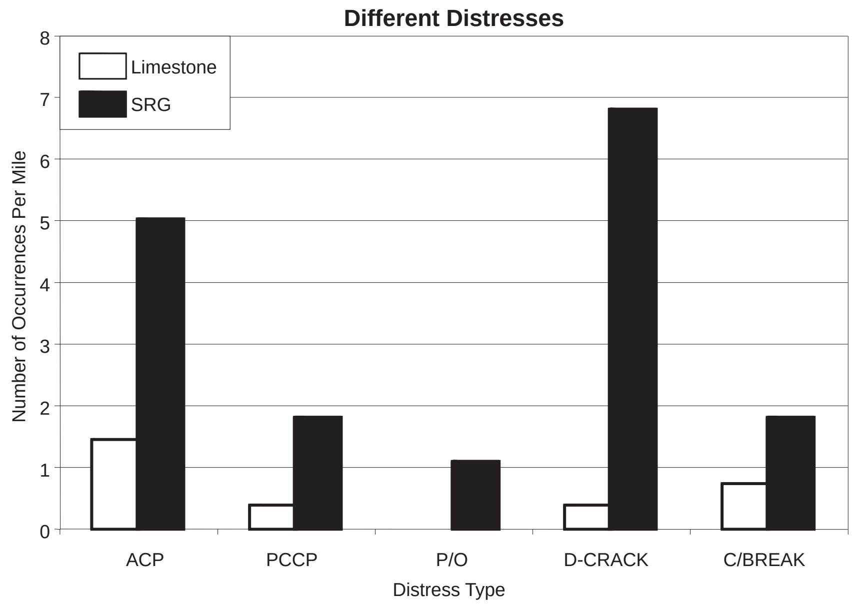

Figure 6.2 Distresses found in the 1994 condition survey by aggregate type in the Dallas District

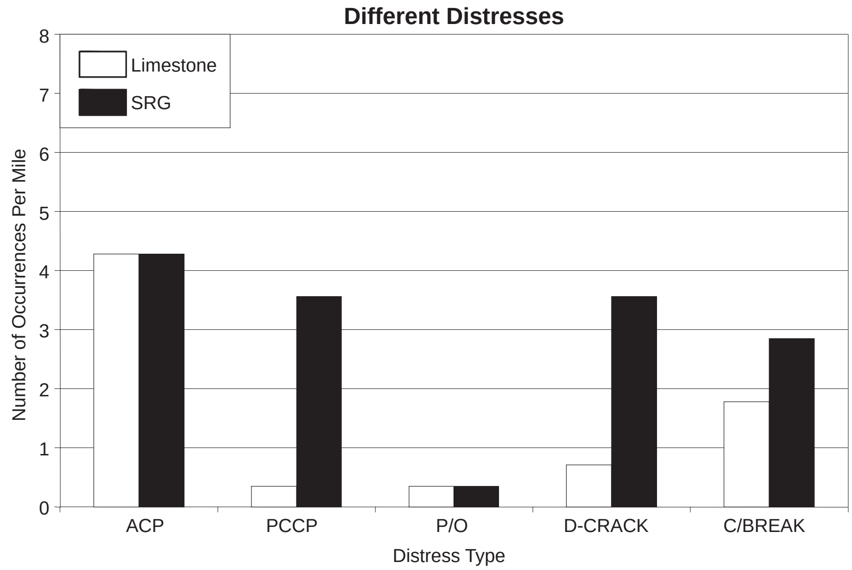

Figure 6.3 Distresses found in the 1998 condition survey by aggregate type in the Dallas District

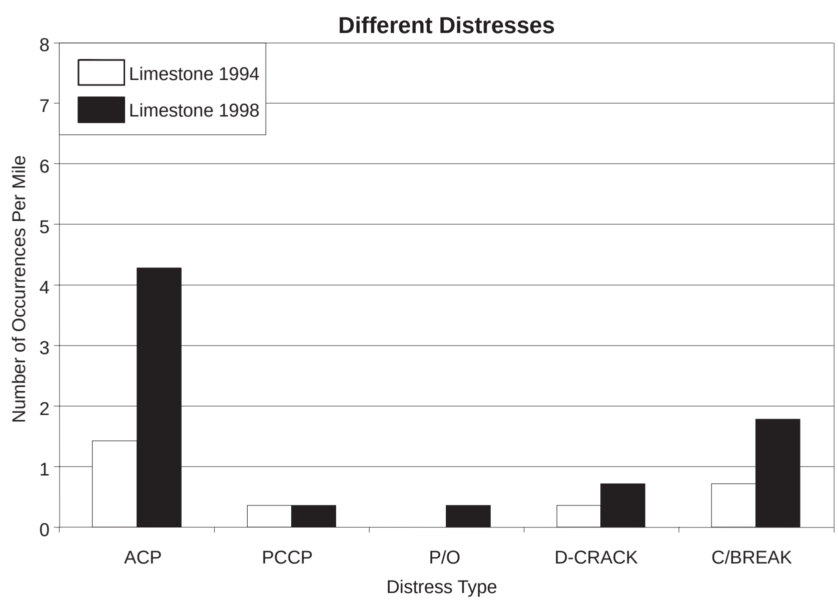

Figure 6.4 Distresses for sections with limestone aggregate for 1994 and 1998 in the Dallas District

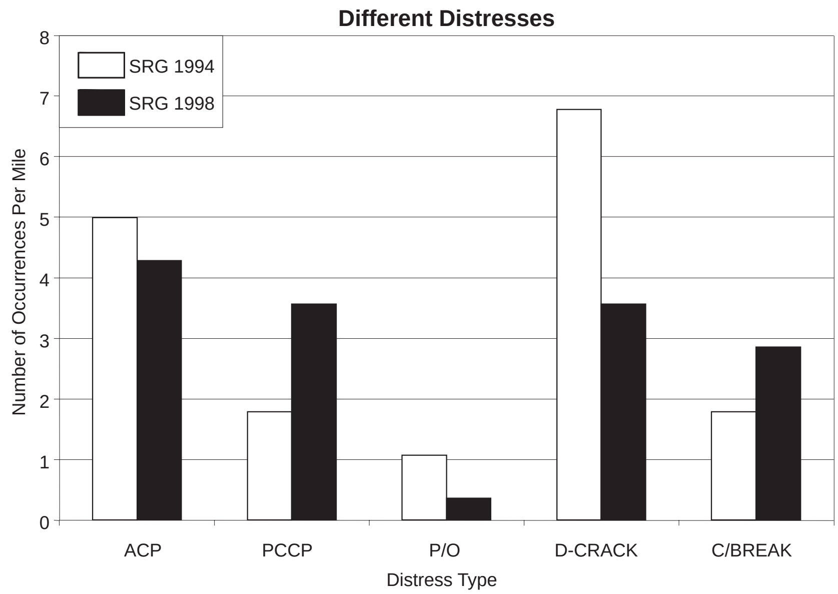

Figure 6.5 Distresses for sections with SRG aggregate for 1994 and 1998 in the Dallas District

In summary, from Figure 6.2 through Figure 6.5, the following pertinent observations may be made:

1. In general, it can be seen that the sections containing limestone as coarse aggregate had considerably fewer distresses than the sections built with siliceous river gravel.
2. The recorded results for the sections containing limestone show a clear historical evolution, i.e., increments of distresses through time.
3. In only a few cases, and particularly when comparing the sections containing SRG, the number of distresses found in 1994 exceeded the distresses found in 1998. This inconsistency may be due to problems or errors experienced while recording the information in the field. A more rational reason may be that more permanent repairs were made by the district between 1994 and 1998, i.e., concrete repairs increased, thus the observed distresses were converted to concrete repairs.

6.2.2 Crack and Joint Spacing Distribution

This part of the analysis focuses on the crack and joint spacing distribution of the same twenty-eight test sections located in the Dallas District. Transverse joints are usually spaced 15 to 20 ft. apart or sometimes more, depending on the pavement design characteristics, such as thickness, subbase type, and presence of reinforcing steel and dowel bars.

Indeed, the analysis presented here corresponds to the transverse cracking; the longitudinal cracking pattern is not considered. Table 6.3 lists the sections analyzed and their corresponding crack and joint spacing distribution as it was recorded in the field during 1994. The first half of the sections contains limestone and the second half contains siliceous river gravel. Table 6.4 lists the same crack and joint spacing distribution, but for the 1998 field visit. In both tables, the displayed units are feet, and on the left portion of the table show the cumulative distance of the cracks or joints from the beginning of each section until the first 200 ft. On the right side of the tables, the partial distance or the distance between cracks or joints, is displayed.

Table 6.3 Crack-joint spacing distribution for SRG and LS coarse aggregates found in the 1994 condition survey

CFTR	CAT	Cumulative Spacing															Crack spacing between joints/cracks													
1816401	L	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1816402	L	14	28	44	59	73	88	104	118	133	148	163	178	193	x	x	14	16	15	14	15	16	14	15	15	15	15	15	x	x
1816403	L	17	20	46	58	80	108	194	x	x	x	x	x	x	x	x	3	26	12	22	28	86	x	x	x	x	x	x	x	x
1817001	L	11	27	42	57	72	87	102	117	132	147	150	153	162	177	192	16	15	15	15	15	15	15	15	15	3	3	9	15	15
1860201	L	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1860202	L	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1860203	L	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1860501	L	15	30	45	60	75	90	106	121	136	152	167	182	188	197	x	15	15	15	15	15	16	15	15	16	15	15	6	9	x
1860502	L	12	28	42	57	72	87	103	118	132	148	164	178	193	x	x	16	14	15	15	15	16	15	14	16	16	14	15	x	x
1860901	L	15	30	45	60	75	90	105	120	136	151	166	181	197	x	x	15	15	15	15	15	15	15	16	15	15	15	16	x	x
1860902	L	15	30	45	60	75	90	105	120	135	150	166	181	196	x	x	15	15	15	15	15	15	15	15	15	16	15	15	x	x
1861001	L	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1861002	L	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1861003	L	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1812001	S	41	60	120	180	x	x	x	x	x	x	x	x	x	x	x	19	60	60	x	x	x	x	x	x	x	x	x	x	x
1812002	S	24	69	130	180	x	x	x	x	x	x	x	x	x	x	x	45	61	50	x	x	x	x	x	x	x	x	x	x	x
1860101	S	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1860101	S	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1860301	S	13	28	43	57	72	87	101	115	130	144	157	173	187	197	x	15	15	14	15	15	14	14	15	14	13	16	14	10	x
1860302	S	12	28	43	57	72	86	101	114	128	143	157	171	185	199	x	16	15	14	15	14	15	13	14	15	14	14	14	14	x
1860401	S	15	30	44	52	61	76	91	106	117	129	140	156	171	187	x	15	14	8	9	15	15	15	11	12	11	16	15	16	x
1860402	S	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1860601	S	15	30	46	61	76	91	107	122	137	153	168	183	198	x	x	15	16	15	15	15	16	15	15	16	15	15	15	x	x
1860602	S	15	30	45	60	75	90	106	121	136	151	166	181	197	x	x	15	15	15	15	15	16	15	15	15	15	15	16	x	x
1860603	S	15	30	45	60	75	91	106	121	136	151	167	182	197	x	x	15	15	15	15	16	15	15	15	15	16	15	15	x	x
1860701	S	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x
1860702	S	15	30	45	60	75	90	105	120	135	150	166	181	196	x	x	15	15	15	15	15	15	15	15	15	16	15	15	x	x
1860703	S	15	30	45	60	75	90	105	120	135	150	165	180	195	x	x	15	15	15	15	15	15	15	15	15	15	15	15	x	x

Table 6.4 Crack-joint spacing distribution for SRG and LS coarse aggregates found in the 1998 condition survey

CFTR	CAT	Cumulative Spacing														Crack spacing between joints/cracks													
1816401	L	15	31	45	61	76.7	92	106	123	138	153	168	184	199	x	16	14	16	15	15	14	16	15	15	15	16	15	x	x
1816402	L	15	20	45	60	74.5	90	105	120	135	150	165	181	197	x	5	25	15	15	15	15	15	15	15	15	16	15	x	x
1816403	L	18	47	58	81	109.11	197	x	x	x	x	x	x	x	x	30	11	23	28	88	x	x	x	x	x	x	x	x	x
1817001	L	12	27	43	58	73.9	88	104	120	130	135	150	165	169	181	15	16	15	16	14	16	16	10	5	15	15	4	12	16
1860201	L	15	31	46	61	75.9	91	106	122	136	151	167	182	198	x	16	15	15	15	15	15	16	14	15	16	15	15	x	x
1860202	L	15	31	46	62	76	92	106	122	137	153	167	182	197	x	15	15	16	14	16	14	15	15	16	14	15	15	x	x
1860203	L	15	31	46	61	76	91	106	122	137	151	167	198		x	15	15	15	15	15	15	15	15	14	16	31	x	x	x
1860501	L	15	30	46	61	76.2	91	107	123	138	154	168	185	199	x	15	16	15	16	15	16	15	16	16	14	17	14	x	x
1860502	L	0	16	32	46	61.6	77	93	108	123	138	153	168	184	199	16	16	15	16	15	16	15	15	15	15	15	15	15	x
1860901	L	15	31	45	60	76.2	92	107	122	137	152	168	182	198	x	16	14	15	16	15	15	15	15	15	15	14	16	x	x
1860902	L	16	31	46	61	76.1	91	107	122	136	152	167	183	198	x	15	15	15	15	15	15	15	14	16	15	15	15	x	x
1861001	L	15	31	46	61	75.9	91	105	121	136	151	167	182	196	x	15	15	15	15	15	14	16	15	15	15	15	14	x	x
1861002	L	15	31	46	61	76.4	91	122	138	153	168	184	198	x	x	15	15	16	15	15	31	15	16	15	16	14		x	x
1861003	L	15	31	46	61	76.2	91	107	121	137	152	168	182	197	x	15	15	15	15	15	16	14	16	15	15	14	15	x	x
1812001	S	7	69	131	174	191.4	x	x	x	x	x	x	x	x	x	62	62	44	17	x	x	x	x	x	x	x	x	x	x
1812002	S	x	x	x	x	x	x	x	x	x	x	x	x	x	x	62	59	22	25	x	x	x	x	x	x	x	x	x	x
1860101	S	16	31	47	62	76.5	92	107	120	137	152	166	182	197	x	15	16	15	15	15	15	13	17	15	14	16	15	x	x
1860101	S	16	31	46	60	76.2	91	107	122	137	152	168	182	198	x	15	15	14	16	15	15	15	15	15	16	15	15	x	x
1860301	S	8	22	37	52	66.9	82	96	110	125	140	154	168	184	198	14	15	15	15	15	14	14	15	15	14	14	16	15	x
1860302	S	11	25	41	56	70.5	85	100	114	129	143	157	173	187	x	15	16	15	15	15	15	15	14	15	14	15	15	x	x
1860401	S	13	28	43	52	60.11	76	91	107	117	130	141	158	172	188	15	15	9	8	16	16	15	11	13	12	16	14	16	x
1860402	S	15	31	47	62	77	92	108	123	137	153	169	184	198	x	16	16	15	15	15	15	15	14	16	16	15	14	x	x
1860601	S	16	31	46	62	77.3	93	108	124	139	154	169	185	199	x	15	15	16	15	15	16	16	15	15	15	16	14	x	x
1860602	S	15	31	46	61	76.3	92	107	121	137	153	168	182	198	x	15	15	15	15	15	15	14	16	16	15	14	16	x	x
1860603	S	16	31	45	61	76.6	91	107	122	138	152	168	184	199	x	15	14	16	15	15	16	15	15	14	16	16	15	x	x
1860701	S	15	31	47	61	76.9	92	107	123	137	153	169	184	198	x	15	16	15	16	15	15	15	14	16	15	15	14	x	x
1860702	S	15	30	46	62	76.11	92	108	123	138	153	169	183	199	x	15	16	15	15	16	16	15	15	15	15	14	16	x	x
1860703	S	15	30	46	61	76	91	106	122	137	152	166	182	198	x	15	15	15	15	15	15	16	15	15	14	16	15	x	x

From these values shown in Tables 6.3 and 6.4, it may be seen that the crack spacing between joints or cracks ranges from 14 to 16 ft., being 15 ft. in most cases. It may be deducted that the range corresponds to the actual joint spacing between the JCP slabs. On the other hand, those values less than this range correspond to the occurrences of transverse cracks.

Table 6.5 shows the frequency distribution and the cumulative percentage of the crack spacing presented in Table 6.3 for the values recorded in 1994. Figure 6.6 plots the distribution presented in Table 6.5. Again, it can be seen that the joint spacing of 15 ft. represents nearly 90 percent of the overall crack spacings for LS and 82 percent for SRG.

Table 6.5 Frequency distribution of crack-joint spacing (1994) for SRG and LS in the Dallas District

Crack spacing (ft)	Limestone		SRG	
	Frequency	Cumulative %	Frequency	Cumulative %
2	0	0.00%	0	0.00%
4	3	1.82%	0	0.00%
6	1	2.42%	0	0.00%
8	0	2.42%	1	0.65%
10	2	3.64%	2	1.96%
12	1	4.24%	3	3.92%
14	6	7.88%	15	13.73%
16	148	97.58%	126	96.08%
18	0	97.58%	0	96.08%
20	0	97.58%	1	96.73%
More	4	100.00%	5	100.00%

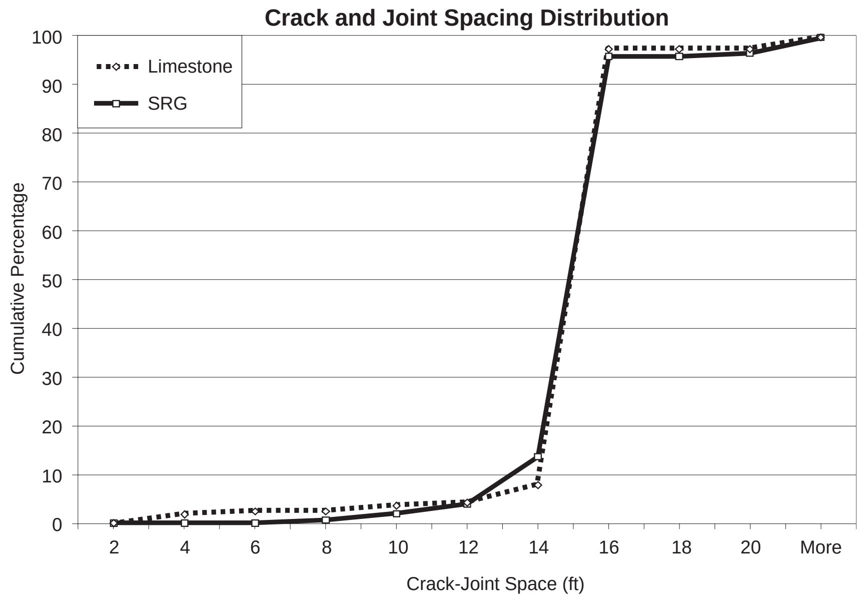

Figure 6.6 LS and SRG crack-joint spacing cumulative distribution (1994)

Table 6.6 shows the frequency distribution and cumulative percentage of the crack spacings presented in Table 6.4 for the 1998 values. Figure 6.7 plots the distribution shown in Table 6.6. In this case, the joint spacing of 15 ft. covers 85 percent of the overall cracks recorded for LS and 80 percent for the SRG aggregate.

Table 6.6 Frequency distribution of crack-joint spacing (1998)

Crack Spacing (ft)	Limestone		SRG	
	Frequency	Cumulative %	Frequency	Cumulative %
2	0	0.00%	0	0.00%
4	1	0.62%	0	0.00%
6	2	1.85%	0	0.00%
8	0	1.85%	1	0.65%
10	0	1.85%	1	1.30%
12	3	3.70%	2	2.60%
14	1	4.32%	8	7.79%
16	137	88.89%	123	87.66%
18	11	95.68%	12	95.45%
20	0	95.68%	0	95.45%
More	7	100.00%	7	100.00%

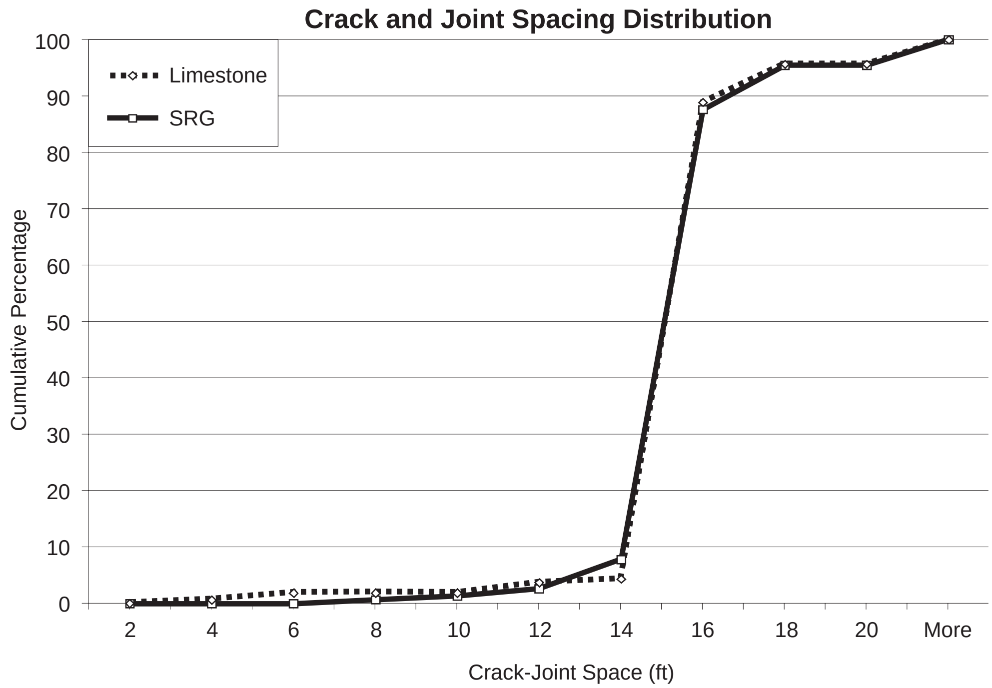

Figure 6.7 Limestone and SRG crack-joint spacing cumulative distribution (1998)

Figure 6.8 compares the crack spacing distributions obtained in 1994 and 1998 for the pavement sections containing LS. Figure 6.9 also makes a comparison between the two-year data for the sections containing SRG. In both cases, the distributions reflect the dominance of the 15-ft. spaced transverse joints. Additionally, it may be seen in these two figures that the slopes of crack spacing of 16 to 18 ft. and 20 ft. or more are steeper for the 1998 than the 1994 results, which means that the number of cracks in those intervals increased from 1994 to 1998.

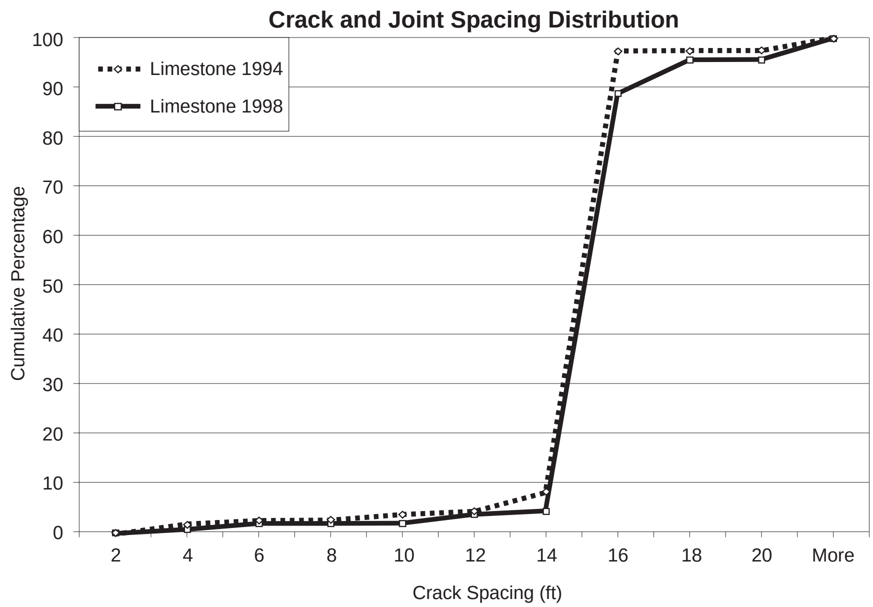

Figure 6.8 Comparison of crack spacing for LS sections (1994 and 1998)

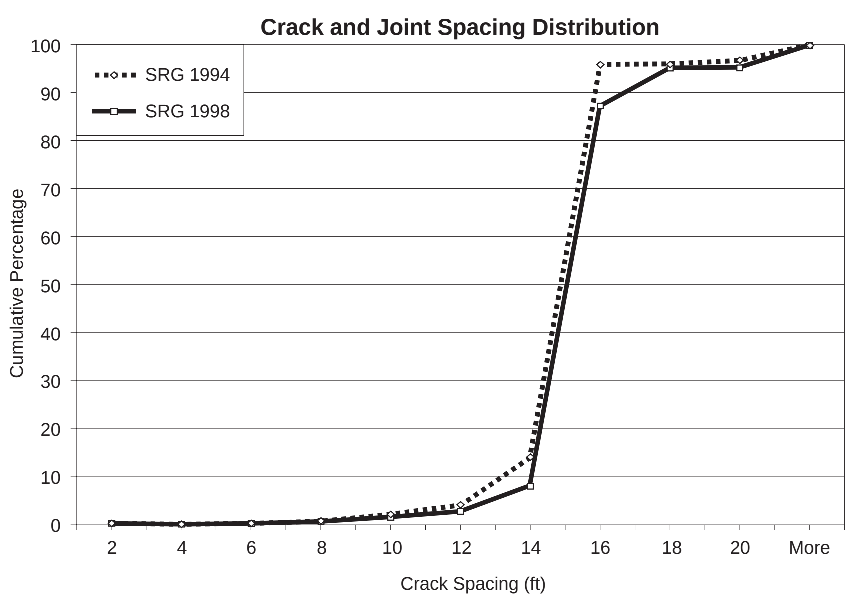

Figure 6.9 Comparison of crack spacing for SRG sections (1994 and 1998)

From the crack spacing distributions, the following observations may be made:

1. Generally, both aggregates have consistent transverse crack spacing.
2. For all the crack spacing frequency distributions, the percentage of 15-ft. spaced transverse joints made up at least 80 percent of the overall crack spacing. The remaining 20 percent or less represented crack spacing below and above 15 ft.
3. The crack spacing, i.e., joint spacing, that evolved more through time was that ranging from 16 to 18 feet.

6.3 Summary

The limited analysis of the 1994 and 1998 condition survey data in the Dallas District reveals several interesting observations with respect to a greater rate of failure with SRG test sections and a more stable joint spacing with LS aggregates. These promising results imply the need for a similar analysis on a statewide basis. If similar trends exist, then the standards for JCP should reflect the difference in aggregate types.

7. Conclusions and Recommendations

7.1 Summary

This report efficiently summarizes all the field and office tasks that have been performed to maintain the RPDB. Field activities include performance data collection for all the existing JCP sections in the database. Special attention was given to the location of the sections in the field using the redundant method – using paint marks on the pavement, mileposts, and reliable GPS coordinates. At present time, all the JCP sections were assigned a GPS location. Office tasks included inputting the collected data in various electronic formats including Microsoft Excel and Access and SAS. Maintaining the data in those formats allows for a variety of analysis of the information contained in the database. Finally, and analysis of the performance of the JCP sections in the Dallas District is presented in Chapter 6. This type of analysis provides a good idea about the progress of pavement distresses and performed maintenance tasks.

7.2 General Conclusions

The CTR of The University of Texas at Austin maintains the RPDB, which contains information for nearly 600 concrete pavement sections that represents the CRCP and JCP highway networks in Texas. The history of the JCP database goes back to 1982, and since then key information related to the inventory and performance of the concrete sections has been collected four times.

The collected information has served as a primary and invaluable tool to develop special research studies and to support reliable performance prediction models for concrete pavement. Within the special studies that have been conducted using the information contained in the database are those related to the evaluation of the performance of concrete containing different coarse aggregates and their thermal properties. Different seasons and customary construction practices such as day- and night-paving effects have also been considered.

Valuable tasks have been accomplished in this project; thus, a contribution has been made to build a cleaner and more viable database that may serve reliable research studies in the area of pavement for years to come. Specific achievements and future direction for studies, i.e., recommendations derived from this project, are described.

7.3 Specific Conclusions

As described earlier in this report, the primary objective of this project was to describe, analyze, and evaluate the current status of the existing RPDB. This objective has been fully accomplished by analyzing and evaluating part of the information contained in the database. The relevance of continuing with the database updating process was highlighted. In the process of achieving the primary objective, a series of sub-objectives were accomplished as follows:

An evaluation and standardization of the procedure in which condition surveys and data collection are performed was described and summarized. This important step was partially achieved by the implementation of a more efficient condition survey form and by documenting the fieldwork step-by-step. Therefore, the information would be collected more efficiently and reliably, and input the information into the database would be easier.

An efficient procedure to store the collected data in an electronic format was developed. This new procedure for processing the data is considered a more efficient way to input, analyze, and report the collected information.

To locate the test sections in the field, this project relied on information from previous studies. In the past only mileposts were used as reference, but now, a GPS location was assigned to every section for future condition surveys. According to the experience gained in this project, using the GPS technology to locate the sections is an accurate, simple, cost effective, and repeatable process. The obtained precision of approximately 15 ft. with availability of differential correction is considered to be sufficient for locating sections.

An important step for this project was the identification of key environmental parameters that have a major influence on pavement performance. The identification of these parameters was accomplished, and they were incorporated into the database and include: average minimum annual temperature (AMAT), average annual rainfall (AARF), average monthly evaporation rate (AMER), low temperature after construction (LTAC), and high temperature during construction (HTDC). Chapter 5 describes these parameters in detail. This additional climatic information updates the past information that included only two indicators: average lowest annual temperature and average annual rainfall amount. Adding and updating this climatic information to the database may result in a significant improvement in its applicability for research studies such as developing performance models.

The demographics of the sections present the characteristics of the pavements contained in the database. When problems are experienced with jointed pavements, these characteristics may be used to extract pertinent information from the database to explain and identify the causes of the problem. Thus, steps may be taken to eliminate or minimize them in the future.

Chapter 6 covers an analysis that focused on the development of pavement distresses and their frequency on pavement sections containing different aggregates. Significant information resulted from this analysis encouraging the investment in continuing with a precise collection of these manifestations during subsequent condition surveys. The analysis presented showed that coarse aggregate type has a significant effect on the performance of jointed pavement. This corresponds to trends discovered with CRCP years ago. Thus, to achieve the intended performance, the design, construction, and maintenance requirements should vary with coarse aggregate type. Therefore, the design standards, construction specifications, and the like will require revisions. The evaluation of crack spacing and joint spacing for the Dallas District revealed a slightly more stable joint spacing for LS coarse aggregates. Thus, perhaps the joint spacing and joint width should be varied with climatic conditions and coarse aggregate type.

7.4 Recommendations

It is recommended that the specific studies in the Dallas District considering coarse aggregate type be expanded to the statewide database. If similar trends are observed, then the design and construction procedures should reflect this difference. Likewise, the transverse crack spacing between joints should be studied on a statewide basis to establish whether the joint spacing used should reflect coarse aggregate type, climatic conditions, subbase type, and so forth, rather than adopting uniform statewide joint spacing.

During the development of this project, various cleaning tasks were performed to avoid accumulating useless or confusing information in the database. As examples of these cleaning tasks, a few sections that did not exist in the field or could not be located were removed, and other representative sections were added to the database. All the collected information for the 1994 project was retrieved from old files and input into an electronic format. That information, as well as the information collected in 1998, is now available in different software formats. Thus, it is recommended to keep performing general cleaning activities on the available information, so it could be compatible with future collected data.

Another important recommendation is to develop a merging process for the two existing databases, the JCP and the CRCP. Even though having two databases is not a major inconvenience, it may be more efficient to have one single database that could differentiate or separate CRCP and JCP sections by simply typing a command.

Because of the priorities of this project, updated traffic information for the sections was not completed. Some initial contacts were made with TxDOT traffic personnel in order to retrieve information for particular sections where weigh-in-motion (WIM) stations are located near pavement sections. It is strongly recommended to revisit this task and promote the inclusion of useful, updated traffic information in the database that could serve as a key element to develop complementary research studies for this project.

Finally, incorporation of more detailed traffic information in the database should be pursued.

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Appendix A

GPS GeoExplorer® and DCI® Receivers Differential Correction Setup Process

Configuration of the GeoExplorer® for real-time differential correction

This appendix includes the instructions for configuring the GeoExplorer® for real-time differential correction (RTCM) using the DCI® receiver manufactured by DCI Digital Communications Inc. The instructions include the types of cables that should be used, as well as the settings to select.

The first step in the field is to check if the GeoExplorer® is receiving the RTCM signal. To accomplish this, on the position screen, the receiver message displayed as 3D changes to 3DX. The necessary cables are shown in Figure A.1. Basically, a download cable P/N 21284 is used. This cable communicates with the receivers and allows RTCM input.

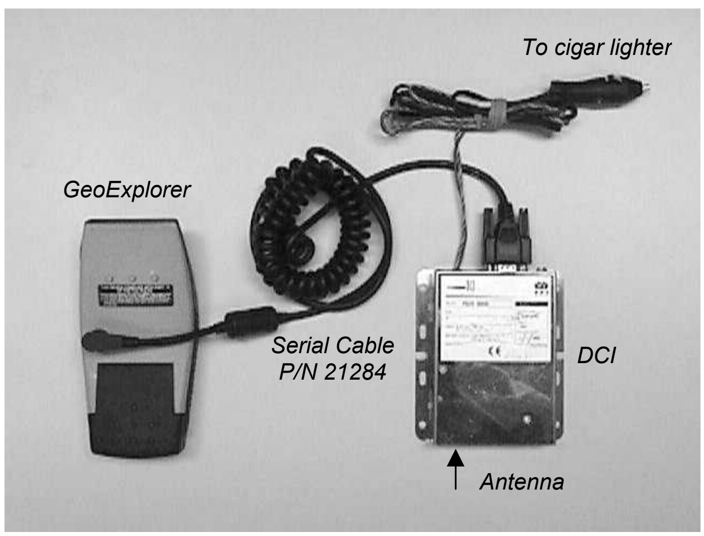

Figure A.1 Connections between the GeoExplorer® and the DCI® receiver

The steps to configure the GeoExplorer® are the following:

a) Plug in all the necessary connections (receivers and FM antenna) and provide AC power to both receivers.
b) Turn on the GeoExplorer® and wait until the main menu appears.
c) Scroll until No. 6 Configuration is highlighted, then press the diamond [♦] key.
d) Scroll until No. 8 RTCM is highlighted, then press the diamond [♦] key.
e) Select 1. Mode = GPS/GPD or Differential. Then press the diamond [♦] key.
f) Select 2. Port = 1. Port A. Then press the diamond [♦] key.
g) Select 1. Protocol = RTCM. Then press the diamond [♦] key.
h) Select 2. Baud = 1200. Then press the diamond [♦] key.
i) Select 3. Parity = None. Then press the diamond [♦] key.
j) Select 4. Data Bits = 8 data bits. Then press the diamond [♦] key.
k) Select 5. Stop bits = 1 stop bits. Then press the diamond [♦] key.
l) Press the [ESC] key twice to return to the RTCM menu.
m) Select 3. Stale time = 10 seconds. Then press the diamond [♦] key.
n) Press the [ESC] key twice to return to the Main menu.

Appendix B

Map of Texas Showing Areas where Differential Correction is Provided by DCI®

Differential correction stations list in Texas

City	Station	Frequency
Abilene	KEAN	105.1
Brownsville	KTEX	100.3
Bryan	KKYS	104.7
Dallas	KCBI	90.9
El Paso	KBNA	97.5
Houston	KILT	100.3
Jacksonville	KOOI	106.5
Laredo	KBDR	100.5
Longview	KYKX	105.7
Memphis	KLSR	105.3
Plainview	KATX	97.3
San Angelo	KCRN	93.9
San Antonio	KXTN	107.5

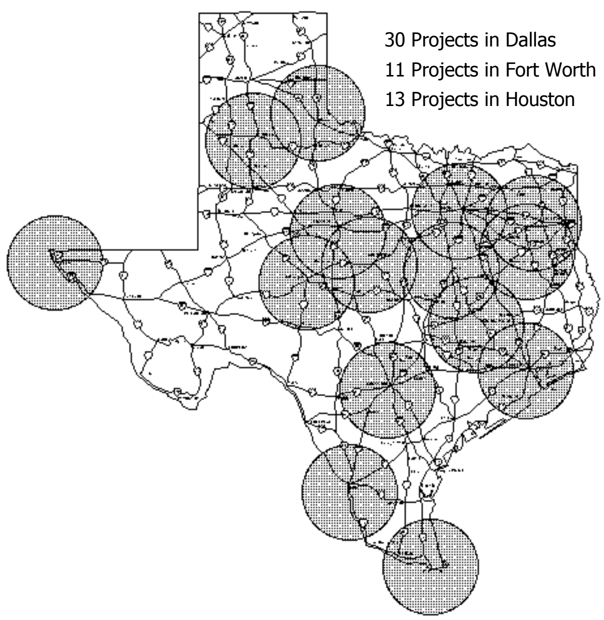

Figure B.1 DCI® FM differential correction coverage in Texas

Appendix C

List of JCP Sections

OBS	DIS	CFTR	COUNTY	HWY	RM1	RM2	GPSLON	GPSLAT
1	1	110101	HUNT	US0069	248+00.45	248+00.25	33.17528	96.13028
2	1	110102	HUNT	US0069	248+00.85	248+00.65	33.17	96.13278
3	1	110103	HUNT	US0069	251+00.8	252+00.0	33.12639	96.13833
4	1	110201	HOPKINS	IH0030			NO REFERENCE MARKERS	
5	1	110201	HOPKINS	IH0030			NO REFERENCE MARKERS	
6	1	110202	HOPKINS	IH0030	123+00.2	123+00.0	33.11806	95.62361
7	1	160101	LAMAR	US0082	703+00.0	703+00.2	33.66028	95.61194
8	1	160102	LAMAR	US0082	703+00.2	703+00.4	33.66	95.60889
9	3	358901	WICHITA	SH0240	467+00.5	467+00.7	33.93722	98.50083
10	3	358902	WICHITA	SH0240	468+00.0	468+00.2	33.93111	98.50056
11	3	358903	WICHITA	SH0240	469+00.05	469+00.25	33.92	98.49028
12	3	359301	WILBARGE	US0287	469+00.4	469+00.2	34.16361	99.31306
13	4	410101	DALLAM	US0087	1000 ft. north of US54	US54 Intersection	36.06556	102.5211
14	4	410101	DALLAM	US0087	Pine st	US54	36.0675	102.5233
15	5	560101	PARMER	SH0086	800 ft. west of OVP	200 ft. east of OVP	34.50806	102.8964
16	5	560101	PARMER	SH0086	200 ft. east of OVP	800 ft. west of OVP	34.50806	102.8964
17	9	960101	LIMESTON	SH0014	364+00.0	363+00.8	31.43194	96.57972
18	9	960102	LIMESTON	SH0014	363+00.8	363+00.6	31.43472	96.57972
19	12	1250501	BRAZORIA	SH0035	522+00.0	522+00.2	29.14833	95.51389
20	12	1250502	BRAZORIA	SH0035	520+00.0	519+00.8	29.15806	95.47833
21	12	1250901	MONTGOME	IH0045	80+00.0	80+00.2	30.21556	95.45694
22	12	1250902	MONTGOME	IH0045	81+00.0	81+00.2	30.22972	95.45806
23	12	1250903	MONTGOME	IH0045	83+00.0	83+00.2	30.25667	95.45639
24	12	1250904	MONTGOME	IH0045	83+00.2	83+00.4	30.25861	95.45528
25	12	1251301	MONTGOME	IH0045	75+00.0	75+00.2	30.14139	95.44611
26	12	1251302	MONTGOME	IH0045	76+00.0	76+00.2	30.15583	95.44889
27	12	1252601	HARRIS	IH0045	66+00.0	66+00.2	30.01417	95.42778
28	12	1253501	MONTGOME	IH0045	85+00.0	85+00.2	30.28194	95.45833
29	12	1253502	MONTGOME	IH0045	88+00.0	88+00.2	30.32667	95.47556
30	12	1253503	MONTGOME	IH0045	89+00.0	89+00.2	30.34028	95.48083
31	12	1253701	HARRIS	IH0045	67+00.0	67+00.2		
32	12	1253702	HARRIS	IH0045				
33	12	1254001	MONTGOME	IH0045	92+00.0	92+00.2	30.38389	95.48583

34	12	1255301	BRAZORIA	SH0035	494+00.0	493+00.8	29.43917	95.23139
35	12	1255302	BRAZORIA	SH0035	496+00.0	495+00.8	29.41167	95.23167
36	12	1255401	BRAZORIA	SH0035	493+00.8	493+00.6	29.44139	95.23333
37	12	1256401	HARRIS	US0225	688+00.0	688+00.2	29.70611	95.25278
38	12	1256402	HARRIS	US0225	688+00.2	688+00.4	29.70611	95.24889
39	12	1257601	WALLER	IH0010	732+00.0	731+00.8	29.77889	95.96667
40	12	1259001	GALVESTO	SH0146	513+00.3	513+00.1	29.39611	94.95083
41	12	1259002	GALVESTO	SH0146	512+00.9	512+00.8	29.40167	94.95222
42	12	1260101	GALVESTO	SH0003	508+00.0	507+00.8	29.34056	94.93444
43	12	1260102	GALVESTO	SH0003	507+00.8	507+00.6	29.34278	94.93639
44	12	1260201	GALVESTO	SH0003	500+00.0	500+00.2	29.43222	95.01972
45	12	1260202	GALVESTO	SH0003	500+00.2	500+00.4	29.43	95.0175
46	12	1260301	HARRIS	IH0010	749+00.0	748+00.8	29.78472	95.68611
47	12	1260302	HARRIS	IH0010	746+00.0	745+00.8	29.78583	95.73639
48	12	1260303	HARRIS	IH0010	745+00.0	744+00.8	29.785	95.7525
49	12	1260304	HARRIS	IH0010	744+00.0	743+00.8	29.785	95.76972
50	12	1260401	HARRIS	SH0146	498+00.0	497+00.8	29.60083	95.03139
51	12	1260402	HARRIS	SH0146	497+00.1	469+00.9	29.61306	95.03361
52	12	1260403	HARRIS	SH0146	496+00.0	495+00.8	29.62917	95.0325
53	12	1260601	FORTBEND	US0059	530+00.0	530+00.2	29.62778	95.59444
54	12	1260602	FORTBEND	US0059	532+00.0	532+00.2	29.60583	95.61528
55	12	1260701	FORTBEND	US0059	540+00.0	539+00.8	29.53611	95.77083
56	12	1260702	FORTBEND	US0059	538+00.0	537+00.8	29.56028	95.69694
57	12	1260703	FORTBEND	US0059	536+00.0	535+00.8	29.56944	95.66583
58	13	1350101	MATAGORD	SH0035	556+00.0	556+00.2	28.98278	95.98417
59	13	1350102	MATAGORD	SH0035	556+00.2	556+00.4	28.98111	95.98722
60	13	1350901	AUSTIN	IH0010	717+00.0	716+00.8	29.76139	96.20778
61	13	1350902	AUSTIN	IH0010	715+00.0	714+00.8	29.75778	96.24056
62	13	1351001	AUSTIN	IH0010	719+00.0	718+00.8	29.76	96.175
63	13	1351002	AUSTIN	IH0010	718+00.8	718+00.6	29.76083	96.17778
64	13	1351201	AUSTIN	IH0010	721+00.0	720+00.8	29.76806	96.14361
65	13	1351301	AUSTIN	IH0010	727+00.0	726+00.8	29.77028	96.04667
66	13	1351302	AUSTIN	IH0010	726+00.0	725+00.8	29.77167	96.06306
67	16	1657001	NUECES	SH0357	556+00.1	556+00.3	27.73556	97.48639
68	16	1657002	NUECES	SH0357	556+00.3	556+00.5	27.73389	97.48361
69	16	1660101	NUECES	FM0665	560+00.1	560+00.3	Find out	Find out

70	16	1660102	NUECES	FM0665	560+00.3	560+00.5	Find out	Find out
71	17	1760201	WASHINGT	FM1155	433+00.8	434+00.0	30.32444	96.1575
72	17	1760202	WASHINGT	FM1155	434+00.0	433+00.8	30.32444	96.1575
73	18	1812001	DALLAS	SH0342	275+00.55	275+00.75	32.65278	96.78222
74	18	1812002	DALLAS	SH0342			We forgot	SYLVIA-1000' NO REFERENCE MARKERS
75	18	1816401	DALLAS	SH0352	592+00.0	592+00.2	32.76611	96.71778
76	18	1816402	DALLAS	SH0352	594+00.0	594+00.2	32.76611	96.685
77	18	1816403	DALLAS	SH0352	596+00.0	596+00.2	32.76111	96.65139
78	18	1817001	DALLAS	LP0244	594+00.0	594+00.2	32.86111	96.71944
79	18	1852501	DALLAS	IH0035E	428+00.8	429+00.0	32.78306	96.81167
80	18	1854101	DALLAS	IH0030	51+00.4	51+00.2	32.79472	96.71583
81	18	1860101	DALLAS	US0067	417+00.8	418+00.0	32.59417	96.9425
82	18	1860101	DALLAS	US0067	418+00.0	417+00.8	32.59167	96.945
83	18	1860201	ELLIS	IH0035E	398+00.0	398+00.2	32.35806	96.85472
84	18	1860202	ELLIS	IH0035E	399+00.0	399+00.2	32.37139	96.86139
85	18	1860203	ELLIS	IH0035E	404+00.0	404+00.2	32.43667	96.85389
86	18	1860301	COLLIN	FM0546	238+00.0	238+00.2	33.17944	96.61833
87	18	1860302	COLLIN	FM0546	238+00.2	238+00.4	33.17972	96.61556
88	18	1860401	COLLIN	FM3038	595+00.0	595+00.2	33.19861	96.65444
89	18	1860402	COLLIN	FM3038	595+00.2	595+00.4	33.19806	96.65139
90	18	1860501	KAUFMAN	SH0034	314+00.0	313+00.8	32.705	96.27694
91	18	1860502	KAUFMAN	SH0034	314+00.0	314+00.2	32.705	96.27694
92	18	1860601	KAUFMAN	IH0020	497+00.8	497+00.6	32.71472	96.33139
93	18	1860602	KAUFMAN	IH0020	497+00.0	496+00.8	32.70944	96.34444
94	18	1860603	KAUFMAN	IH0020	495+00.9	495+00.7	32.70139	96.36028
95	18	1860701	ROCKWALL	IH0030	76+00.0	75+00.8	32.95944	96.34861
96	18	1860702	ROCKWALL	IH0030	75+00.8	75+00.6	32.95833	96.35111
97	18	1860703	ROCKWALL	IH0030	72+00.0	71+00.8	32.92417	96.40167
98	18	1860801	DENTON	IH0035E	448+00.9	448+00.7	33.00944	96.97611
99	18	1860901	DENTON	SH0121	272+00.6	272+00.8	33.04611	96.95917
100	18	1860902	DENTON	SH0121	273+00.1	273+00.3	33.04722	96.94972
101	18	1861001	DENTON	IH0035	472+00.0	472+00.2	33.27194	97.1775
102	18	1861002	DENTON	IH0035	474+00.0	474+00.2	33.30028	97.17778
103	18	1861003	DENTON	IH0035	477+00.2	477+00.4	33.34667	97.18139
104	19	1910101	HARRISON	IH0020	621+00.2	621+00.4	32.49361	94.29167
105	19	1910102	HARRISON	IH0020	621+00.6	621+00.8	32.49444	94.28472

106	19	1910103	HARRISON	IH0020	622+00.0	622+00.2	32.49528	94.27722
107	19	1910104	HARRISON	IH0020	623+00.0	623+00.2	32.49389	94.26083
108	19	1910201	HARRISON	IH0020	632+00.8	632+00.6	32.48028	94.09611
109	19	1910202	HARRISON	IH0020	632+00.0	631+00.8	32.48306	94.10806
110	20	2011101	JASPER	US0096	US96 & FM2800	US96 & FM2801+1000'	30.93694	93.99639
111	20	2057401	JASPER	US0096	387+00.8	387+00.6	31.00611	93.98194
112	20	2057402	JASPER	US0096	387+00.6	387+00.4	31.00722	93.98194
113	20	2057403	JASPER	US0096				
114	20	2057501	JASPER	US0096	390+00.0	389+00.8	30.97278	93.98889
115	20	2057502	JASPER	US0096	389+00.7	389+00.5	30.97833	93.98722
116	20	2057503	JASPER	US0096	388+00.0	387+00.8	31.0025	93.98278
117	20	2057801	JEFFERSO	SH0073	764+00.0	763+00.8	29.88583	94.00722
118	20	2057802	JEFFERSO	SH0073	762+00.9	762+00.7	29.88833	94.02528
119	20	2058401	JEFFERSO	US0069	527+00.9	528+00.1	30.04	94.11889
120	20	2058402	JEFFERSO	US0069	528+00.2	528+00.4	30.03833	94.11528
121	20	2058601	JEFFERSO	FM365	774+00.0	773+00.8	29.99111	93.95889
122	20	2058602	JEFFERSO	FM365	773+00.55	773+00.35	29.985	93.95972
123	20	2058701	JEFFERSO	FM0366	450+00.0	450+00.2	29.98611	94.00333
124	20	2058702	JEFFERSO	FM0366	452+00.0	452+00.2	29.97361	93.94111
125	20	2058703	JEFFERSO	FM0366	554+00.0	554+00.2	29.96222	93.91194
126	20	2059001	LIBERTY	US0090				
127	20	2059002	LIBERTY	US0090				
128	20	2060101	JASPER	US0096	391+00.7	391+00.5	30.94972	93.99472
129	20	2060102	JASPER	US0096	391+00.0	390+00.8	30.95917	93.99278
130	20	2060103	JASPER	US0096	390+00.65	390+00.45	30.96333	93.99139
131	20	2060201	JEFFERSO	US0090	902+00.0	902+00.2	30.03722	94.41222
132	20	2060202	JEFFERSO	US0090	902+00.8	903+00.0	30.03972	94.39889
133	20	2060301	ORANGE	FM0105	440+00.0	439+00.8	30.15611	94.01611
134	24	2460101	ELPASO	US0085				
135	24	2460102	ELPASO	US0085				
136	25	2560101	CHILDRES	US0287	232 -75ft.	231-00.8	35.42778	100.2072
137	25	2560102	CHILDRES	US0287	232 -75ft.	231+00.8	34.42778	100.2072

Appendix D

Detailed Climatic Information for Various JCP Sections

		Construction date		Weather	
CFTR	County	Year	day-month	Station	Average min
				(NCDC	annual temp
				SAMSON)	F
1101	HUNT	1980.22	21-Mar	1	12.8
1101	HUNT	1980.22	21-Mar	1	12.8
1101	HUNT	1955.37	17-May	1	12.8
1102	HOPKINS	1956.88	23-May	1	12.8
1102	HOPKINS	1956.88	23-May	1	12.8
1102	HOPKINS	1956.88	23-May	1	12.8
1601	LAMAR	1946.78	17-Oct	1	12.8
1601	LAMAR	1946.78	17-Oct	1	12.8
3589	WICHITA	1958.96	16-Dec	11	6.5
3589	WICHITA	1958.96	16-Dec	11	6.5
3589	WICHITA	1958.96	16-Dec	11	6.5
3593	WILBARGE	1965.55	22-Jul	11	6.5
4101	DALLAM	1940.20	14-Mar	16	-2.2
4101	DALLAM	1940.20	14-Mar	16	-2.2
5601	PARMER	1940.53	15-Jul	16	-2.2
5601	PARMER	1940.53	15-Jul	16	-2.2
9601	LIMESTON	1935.00	1-Jan	9	14.5
9601	LIMESTON	1935.00	1-Jan	9	14.5
12505	BRAZORIA	1955.13	18-Feb	7	20.2
12505	BRAZORIA	1955.13	18-Feb	7	20.2
12509	MONTGOME	1960.13	18-Feb	7	20.2
12509	MONTGOME	1960.13	18-Feb	7	20.2
12509	MONTGOME	1960.13	18-Feb	7	20.2
12509	MONTGOME	1960.13	18-Feb	7	20.2
12513	MONTGOME	1960.80	23-Oct	7	20.2
12513	MONTGOME	1960.80	23-Oct	7	20.2
12526	HARRIS	1961.96	15-Dec	7	20.2
12535	MONTGOME	1962.96	15-Dec	7	20.2
12535	MONTGOME	1962.96	15-Dec	7	20.2
12535	MONTGOME	1962.96	15-Dec	7	20.2
12537	HARRIS	1963.29	18-Apr	7	20.2
12537	HARRIS	1963.29	18-Apr	7	20.2
12540	MONTGOME	1963.71	22-Sep	7	20.2
12553	BRAZORIA	1964.80	24-Oct	7	20.2
12553	BRAZORIA	1964.80	24-Oct	7	20.2
12554	BRAZORIA	1964.80	24-Oct	7	20.2
12564	HARRIS	1966.88	20-Nov	7	20.2
12564	HARRIS	1966.88	20-Nov	7	20.2
12576	WALLER	1967.30	21-Apr	7	20.2
12590	GALVESTO	1971.89	27-Nov	7	20.2
12590	GALVESTO	1971.89	27-Nov	7	20.2
12601	GALVESTO	1928.00	1-Jan	7	20.2
12601	GALVESTO	1928.00	1-Jan	7	20.2

12602	GALVESTO	1928.00	1-Jan	7	20.2
12602	GALVESTO	1928.00	1-Jan	7	20.2
12603	HARRIS	1966.88	20-Nov	7	20.2
12603	HARRIS	1966.88	20-Nov	7	20.2
12603	HARRIS	1966.88	20-Nov	7	20.2
12603	HARRIS	1966.88	20-Nov	7	20.2
12604	HARRIS	1972.47	23-Jun	7	20.2
12604	HARRIS	1972.47	23-Jun	7	20.2
12604	HARRIS	1972.47	23-Jun	7	20.2
12606	FORTBEND	1962.60	8-Aug	7	20.2
12606	FORTBEND	1973.33	1-May	7	20.2
12607	FORTBEND	1976.14	1-Mar	7	20.2
12607	FORTBEND	1976.14	1-Mar	7	20.2
12607	FORTBEND	1976.14	1-Mar	7	20.2
13501	MATAGORD	1961.29	17-Apr	7	20.2
13501	MATAGORD	1961.29	17-Apr	7	20.2
13509	AUSTIN	1966.80	23-Oct	7	20.2
13509	AUSTIN	1966.80	23-Oct	7	20.2
13510	AUSTIN	1966.96	15-Dec	7	20.2
13510	AUSTIN	1966.96	15-Dec	7	20.2
13512	AUSTIN	1966.96	15-Dec	7	20.2
13513	AUSTIN	1967.30	21-Apr	7	20.2
13513	AUSTIN	1967.30	21-Apr	7	20.2
16570	NUECES	1941.78	16-Oct	6	24.7
16570	NUECES	1941.78	16-Oct	6	24.7
16601	NUECES	1942.28	11-Apr	6	24.7
16601	NUECES	1942.28	11-Apr	6	24.7
17602	WASHINGT	1933.00	1-Jan	7	20.2
17602	WASHINGT	1933.00	1-Jan	7	20.2
18120	DALLAS	1969.14	20-Feb	1	12.8
18120	DALLAS	1969.14	20-Feb	1	12.8
18164	DALLAS	1965.80	22-Oct	1	12.8
18164	DALLAS	1965.80	22-Oct	1	12.8
18164	DALLAS	1965.80	22-Oct	1	12.8
18170	DALLAS	1959.88	20-Nov	1	12.8
18525	DALLAS	1959.63	21-Aug	1	12.8
18541	DALLAS	1960.29	17-Apr	1	12.8
18601	DALLAS	1979.97	20-Dec	1	12.8
18601	DALLAS	1979.97	20-Dec	1	12.8
18602	ELLIS	1990.81	26-Oct	1	12.8
18602	ELLIS	1990.81	26-Oct	1	12.8
18602	ELLIS	1990.81	26-Oct	1	12.8
18603	COLLIN	1970.63	21-Aug	1	12.8
18603	COLLIN	1970.63	21-Aug	1	12.8
18604	COLLIN	1970.63	21-Aug	1	12.8
18604	COLLIN	1970.63	21-Aug	1	12.8
18605	KAUFMAN	1975.84	6-Nov	1	12.8

18605	KAUFMAN	1975.84	6-Nov	1	12.8
18606	KAUFMAN	1988.73	25-Sep	1	12.8
18606	KAUFMAN	1988.73	25-Sep	1	12.8
18606	KAUFMAN	1988.73	25-Sep	1	12.8
18607	ROCKWALL	1987.31	24-Apr	1	12.8
18607	ROCKWALL	1987.31	24-Apr	1	12.8
18607	ROCKWALL	1987.31	24-Apr	1	12.8
18608	DENTON	1983.56	25-Jul	1	12.8
18609	DENTON	1991.75	5-Oct	1	12.8
18609	DENTON	1991.75	5-Oct	1	12.8
18610	DENTON	1990.90	29-Nov	1	12.8
18610	DENTON	1990.90	29-Nov	1	12.8
18610	DENTON	1990.90	29-Nov	1	12.8
19101	HARRISON	1965.80	21-Oct	17	16.2
19101	HARRISON	1965.80	21-Oct	17	16.2
19101	HARRISON	1965.80	21-Oct	17	16.2
19101	HARRISON	1965.80	21-Oct	17	16.2
19102	HARRISON	1964.80	21-Oct	17	16.2
19102	HARRISON	1964.80	21-Oct	17	16.2
	JASPER	1968.00	1-Jan	17	16.2
20574	JASPER	1977.39	23-May	17	16.2
20574	JASPER	1977.39	23-May	17	16.2
20574	JASPER	1977.39	23-May	17	16.2
20575	JASPER	1971.47	22-Jun	17	16.2
20575	JASPER	1971.47	22-Jun	17	16.2
20575	JASPER	1977.39	23-May	17	16.2
20578	JEFFERSO	1960.29	17-Apr	3	21.7
20578	JEFFERSO	1960.29	17-Apr	3	21.7
20584	JEFFERSO	1971.30	19-Apr	3	21.7
20584	JEFFERSO	1971.30	19-Apr	3	21.7
20586	JEFFERSO	1975.06	22-Jan	3	21.7
20586	JEFFERSO	1975.06	22-Jan	3	21.7
20587	JEFFERSO	1952.79	19-Oct	3	21.7
20587	JEFFERSO	1952.79	19-Oct	3	21.7
20587	JEFFERSO	1952.79	19-Oct	3	21.7
20590	LIBERTY	1970.89	26-Nov	3	21.7
20590	LIBERTY	1970.89	26-Nov	3	21.7
20601	JASPER	1971.47	22-Jun	17	16.2
20601	JASPER	1971.47	22-Jun	17	16.2
20601	JASPER	1971.47	22-Jun	17	16.2
20602	JEFFERSO	1971.97	21-Dec	3	21.7
20602	JEFFERSO	1971.97	21-Dec	3	21.7
20603	ORANGE	1985.33	1-May	3	21.7
24601	ELPASO	1957.21	18-Mar	15	12.7
24601	ELPASO	1957.21	18-Mar	15	12.7
25601	CHILDRES	1987.56	25-Jul	16	-2.2
25601	CHILDRES	1987.56	25-Jul	16	-2.2

CFTR	Average annual rain Inches	Average month evap* lb/ft^2/hr	Low temp after const** F	High temp during const*** F
1101	41.6	0.086	10.9	65.5
1101	41.6	0.086	10.9	65.5
1101	41.6	0.098	12.9	82.5
1102	41.6	0.098	12.9	82.5
1102	41.6	0.098	12.9	82.5
1102	41.6	0.098	12.9	82.5
1601	41.6	0.081	12.9	76.8
1601	41.6	0.081	12.9	76.8
3589	28.5	0.066	6.5	56.1
3589	28.5	0.066	6.5	56.1
3589	28.5	0.066	6.5	56.1
3593	28.5	0.148	-2.9	95.0
4101	19.3	0.113	-1.5	60.7
4101	19.3	0.113	-1.5	60.7
5601	19.3	0.157	-1.5	87.8
5601	19.3	0.157	-1.5	87.8
9601	31.6	0.065	15.0	58.0
9601	31.6	0.065	15.0	58.0
12505	47.2	0.058	21.4	65.5
12505	47.2	0.058	21.4	65.5
12509	47.2	0.058	21.4	65.5
12509	47.2	0.058	21.4	65.5
12509	47.2	0.058	21.4	65.5
12509	47.2	0.058	21.4	65.5
12513	47.2	0.056	21.4	80.0
12513	47.2	0.056	21.4	80.0
12526	47.2	0.060	17.1	64.9
12535	47.2	0.056	18.0	63.5
12535	47.2	0.056	18.0	63.5
12535	47.2	0.056	18.0	63.5
12537	47.2	0.072	19.9	81.5
12537	47.2	0.072	19.9	81.5
12540	47.2	0.065	19.9	89.1
12553	47.2	0.066	26.1	79.8
12553	47.2	0.066	26.1	79.8
12554	47.2	0.066	26.1	79.8
12564	47.2	0.063	26.1	72.2
12564	47.2	0.063	26.1	72.2
12576	47.2	0.079	28.9	80.8
12590	42.2	0.041	23.0	73.4
12590	42.2	0.041	23.0	73.4
12601	42.2	0.053	21.4	62.8
12601	42.2	0.053	21.4	62.8

12602	42.2	0.053	21.4	62.8
12602	42.2	0.053	21.4	62.8
12603	47.2	0.063	26.1	72.2
12603	47.2	0.063	26.1	72.2
12603	47.2	0.063	26.1	72.2
12603	47.2	0.063	26.1	72.2
12604	47.2	0.046	21.0	87.0
12604	47.2	0.046	21.0	87.0
12604	47.2	0.046	21.0	87.0
12606	47.2	0.055	18.0	92.8
12606	47.2	0.052	23.0	81.6
12607	47.2	0.063	18.0	74.1
12607	47.2	0.063	18.0	74.1
12607	47.2	0.063	18.0	74.1
13501	38.5	0.070	17.1	79.6
13501	38.5	0.070	17.1	79.6
13509	47.2	0.066	26.1	80.5
13509	47.2	0.066	26.1	80.5
13510	47.2	0.063	26.1	67.0
13510	47.2	0.063	26.1	67.0
13512	47.2	0.063	26.1	67.0
13513	47.2	0.079	28.9	80.8
13513	47.2	0.079	28.9	80.8
16570	32.4	0.074	24.8	81.9
16570	32.4	0.074	24.8	81.9
16601	32.4	0.085	24.8	80.0
16601	32.4	0.085	24.8	80.0
17602	36.2	0.053	21.4	62.8
17602	36.2	0.053	21.4	62.8
18120	32.8	0.069	14.0	58.4
18120	32.8	0.069	14.0	58.4
18164	32.8	0.083	10.0	78.8
18164	32.8	0.083	10.0	78.8
18164	32.8	0.083	10.0	78.8
18170	32.8	0.072	12.9	66.8
18525	32.8	0.108	12.9	92.0
18541	32.8	0.094	12.9	74.7
18601	32.8	0.060	16.0	58.2
18601	32.8	0.060	16.0	58.2
18602	32.8	0.071	10.0	79.8
18602	32.8	0.071	10.0	79.8
18602	32.8	0.071	10.0	79.8
18603	32.8	0.096	15.1	91.2
18603	32.8	0.096	15.1	91.2
18604	32.8	0.096	15.1	91.2
18604	32.8	0.096	15.1	91.2
18605	32.8	0.086	12.0	70.0

18605	32.8	0.086	12.0	70.0
18606	32.8	0.112	12.9	88.3
18606	32.8	0.112	12.9	88.3
18606	32.8	0.112	12.9	88.3
18607	32.8	0.095	16.0	75.9
18607	32.8	0.095	16.0	75.9
18607	32.8	0.095	16.0	75.9
18608	32.8	0.114	5.0	91.3
18609	32.8	0.081	10.0	62.6
18609	32.8	0.081	10.0	62.6
18610	32.8	0.070	10.0	67.6
18610	32.8	0.070	10.0	67.6
18610	32.8	0.070	10.0	67.6
19101	47.3	0.047	10.0	80.4
19101	47.3	0.047	10.0	80.4
19101	47.3	0.047	10.0	80.4
19101	47.3	0.047	10.0	80.4
19102	47.3	0.041	19.9	79.2
19102	47.3	0.041	19.9	79.2
	47.3	0.041	19.9	58.3
20574	47.3	0.053	17.1	84.7
20574	47.3	0.053	17.1	84.7
20574	47.3	0.053	17.1	84.7
20575	47.3	0.073	21.0	89.2
20575	47.3	0.073	21.0	89.2
20575	47.3	0.053	17.1	84.7
20578	42.2	0.067	21.7	76.9
20578	42.2	0.067	21.7	76.9
20584	42.2	0.068	21.0	76.5
20584	42.2	0.068	21.0	76.5
20586	42.2	0.052	19.0	63.7
20586	42.2	0.052	19.0	63.7
20587	42.2	0.055	21.7	79.1
20587	42.2	0.055	21.7	79.1
20587	42.2	0.055	21.7	79.1
20590	42.2	0.056	28.9	72.6
20590	42.2	0.056	28.9	72.6
20601	47.3	0.073	21.0	89.2
20601	47.3	0.073	21.0	89.2
20601	47.3	0.073	21.0	89.2
20602	42.2	0.053	21.0	66.5
20602	42.2	0.053	21.0	66.5
20603	42.2	0.054	25.0	84.7
24601	9.4	0.115	12.9	69.5
24601	9.4	0.115	12.9	69.5
25601	28.5	0.132	-5.1	86.5
25601	28.5	0.132	-5.1	86.5

* For sections with a construction date before January 1961 or after November 1990, the evaporation rate was computed by taking the average evaporation for the three-month period around construction over 30 years (1961-1990).

** For sections with a construction date before January 1961, the low temperature after construction was computed as the average of the yearly low temperatures over 30 years (1961-1990). For sections constructed after January 1990, the low temperature was obtained from the National Climatic Data Center (NCDC) Web site.

*** For sections with a construction date before January 1961 or after November 1990, the high temperature during construction was computed by taking the average high temperature for the three-month period around construction over 30 years (1961-1990). For sections constructed after November 1990, the average high temperature was obtained from the National Climatic Data Center (NCDC) Web site.

Appendix E

Measurement of Distresses

When a condition survey is performed, field activities include the identification, classification, and quantification of various distresses in the pavement. These distresses are collected for both overlaid and nonoverlaid pavements. This appendix describes the problems most commonly found; causes of the manifestations and how they are rated.

Nonoverlaid Sections

The distresses for nonoverlaid pavement fall into the categories of cracking, faulting, failures, and durability cracking. A rating is also described for the shoulder condition.

Cracking Distresses

The characteristics of longitudinal and transverse cracking are described in the following sections.

Longitudinal Cracks. These cracks are parallel to the pavement centerline and generally occur as a result of the absence, or inadequate construction, of the longitudinal joints. The number of slabs with longitudinal cracks within the sample unit is recorded. Figure E.1 shows a JCP section with a severe longitudinal crack that extends through three slabs.

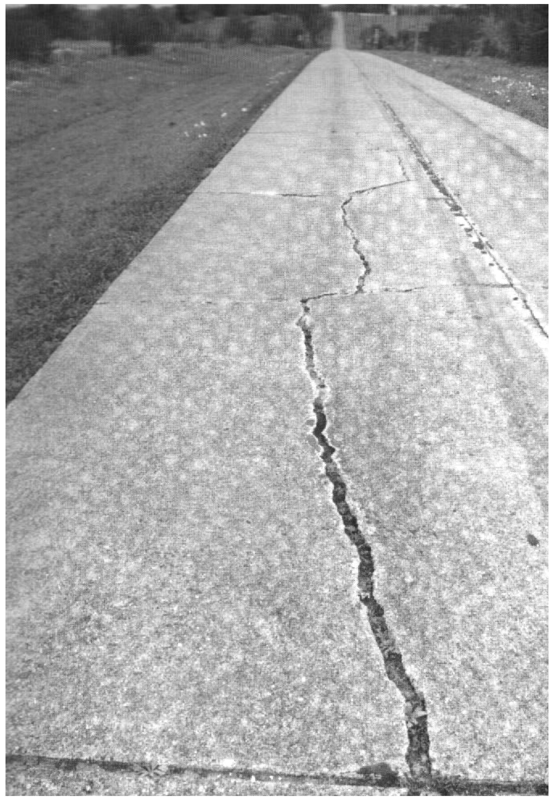

FIGURE E.1 LONGITUDINAL CRACK

Transverse Cracks. Opposite to longitudinal cracks, transverse cracks run perpendicularly to the pavement centerline. They are caused by repetition of heavy traffic loads, thermal and moisture gradient stresses, and drying shrinkage stresses. The number of cracks within the sample unit is recorded. The crack spacing for the first 200 ft. is also recorded by measuring the cumulative distance from the starting point of the test section to each crack. Figure E.2 shows a section located in Washington County that has several transverse and longitudinal cracks.

FIGURE E.2 TRANSVERSE AND LONGITUDINAL CRACKS

Faulting

A fault is the absolute value of the difference in pavement surface elevation across a transverse joint measured in millimeters (mm). Usually, elevations are measured on either side of a transverse joint in the outside wheel path. Faulted joints should not be rated as failed unless they have spalled (TxDOT 1998).

Miscellaneous Failures

These failures usually include corner breaks, crack or joint spalling, patches, and punchouts. A description of each is presented in the following sections.

Corner Breaks. A corner break is defined as a crack intersecting a transverse and longitudinal joint, or an edge at a distance of fewer than 6 ft. from the corner of the slab on each side. To be rated as a failure, the crack must intersect between 1 ft. and halfway across each edge. A corner break results from the combination of traffic loads, poor load transfer at the joint, and thermal curling and moisture warping stresses. The total number of corner breaks in a sample unit is counted and recorded. Figure E.3 shows a corner break that has led to a punchout in the slab.

FIGURE E.3 CORNER BREAK

Spalling. Spalling is defined as the cracking, breaking, or chipping of the slab edges

along some or all of the length of the joint or crack. Spalling is usually a result of excessive stress at the joint or crack, which can be caused by infiltration of undesirable incompressible materials that induce the slab to expand. Deficient load transfer devices and heavy repeated traffic loads aggravate the conditions of a spalled joint or crack. The total number of spalled joints and cracks within the sample unit is recorded. Figure E.4 presents a pavement with a spalled transverse crack.

FIGURE E.4 SPALLED CRACK

ACP and PCC Patches. These are portions of the original distressed pavement slab that have been removed and completely filled with asphalt concrete (ACP) or portland cement concrete (PCC). The severity level is measured according to the total occurrences within 1 to 50 ft^2, 51 to 150 ft^2, and > 150 ft^2. The overall number of occurrences in each of the three categories is recorded for every 200 ft. in the section. Figure E.5 shows a long PCC patch.

FIGURE E.5 PCC PATCH

Punchouts. These distresses are formed when two transverse cracks are intersected by a longitudinal crack, forming a block. The block could be either a rectangular shape or an indefinite shape. Its severity is classified as minor (M) or severe (S). A minor punchout consists of hairline cracks with no spalling or minimal spalling, and no movement of the concrete blocks occurring under traffic loads. A severe punchout is formed by wide cracks that show signs of pumping and movement of the concrete blocks under traffic loads. The number of punchouts within the sample unit is collected according to severity level. Figure E.6 shows a severe punchout.

FIGURE E.6 SEVERE PUNCHOUT

Durability Cracking

These are a series of closely spaced, crescent-shaped hairline cracks that appear at the slab surface adjacent and roughly parallel to transverse and longitudinal joints, cracks, and slab edges. D-cracking is usually caused by expansive effects of certain types of coarse aggregates under the action of freeze and thaw cycles. The total number of failures is recorded for the total sample unit. Figure E.7 presents a typical durability D-cracking failure. The slab is located in the inside lane of the roadbed.

FIGURE E.7 DURABILITY D-CRACKING

Shoulder Condition

This consists of a brief description of the condition of the pavement shoulder. Observed distresses, such as joint deficiencies between the pavement and the shoulder, should be recorded. Level differences, signs of scuffing, and any indication of problems with drainage should also be considered. Figure E.8 shows a cracked and spalled outside shoulder of a section in Houston, Texas.

FIGURE E.8 CRACKED AND SPALLED SHOULDER

Overlaid Sections

Overlaid pavements present a combination of distress types resulting from either a reflection of the PCCP pavement or developing as independent stresses. These distresses are described in the following sections for cracking and deformation. The failures would be described in the same manner as a nonoverlaid pavement.

Cracking

The cracking distresses fall into alligator, block, and reflected categories. The alligator cracking is generally only related to asphalt concrete pavement (ACP), whereas the latter two results from the underlying portland cement concrete pavement (PCCP) layer.

Alligator Cracking. Alligator cracking is formed by a series of interconnected cracks that produce a grid of cracks less than 1 ft^2. This manifestation is a result of repeated traffic loads that cause the asphalt surface to experience fatigue. The percentage of the total surface area for the rated lane is recorded on the survey form, as specified by the TxDOT PMIS Rater's Manual (TxDOT 1998). Figure E.9 shows the typical pattern and size of polygons in alligator cracking.

FIGURE E.9 ALLIGATOR CRACKING

Block Cracking. Similar to the alligator cracking distress, however block cracking differs in the size of the pieces of asphalt. Usually in block cracking the size of the polygons of asphalt ranges between 1 ft^2 and 100 ft^2. This is also recorded as a percentage of the total surface of the rated lane. Figure E.10 shows a section presenting block cracking. The polygons here are larger than those shown in the previous figure.

FIGURE E.10 BLOCK CRACKING

Reflection Cracking. This distress may or may not be detrimental. It occurs when concrete pavement is resurfaced and cracks generally appear in the new surface at the joint locations and crack locations of the underlying slab. Reflected cracks should be sealed promptly in order to avoid infiltration of water and undesirable particles that affect the pavement. Figure E.11 shows reflected transverse cracks, transverse joints, and longitudinal joints.

FIGURE E.11 REFLECTION CRACKING

Deformation

Deformation distresses are classified as faulting or rutting. Faulting is simply a reflection of the distress in the PCCP slab, while rutting is a function of the asphalt concrete pavement layers.

Rutting. This is a longitudinal surface depression observed at the wheel path. It is caused by displacement or densification of the asphalt layer under repeated action of wheel loads. The severity levels include shallow rutting, which ranges from 0.5 to 1.0 in. and deep rutting, which ranges from 1.0 to 3.0 in. Rutting is recorded as the percentage of the area having the distress for the sample unit. Figure E.12 shows a section that presents shallow rutting on the inside third of the lane.

FIGURE E.12 RUTTING IN AN OVERLAID SECTION

AC patches, faulted joints, slabs with reflected cracks, punchouts, and shoulder conditions are also collected and recorded for overlaid pavements. The collection methodology for these manifestations is similar to that used for nonoverlaid pavements.

Faulting. As mentioned before, a fault is the absolute value of the difference in pavement surface elevation across a transverse joint measured in millimeters (mm). Commonly, elevations are measured on either side of a transverse joint in the outside wheel path. Faulted joints should not be rated as failed unless they have spalled (TxDOT 1998).

Summary of Observed Distresses

Table E.1 summarizes different distress types observed on JCP sections. All these distresses are recorded when condition surveys are performed.

TABLE E.1 SUMMARY OF COMMON DISTRESSES OF JCP

Nonoverlaid Pavements	Overlaid Pavements
Cracking	
Longitudinal cracks Transverse cracks Corner breaks Durability D-cracking	Longitudinal cracks Transverse cracks Reflection cracking Alligator cracking Block cracking Corner breaks
Joint Deficiencies	
Spalling of longitudinal and transverse joints/cracks Faulting of transverse joints/cracks	Faulted deficiencies
Miscellaneous Distresses	
AC and PCC patches Punchouts Shoulder conditions	AC and PCC patches Punchouts Rutting Shoulder conditions

Appendix F

Typical Data Collection Survey

The objective of this appendix is to describe the standard procedure followed in a condition survey.

Selection of Typical Section

The activities to be accomplished begin with the collection of information from previous studies. This information is retrieved from the existing electronic database and from previous research reports.

This section illustrates and explains the tasks performed to collect information from a few sections in Dallas. In order to begin with the field activities, it is necessary to obtain key information to locate a section on the highway. The information consists of a printed report that displays the district where the section is located, the county name, the Center for Transportation Research (CTR) number of the section (CFTR), the highway, the Texas Department of Transportation (TxDOT) control and section numbers[2], the direction of the highway, and the physical milepost numbers of the location of the section.

Having collected that information, a crew goes to the field and collects the data. Table F.1 presents a layout of a printed report showing the information necessary to find an existing section in the field.

Table F.1 Basic information needed in the field to find a section

DISTRICT	COUNTY	CFTR	HWY	CTRL	SEC	DIR	RM1	RM2
Dallas	Dallas	18164-01	SH0352	430	1	E	592+0.0	592+0.2
Dallas	Dallas	18164-02	SH0352	430	1	E	594+0.0	594+0.2
Dallas	Dallas	18164-03	SH0352	430	1	E	596+0.0	596+0.2
…	…	…	…	…	…	…	…	…

[2] According to the current database and TxDOT District Control-Section maps.

Narrative of Condition Survey Process

The steps for conducting a condition survey are cyclic and may be mastered after surveying a few sections. It is imperative that heavy volumes of traffic and inclement weather conditions are avoided as possible to avoid potential accidents. The best approach to survey as many sections as possible is to begin the field activities early in the morning, if the aforementioned conditions are acceptable, and continue until sunset.

To illustrate the process of a standard condition survey, the activities followed when surveying a test section in Dallas are described here. These activities correspond to the survey performed for the first section in Table F.1.

Having the printed report showing the district, county, and highway information, the first step was to drive along SH 352 and locate the milepost No. 592. For this particular section, it was easy to find the starting point in the field because mileposts were located every mile along the highway. Thus, locating the section was successfully completed. The paint on the pavement showing the CFTR section number from the 1993 survey was still visible.

Once the starting point of the section was located, the next step was to assign the global positioning system (GPS) coordinates to the starting point of the section. If no response is received from the GPS device, this step should be the last in the process. By doing this, the time that runs from the beginning of the survey to the end, usually ranging from 10 to 15 minutes, will allow the GPS receiver to stabilize and retrieve the information from the satellites.

Next, the section is surveyed. In this case the starting point was located right at milepost No. 592 and extended 1000 feet to the east. In other words, the official reference markers of the section were 592+0.0 at the beginning (RM_1) and 592+0.2 at the end (RM_2). While surveying the section, the crew members recorded all visible distresses and special features of the pavement section and adjacent shoulder conditions. The completed condition survey form is shown in Figure F.1.

CFTR No.	Dir.	Hwy.	Date	Surveyor	GPS Location
18164-1	E	SH352	4/09/98	RR	N. 32° 45` 57`` 86
Reference Marker: 592+0.0 to 592+0.2		**County:** DALLAS	(JCP) / CRCP	Overlaid / (Non-Overlaid)	W. 96° 43` 3`` 63; **Elevation:** 87 m

Number of Lanes: 3; Surv. lane: R1	Cracking %: Alligator; (% of total surface area)	Cracking %: Block; (% of total surface area)	Rutting %: Shallow .5"-1" (% of wheel path)	Rutting %: Deep 1"-3" (% of wheel path)	Patches (Size determined in square feet.) AC: 0-50	AC: 51-150	AC: > 150	PCC: 0-50	PCC: 51-150	PCC: > 150	No. of Punchouts (Minor, Severe): M	No. of Punchouts: S	No. of D-Cracks	No. of Corner Breaks	No. of Spalled Joints / Cracks	No. of Faulted Joints	Slabs w/ Longitudinal Cracks	Total No. of Cracks
0 ft - 200 ft																		15
200 ft - 400 ft																		14
400 ft - 600 ft													1					13
600 ft - 800 ft																		13
800 ft - end																		13

Road Profile	Cut / Fill / (Grade) / Transition	Amount of fill or cut (in feet):	(Curve Right) / Curve Left / Tangent

Comments:

Crack Locations: 0 to 200 ft; circle indicates a joint

(15.2)	(91.8)	(168.3)
(30.8)	(106.1)	(183.9)
(45.11)	(122.6)	(198.6)
(61.3)	(137.9)	
(76.7)	(153)	

Figure F.1 Completed condition survey form for Section 18164-01

As can be seen in the recorded information for Section 18164-01, there were no distresses except for D-cracks located in the 400- to 600-ft. span and the conventional contraction joints, spaced at approximately 15-ft. centers.

Photographs

After conducting the condition survey and collecting the GPS data, a standard procedure is to take at least two digital photographs showing general conditions, distresses, or interesting features of the section. Figure F.2 shows a surveyor painting the CFTR number on the pavement at the end of a section. With his left hand, the surveyor grabs the measuring wheel that is used to measure distances between joints and cracks.

Figure F.2   Surveyor painting the CFTR number of a section

Figure F.3 shows the CFTR number at the beginning of Section 18164-02. Note in the photograph that the section is located on a right-turning horizontal curve, and that the traffic and weather conditions at that moment were optimal for the field activities.

Figure F.3   Starting point of Section 18164-02

Figure F.4 shows the conventional paint stripe and number sizes. The number “2” indicates the end of the first 200 ft. span and the beginning of the second 200 ft. span. Finally, Figure F.5 shows the beginning of Section 18164-03, at the point where the milepost is located. Note that the milepost number can be seen on the upper-right edge of the photograph.

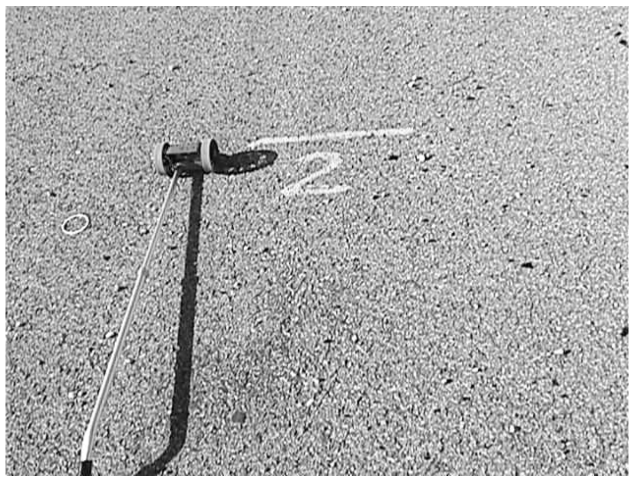

Figure F.4 Conventional paint stripe and measuring wheel

Figure F.5 Panoramic of Section 18164-03

Data Sheet Compilation

After performing routine quality-control activities in the field and checking that all the spaces in the condition survey form have been completed, the collected information, including the photographs, are ready to be incorporated into the electronic database.

Once the data is in electronic format, data sheets can be prepared and displayed by reports or lists. Usually, data sheets display detailed inventory and performance-related data about the sections, and that is the required format for demographic and distress analysis of the sections. Appendix C presents a list of the JCP sections in the database and Chapter 6 presents a distress analysis of the JCP sections located in the Dallas District.