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16. Abstract

This report summarizes the requirements for development of a long-term pavement performance (LTPP) program for the state of Texas. This work is part of a project sponsored by the Texas Department of Transportation to develop distress prediction models for rigid pavements which are to be incorporated in the Texas pavement management information system (PMIS) currently under development. As in other pavement management systems, test sections are identified for which distress data can be collected to develop the required models.

An experiment design which keeps in view the existing LTPP and Center for Transportation Research (CTR) experiment designs is described. The recommended experiment designs meet the current pavement design standards, latest research criteria, and climatic and geographic needs of Texas. The experiment design is followed by a discussion of the type of data which should be collected. The data items to be collected are divided into two categories, (1) inventory data items and (2) monitoring data items. Inventory data item sources are also identified. The human and financial resources required to establish the database and maintain and monitor it periodically are also evaluated.

17. Key Words
rigid pavements, factorial experiment design, inventory data, monitoring data, Thornthwaite moisture index, data requirements, condition survey, human resources, traffic data

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by

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Research Report 1908-2

Research Project 7-1908

Texas Pavement Management System

conducted for the

Texas Department of Transportation

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

August 1993

IMPLEMENTATION STATEMENT

The long-term pavement performance (LTPP) program developed in this study provides a basis for collecting the data items needed for analysis to update current pavement design standards, and to carry out needed research covering climatic and geographic needs of Texas, for the Texas Pavement Management Information System (PMIS). The accuracy of the initial performance / distress prediction models developed and used in PMIS can be compared to the new data and improved through implementation of the Texas LTPP program and use of the data.

Prepared in cooperation with the Texas Department of Transportation

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W. Ronald Hudson (Texas No. 16821)
Research Supervisor

PREFACE

This is the second in a series of reports that describe the work done on Research Project 1908, "Texas Pavement Management Information System." This report focuses on the development requirements for a Texas long-term pavement performance (LTPP) program.

This report presents the development of a factorial experiment design for rigid pavements in Texas, keeping in view previous efforts in this direction. The recommended data items to be collected for the LTPP program are discussed, and the human and financial resources required for data collection are also evaluated.

The authors would like to extend their appreciation to all those who contributed their help towards the completion of this report. Thanks are also extended to TxDOT personnel, especially Bob Briggs and Bryan Stampley, for their help and valuable comments.

ABSTRACT

This report summarizes the requirements for development of a long-term pavement performance (LTPP) program for the state of Texas. This work is part of a project sponsored by the Texas Department of Transportation to develop distress prediction models for rigid pavements which are to be incorporated in the Texas pavement management information system (PMIS) currently under development. As in other pavement management systems, test sections are identified for which distress data can be collected to develop the required models.

An experiment design which keeps in view the existing LTPP and Center for Transportation Research (CTR) experiment designs is described. The recommended experiment designs meet the current pavement design standards, latest research criteria, and climatic and geographic needs of Texas. The experiment design is followed by a discussion of the type of data which should be collected. The data items to be collected are divided into two categories, (1) inventory data items and (2) monitoring data items. Inventory data item sources are also identified. The human and financial resources required to establish the database and maintain and monitor it periodically are also evaluated.

KEY WORDS: rigid pavements, factorial experiment design, inventory data, monitoring data, Thornthwaite moisture index, data requirements, condition survey, human resources, traffic data

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SUMMARY

This research effort summarizes the requirements for development of a long-term pavement performance (LTPP) program for the state of Texas. An improved and updated factorial experiment design for rigid pavements is described. The data items to be collected for the LTPP are recommended, and the human and financial resources required to collect the data are also estimated.

CHAPTER 1

INTRODUCTION

1.1 Background

The United States spends approximately $30 billion annually on highway and bridge infrastructure (AASHTO 90). This fact has received considerable attention in both the public and private sectors, and as a result significant actions have been taken at state and federal levels to address the problems of safeguarding this large investment.

Under the sponsorship of the Federal Highway Administration (FHWA) and with the cooperation of the American Association of State Highway and Transportation Officials (AASHTO), the Transportation Research Board (TRB) of the National Research Council (NRC) undertook in 1983 a study to investigate the effect of expanded research on improving highway transportation (TRB 84).

The results of the study were reported in Transportation Research Board Special Report 202, "American Highways, Accelerating the Search for Innovation" (TRB 84). This study recommended six important research areas combined under one program called the Strategic Highway Research Program (SHRP). The goal was to focus on highly innovative research approaches to achieve significant gains in the six emphasized areas of study rather than on incremental research advances in dozens of areas of highway technology.

1.2 Long-Term Pavement Performance Program (LTPP)

In spite of all the national concern about substandard highway conditions, the United States has not systematically studied highway performance since the AASHO (American Association of State Highway Officials) Road Test in 1958 to 1960 (HRB 62). That test was a massive experiment that gave the nation, as well as the world, its soundest understanding of the properties of pavements, but which of necessity also left many unanswered questions.

Only one climate was represented in the AASHO Road Test, and the test itself was conducted in an accelerated manner using only selected test trucks for traffic loading. It also incorporated some atypical maintenance procedures. A long-term field test is needed that systematically covers a wide range of climate, soil, construction, maintenance, and loading conditions. This test will be able to substantially refine and expand the findings of the AASHO Road Test and thus will potentially yield large payoffs in terms of reduced construction and maintenance costs.

The objectives of the Long-Term Pavement Performance (LTPP) program are to (SHRP 86):

- evaluate existing design methods;
- develop improved design methods and strategies for the rehabilitation of existing pavements;
- develop improved design equations for new and reconstructed pavements;
- determine the effects of loading, environment, material properties and variability, construction quality, and maintenance levels on pavement distress and performance;
- determine the effects of specific design features on pavement performance; and
- establish a national long-term pavement database.

The LTPP program is to collect data on in-service pavement sections throughout the country for a twenty-year period. The data are stored at TRB in Washington, D.C. The database is supposed to continue to evolve during the course of the LTPP program so as to accommodate the data collected, as well as the needs of researchers as they are identified (SHRP 91).

1.2.1 LTPP Experiments

Data are collected from LTPP test sections located throughout the United States and Canada. Various types of data are collected for each section, including climatic, material properties, traffic loads, profile, distress, and friction, among others (SHRP 91). Pavement sections studied under the LTPP program are either General Pavement Studies (GPS) or Specific Pavement Studies (SPS). GPS sections are the in-service pavements nominated by the state Department of Transportation (DOT) officials, with the final selection made by LTPP personnel. The most common pavement structural designs, used both nationally and internationally, are represented by these test sections. A sampling template describes each experiment, and consists of row and column factors that describe a pavement structurally and the conditions to which that pavement is subjected. Using this factorial-type design, pavement sections are assigned to individual cells within an experiment based on various factors (SHRP 86). The GPS experiment definitions are listed in Table 1.1, and the location of existing GPS sites is shown in Figure 1.1.

SPS test sections are specially designed pavement structures chosen to develop a better understanding of the effects on performance of a few targeted factors which are not adequately covered in GPS. SPS sections are constructed under the LTPP program to allow for initiation of performance monitoring from the initial construction date or whenever the pavement was opened for traffic.

Table 1.1 *GPS Experiment Definitions (SHRP 91)*

LTPP General Pavement Studies Experiments	
GPS 1	Asphalt Concrete (AC) on Granular Base
GPS 2	Asphalt Concrete (AC) on Bound Base
GPS 3	Jointed Plain Concrete (JCP)
GPS 4	Jointed Reinforced Concrete (JRCP)
GPS 5	Continuously Reinforced Concrete (CRCP)
GPS 6 A	Existing AC Overlay on Asphalt Concrete (AC)
GPS 6 B	New Asphalt Concrete (AC) on Asphalt Concrete (AC)
GPS 7 A	Existing Asphalt Concrete (AC) Overlay on Portland Cement Concrete (PCC) Pavements
GPS 7 B	New Asphalt Concrete (AC) Overlay on Portland Cement Concrete (PCC) Pavements
GPS 9	Unbound Portland Cement Concrete (PCC) Overlay of Portland Cement Concrete (PCC) Pavements

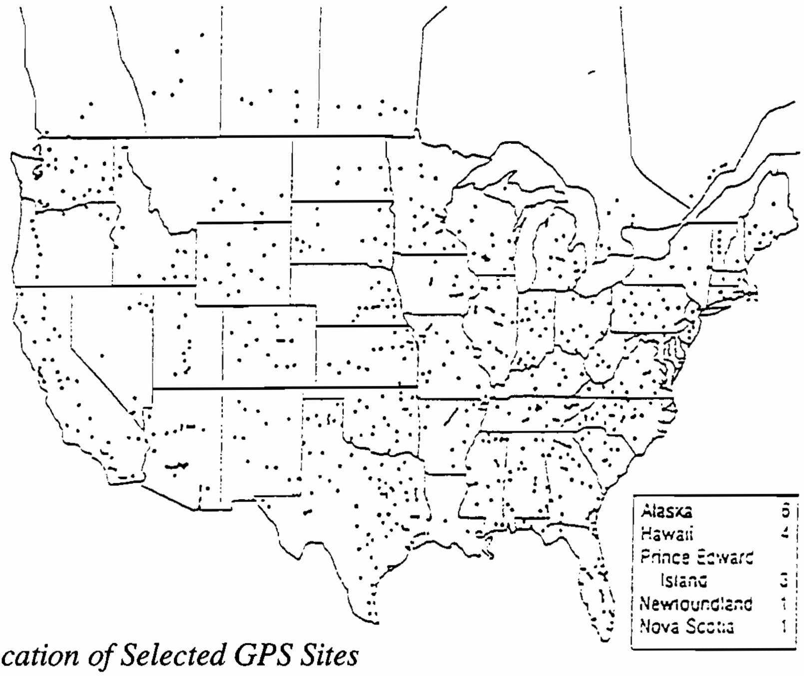


Figure 1.1 *Location of Selected GPS Sites*

The intent of SPS is to collect reliable data over the entire life of the section so that the performance prediction models can be calibrated accurately. The eight SPS experiments are as listed in Table 1.2, and the location of constructed SPS sites as of January '93 is shown in Figure 1.2.

Table 1.2 *SPS Experiment Definitions*

LTPP Specific Pavement Studies Experiments	
SPS 1	Strategic Study of Structural Factors for Flexible Pavements
SPS 2	Strategic Study of Structural Factors for Rigid Pavements
SPS 3	Preventive Maintenance Effectiveness for Flexible Pavements
SPS 4	Preventive Maintenance Effectiveness for Rigid Pavements
SPS 5	Rehabilitation of Asphalt Concrete (AC) Pavements
SPS 6	Rehabilitation of Jointed Portland Cement Concrete Pavements
SPS 7	Bonded Portland Cement Concrete Overlays of Concrete Pavements
SPS 8	Study of Environmental Effects in the Absence of Heavy Loads

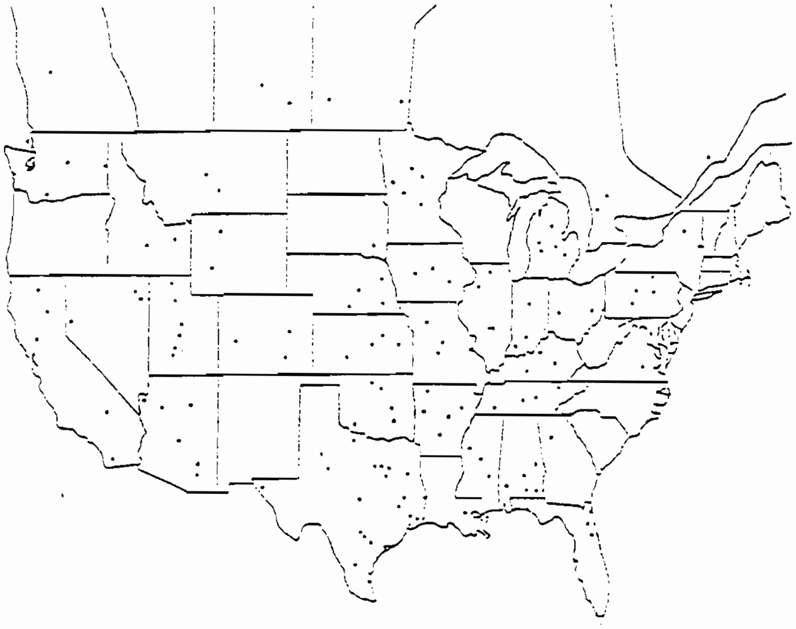


Figure 1.2 *Location of Constructed SPS Sites as of Jan. '93*

1.2.2 Structure of the Study

The LTPP is administered from four regional offices and one national office. The four regional offices are established to coordinate and communicate LTPP-related activities across the United States and Canada. Each region has a group of states and/or provinces in its jurisdiction, and the test sections are located throughout the area. The regional offices are listed in Table 1.3, and the four regions are identified on the map shown in Figure 1.3.

Data are generally collected and entered, and quality assured, at the regional level. Data are managed at the national level by the Transportation Research Board (TRB) of the National Research Council (NRC) located in Washington, D.C.

Table 1.3 *LTPP Regional Offices*

Region Name	Location	State / Provinces* in Region
North Atlantic (NA)	Buffalo, NY	NC, VA, WV, MD, DE, DC, NJ, PA, NY, CT, RI, MA, VT, ME, NH, ON*, NB*, NS*, PE*, and NF*
North Central (NC)	St. Paul, MN	KS, OH, MI, KY, IN, IA, IL, NE, SD, ND, MN, WI, MI, MB*, and SK*
Southern (S)	Austin, TX	NM, TX, OK, AR, LA, MS, TN, AL, GA, SC, FL, and PR
Western (W)	Reno, NV	AZ, UT, CA, HI, ID, NV, CO, WY, OR, WA, MT, AK, BC*, and AB*
		*** Canadian Provinces**

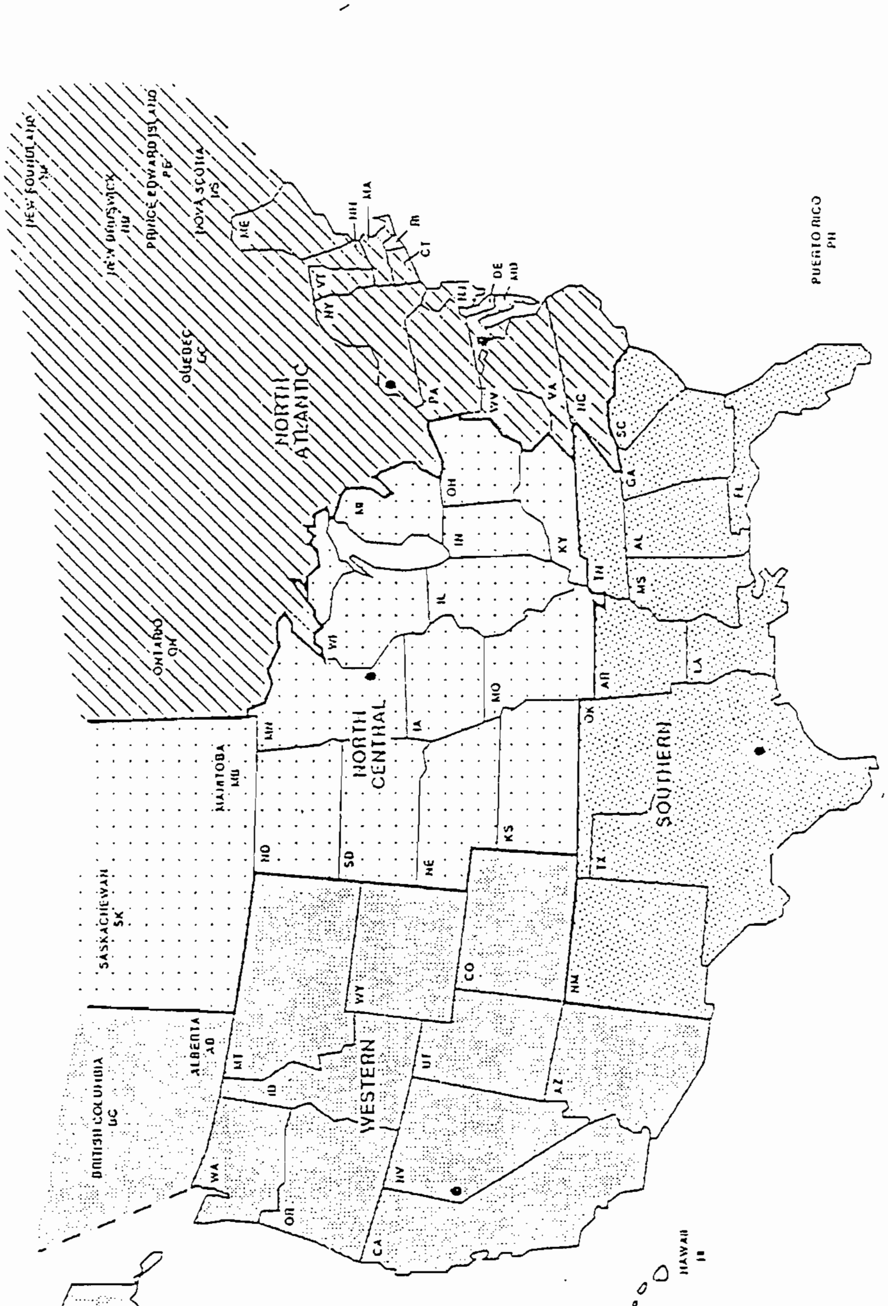


Figure 1.3 *The Four LTPP Regions*

1.3 LTPP and Texas

Highway agencies are participating in the LTPP program by making the pavement sections available. In addition to this, the agencies also provide traffic control during test section selection and data-collection phases of the study, as well as substantial portions of the actual data, including details of the design and construction of the pavements, historical records of traffic, and measurement of traffic and vehicle loads in the future, as well as pavement surface friction measurements. Consequently, highway agency participation is an integral and necesary part of the program.

As of January 1993, Texas Department of Transportation (TxDOT) maintains a total of 90 LTPP General Pavement Studies (GPS) test sections. Their distribution according to the experiment type is shown in Table 1.4.

Table 1.4 *LTPP GPS Test Sections in Texas*

Experiment	Description	Test Sections in Texas
GPS 1	Asphalt Concrete (AC) on Granular Base	40
GPS 2	AC on Bound Base	09
GPS 3	Jointed Plain Concrete (JCP)	03
GPS 4	Jointed Reinforced Concrete (JRCP)	05
GPS 5	Continuously Reinforced Concrete (CRCP)	19
GPS 6A	Existing AC Overlay on AC	05
GPS 6B	New AC Overlay on AC	03
GPS 7A	Existing AC Overlay on Portland Cement Concrete (PCC) Pavements	02
GPS 7B	New AC Overlay on Portland Cement Concrete (PCC) Pavements	
GPS 9	Unbound PCC Overlay of PCC Pavements	04
	Total	**90**

1.4 Objective

The objective of this work is to design a long-term pavement performance program for Texas which will also incorporate the existing LTPP test sections to the degree useful. The resulting test sections will comprise a self-contained database in Texas which could be used to model future pavement management (PMS) needs and efforts.

The total cost, in terms of man-hours required, for site selection, drilling and sampling, condition surveys, traffic control, and traffic data collection will also be examined.

The result will be a list of test sections required to structure the database and the costs associated with maintaining and monitoring the test sections.

1.5 Scope and Study Organization

With the assistance of the Center for Transportation Research (CTR) at The University of Texas at Austin and the Texas Transportation Institute (TTI) at Texas A&M University, the Texas Department of Transportation (TxDOT) is currently developing an automated Pavement Management Information System (PMIS), with operational status targeted for August 1995.

This study will help define the basic test sections required to address cost-effective decision-making as to what treatment is most effective, where treatments are needed, and when is the best time to program a treatment.

In Chapter 2, the problem is to compare LTPP rigid pavement factorial experiment design to the existing CTR rigid pavement factorial experiment design. In an attempt to follow LTPP test standards and specifications, a new rigid pavement factorial experiment design or sampling frame will be proposed, keeping in focus Texas climatic conditions and geography. Additional test sections will be recommended, along with a strategy for selecting new test sections. Results of a survey conducted to determine the predominant rigid pavement types in each of the TxDOT districts are also presented.

Chapter 3 is devoted to defining the main data-collection factors for the Texas LTPP database.

Chapter 4 estimates and presents the costs involved for maintaining and monitoring the new proposed test sections.

Chapter 5 summarizes the findings of the study and gives recommendations for future research needs.

1.6 Research Approach

It is improbable that all LTPP standards and specifications can be justified for the Texas LTPP, as it operates at a regional level rather than at the national LTPP level. The Center for Transportation Research (CTR) has carried out significant research on rigid pavements over the past twelve years for TxDOT; therefore, a comparison of the national LTPP specification was made with the CTR specification that has been developed for the same purpose. After the comparison, additions and / or deletions have been recommended so that the resulting specification satisfies Texas LTPP needs.

TxDOT maintains electronic files on what type of pavement is built in what district. These files were used to extract the required information for the study.

In order to determine the cost of maintaining and monitoring the observation sections, close cooperation was maintained with other CTR research projects (e.g., Project 1342) which were carrying out related studies. Also, LTPP regional contractors and TxDOT offices were contacted which have maintained and monitored test sections for LTPP.

CHAPTER 2

LTPP RIGID PAVEMENT EXPERIMENT DESIGN

As stated in Chapter 1, the basic objective of this report is to develop a long-term pavement performance program for Texas. The resulting database should be able to provide for better modeling of future pavement performance for overall management needs. To the extent possible, Texas LTPP test sections will be made a part of the new experiment and database so that some data are available immediately.

The Center for Transportation Research (CTR) maintains a rigid pavement database for TxDOT. This database will be utilized to the extent possible when the new LTPP database is being set up.

In light of the above discussion, it becomes evident that a comparison needs to be made of the similarities and differences between the CTR and the LTPP factorial experiment designs. The comparison is based solely on the variables incorporated in the experiment design and what are limiting values for each variable in the two experiment designs.

2.1 Factorial Experiment Design

An experiment design is a plan for orderly collection of data. Since a number of different factors affect pavement performance, a factorial experiment design is used so that the effects of various factors can be investigated simultaneously. The factorial approach is efficient and results in considerable savings of time and resources, in comparison to the alternate procedure of conducting separate experiments, each of which deals with a single factor.

Also, in factorial experiment design, the effects of each factor can be studied individually and their interaction with other factors can also be examined. Hence, more information can be gathered about the true effects than with one-factor-at-a-time experiments (Anderson 74, Cochran 62, & Clark 79).

2.2 SHRP LTPP Experiment Design for Continuously Reinforced Concrete Pavements

A CRCP pavement is defined as a continuously reinforced portland cement concrete pavement placed over one or more base or subbase layers (SHRP 86). The variables included in the factorial experiment design are:

1. Moisture,
2. Temperature,
3. Subgrade,
4. Traffic,
5. Percentage of Steel Reinforcement, and
6. Pavement Thickness.

The factor midpoints for these variables were selected by LTPP personnel.

2.2.1 Moisture

In 1948, an American climatologist C. W. Thornthwaite (1899-1963) introduced an empirical climatic classification based on the climatic water budget. The classification involves a thermal efficiency index, which is equivalent to the potential evapotranspiration, the amount of moisture that would be evaporated from soil and transpired by plants if the supply was unlimited, and a moisture index, which is the difference between precipitation and potential evapotranspiration (Thornthwaite 48 & Oliver 73). Figure 2.1 shows the distribution of the Thornthwaite Moisture Index in the United States.

The Thornthwaite Moisture Index (NOAA 82) in the United States is used to determine whether the test section is in the dry region or in the wet region. If the section has a positive Thornthwaite Moisture Index (TMI) (that is, above zero), it is considered wet. If the section has a negative TMI, it is considered to be in the dry region.

In the LTPP experiment design, all test sections are classified, according to the Thornthwaite Moisture Index (TMI), as belonging to one of the two regions.

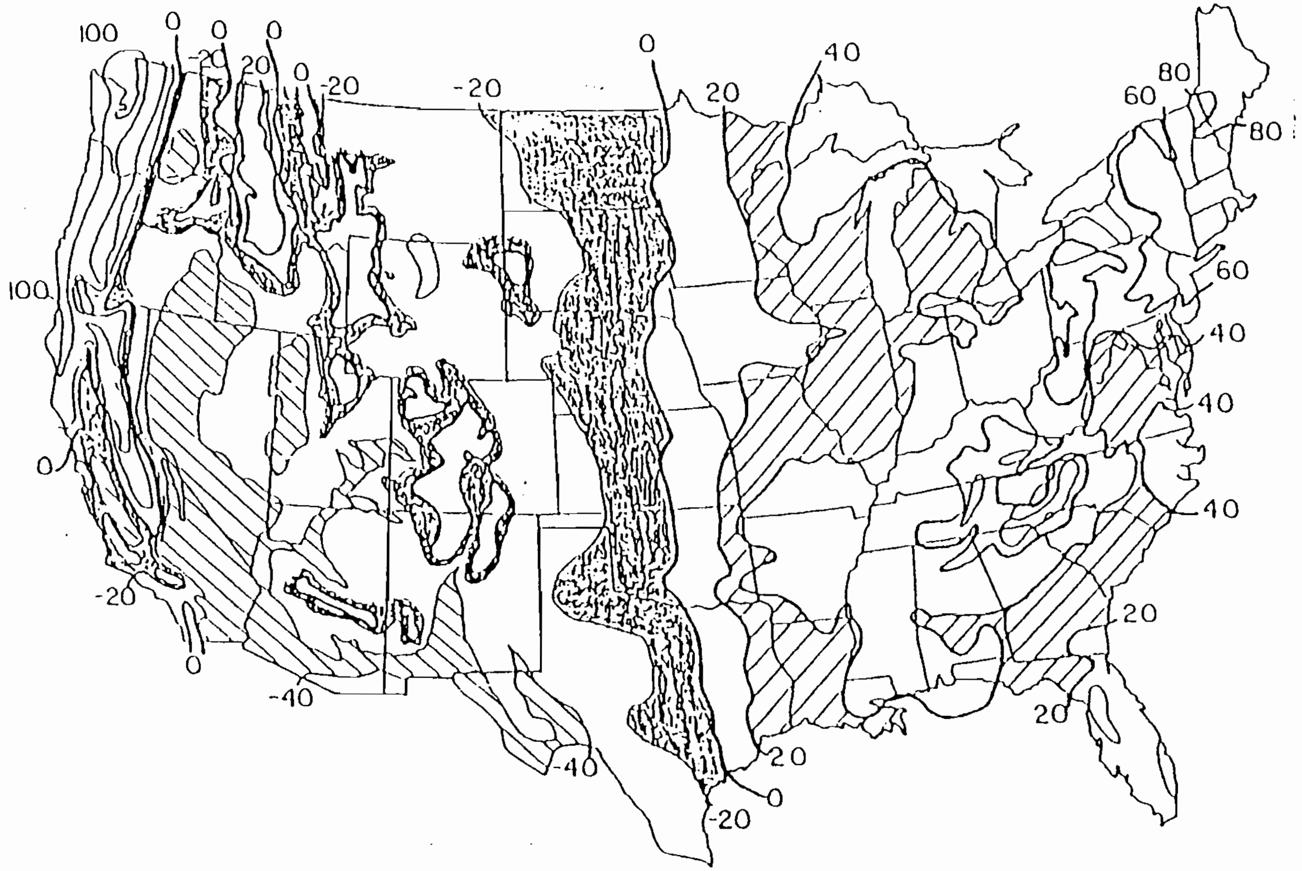


Figure 2.1 *Distribution of Thorntwaite Moisture Index in United States*

2.2.2 *Temperature*

Mean Freezing Index values are used to determine whether the test section is in the "Freeze" or "No-Freeze" region (NOAA 82). For LTPP purposes Texas is classified as belonging in the "No-Freeze" region. It must, however, be noted that the Panhandle area is susceptible to frost penetration to a depth of 30.48 cm (12 inches) on the average of 1 year in 10 years. Mean Freezing Index values are expressed in degree days below 0° C (32° F). One degree day represents one day with a mean air temperature of one degree (Fahrenheit) below freezing.

In the LTPP experiment design all test sections are classified, according to the Mean Freezing Index values, as belonging in either the "Freeze" or the "No-Freeze" region. Figure 2.2 shows the distribution of Mean Freezing Index values in the United States.

2.2.3 *Subgrade*

In the LTPP factorial experiment design a test section is categorized in the fine subgrade category or in the coarse subgrade category. That portion of the subgrade material retained on the #4 sieve is called coarse, and the portion passing is called fine.

2.2.4 *Traffic*

In the experiment, traffic is termed to be either high or low depending upon the estimated number of equivalent 18-kip single axles per year on all the lanes in one direction. LTPP sections with an estimated traffic value below 300,000 18-kip ESAL / year are termed to be low traffic volume, and those above 300,000 18-kip ESAL / year are termed to be high traffic volume.

2.2.5 *Percentage of Steel Reinforcement*

The amount of steel reinforcement is classified to be high steel content, if greater than or equal to 0.61 percent, while 0.60 percent or less is classified as low steel content.

2.2.6 *Pavement Thickness*

A slab thickness of 21.59 cm (8.5 inches) is used as the factor midpoint between the low and high pavement thicknesses. If the PCC thickness is greater than or equal to 21.59 cm (8.5 inches), then the slab thickness is high; otherwise, it is low.

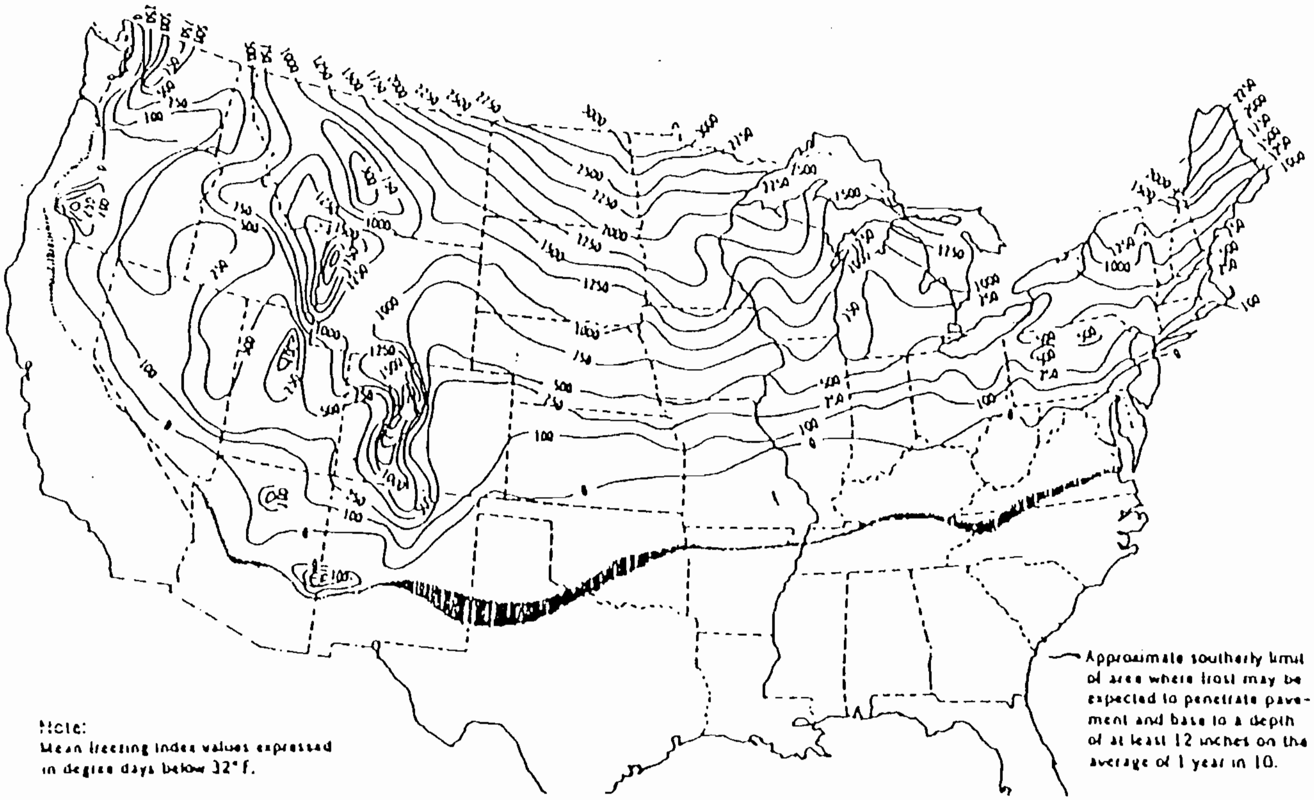


Figure 2.2 *Distribution of Mean Freezing Index values in the United States*

2.2.7 LTPP CRCP Experiment

LTPP studies divide the factorial experiment design into two parts, namely the primary factorial experiment and the secondary factorial experiment, which when combined constitute the main factorial experiment design. The LTPP CRCP factorial experiment design is shown in Figure 2.3.

2.2.8 LTPP CRCP Test Sections in Texas

A total of 19 CRCP LTPP test sections currently exist in Texas; 5 of the 19 are in the "Wet – No-Freeze" region and the remaining 14 in the "Dry – No-Freeze" region, as shown in Figure 2.4.

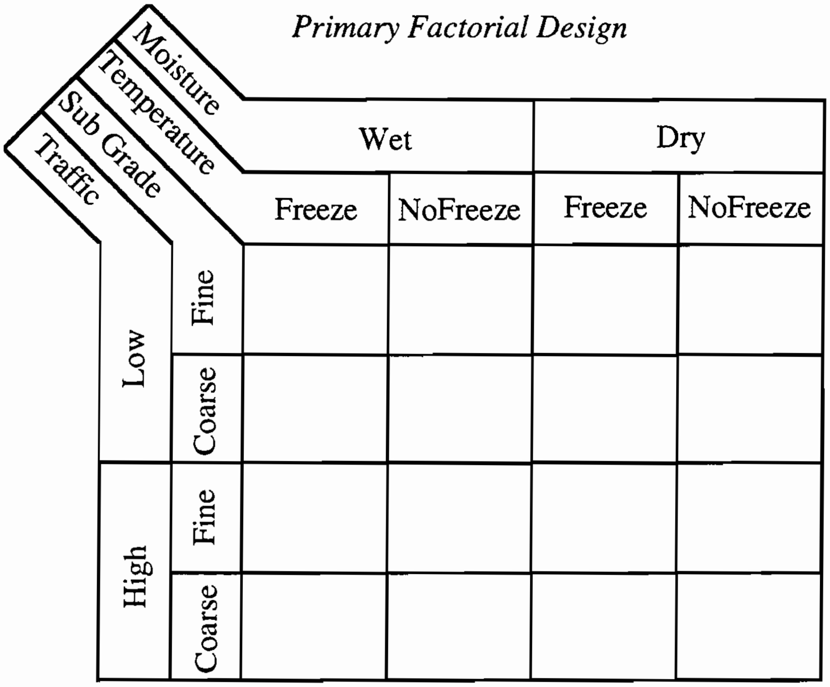
2.3 CTR Experiment Design for Continuously Reinforced Concrete Pavements

In 1972 a statewide survey of all the CRCP sections was conducted by CTR, so a factorial experiment design or sampling template was not required. In 1987 the experimental sampling factorial was established and is documented in CTR Research Report 472-2 (CTR 88) .

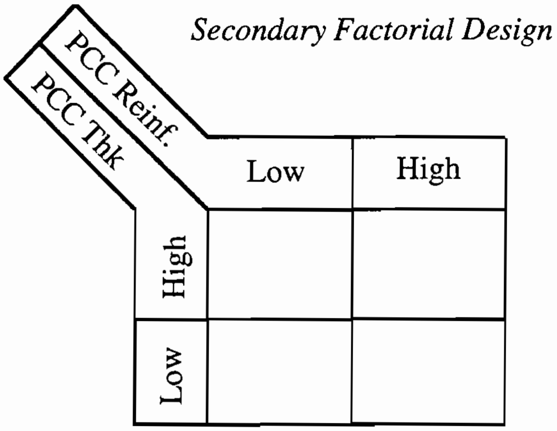
The principal factors considered are slab thickness, coarse aggregate type for the slab, subbase treatment type, roadbed soil type, whether the pavement is susceptible to swelling or not, average annual rainfall, average annual lowest temperature, and the pavement age. Traffic was not considered in the experiment design, but AADT values were stored in the database for each of the test sections.

2.3.1 Slab Thickness

This is the upper layer of the pavement structure and consists of portland cement concrete and steel reinforcement. There are four thicknesses in the study, 15.24, 20.32, 22.86, and 33.02 cm (6, 8, 9, and 13 inches) (CTR 88). This information is found from the construction plans for each project available at TxDOT. It is necessary to know the county and the construction control section job number (CSJ no.) to locate the corresponding construction plans.



Primary Factorial Design



Secondary Factorial Design

Figure 2.3 *LTPP CRCP Factorial Experiment Design (SHRP 86)*

	Moisture	Wet								Dry							
	Temperature	Freeze				No Freeze				Freeze				No Freeze			
	Sub Grade	Fine		Coarse		Fine		Coarse		Fine		Coarse		Fine		Coarse	
	Traffic	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
PCC Thickness	PCC Reinforcement																
Low	Low						2		1					2	2	2	1
	High																
High	Low					1	1							2	3	2	
	High																

Factor Midpoints:

Traffic Rate	- 300,000 18-kip ESAL / year
Percentage Reinforcement	- 0.61%
PCC thickness	- 8.5 inches

Figure 2.4 *LTPP CRCP Test Sections Existing in Texas as of Jan. '93*

2.3.2 *Subbase Type*

The CRCP subbase generally consists of granular or stabilized material placed in one to three compacted layers, the effect of which is to provide a strong layer capable of supporting the concrete slab placed on it.

Four subbase types are used in Texas — asphalt-treated, cement-treated, lime-treated, and natural crushed stone. Information about these can be obtained from the construction plans as explained earlier.

2.3.3 *Coarse Aggregate Type*

Two typical coarse aggregate types are included in the study, i.e., limestone and siliceous river gravel. The amount of coarse aggregate in the portland cement concrete mix design is based on the AASHTO guides "Specifications for Highway Construction" and "Standard Specifications for Transportation Materials" (AASHTO 81 & AASHTO 86).

Coarse aggregate type has a significant influence on pavement performance, as is indicated by various CTR research studies. It not only affects the load transfer capability and the concrete strength but also governs the thermal coefficient of concrete (CTR 92b). This influences early-age crack spacing, which in turn results in punchouts and early failure.

2.3.4 *Roadbed Soil Type*

The shrinkage / swell characteristic of the subgrade soil determines the potential for layer movement within the structure. Therefore, the prime surfacial soil characteristic is affected by the presence of swelling clay in the surface layer (CTR 88). This characteristic of the roadbed soil under the pavement structure was obtained by locating the section approximately on the Texas Resources Map (Kier 89).

In the experiment design, the roadbed soil can have either low swelling or high swelling.

2.3.5 *Average Annual Rainfall*

In the CTR factorial experiment, average annual rainfall is categorized into low, medium, and high categories. The data collected for this parameter were the arithmetic means computed over a time period spanning three consecutive decades, 1951-1980. The average annual rainfall for each pavement section can be obtained by roughly locating the pavement section on a contour map constructed from data collected by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, for the period 1951-1980, and is available from the Weather and Climate Section, Texas Department of Water Resources (NOAA 82).

The factor midpoints are 38.10 cm and 101.6 cm (15 inches and 40 inches) of rain per year.

2.3.6 Average Annual Lowest Temperature

For the CTR factorial design, average annual lowest temperature is categorized as either low or high. The data collected for this parameter were also the arithmetic means over a time period spanning three consecutive decades, 1951-1980.

These data are collected by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce and is available from the Weather and Climate Section, Texas Department of Water Resources (NOAA 82).

2.3.7 Age

Pavement age is an important factor which was included in the experiment design because it defines the years of service, a crude measure of performance. It not only is an indication of traffic but also has strong interaction with the other environmental factors.

2.3.8 CRCP Sections in Texas CTR Database

There are 355 CRCP projects in the CTR network, but only 262 projects qualified for the experiment design because of their corresponding levels of parameters. Pavement projects which had slab thickness other than 15.24, 20.32, 22.86, and 33.02 cm (6, 8, 9, and 13 inches), or a coarse aggregate type different from limestone or siliceous river gravel, were excluded from the experiment design (CTR 88). Due to the Texas and FHWA design policies during the years 1950-1970, a large portion of CRCP sections in Texas have a slab thickness of 15.24 cm (8 inches). Table 2.1 shows the slab thicknesses of the CRCP projects in Texas.

Table 2.1 *Distribution of Slab Thicknesses (CTR 88)*

Thickness	Overlaid	Non Overlaid	Subtotal
6"	1	23	**24**
8"	25	190	**215**
9"	8	10	**18**
13"	0	5	**5**
Subtotal	**34**	**228**	
		Total	**262**

Thirty-four projects out of 262 have been overlaid once or more during their service life. In order to compare the pavement performance of overlaid and non-overlaid pavements, some test sections of both types needed to be observed. The CTR factorial experiment designs are shown in Figures 2.5 through 2.12 for both the overlaid and non-overlaid sections (CTR 88).

		SOIL [SWELL]	LOW						HIGH					
		RAINFALL	L		M		H		L		M		H	
		TEMPERATURE [F]	L	H	L	H	L	H	L	H	L	H	L	H
SUBBASE TREAT.	AGG. TYPE	AGE [YRS]												
ASPHALT	SRG	<15												
		>15												
	LST	<15				3						4		
		>15			1	3						1		
CEMENT	SRG	<15												
		>15												1
	LST	<15												
		>15			1									
LIME	SRG	<15												
		>15												
	LST	<15												
		>15												
CRUSHED STONE	SRG	<15												
		>15												
	LST	<15												
		>15				2								

Figure 2.5 *CTR Factorial Experiment Design, 6" Non-Overlaid*

SOIL [SWELL]			LOW						HIGH					
RAINFALL			L		M		H		L		M		H	
TEMPERATURE [F]			L	H	L	H	L	H	L	H	L	H	L	H
SUBBASE TREAT.	AGG. TYPE	AGE [YRS]												
ASPHALT	SRG	< 15												
		> 15				1								
	LST	< 15												
		> 15			2	2		1						
CEMENT	SRG	< 15												
		> 15												
	LST	< 15												
		> 15			2									
LIME	SRG	< 15												
		> 15												
	LST	< 15												
		> 15												
CRUSHED STONE	SRG	< 15												
		> 15												
	LST	< 15												
		> 15												

Figure 2.6 *CTR Factorial Experiment Design, 6" Overlaid*

		SOIL [SWELL]	LOW						HIGH					
		RAINFALL	L		M		H		L		M		H	
		TEMPERATURE [F]	L	H	L	H	L	H	L	H	L	H	L	H
SUBBASE TREAT.	AGG. TYPE	AGE [YRS]												
ASPHALT	SRG	< 15	4											1
		> 15	2			1		2						
	LST	< 15		3	2	9						7		
		> 15	1		3	6					1	2		
CEMENT	SRG	< 15	1					2						6
		> 15	3					3						9
	LST	< 15				4					1	3		
		> 15	1	1	3	1			3			3	1	3
LIME	SRG	< 15	1					1						
		> 15	1										2	1
	LST	< 15	4						2					
		> 15			1	4		2	3					
CRUSHED STONE	SRG	< 15												
		> 15				1								
	LST	< 15												
		> 15				10					1	3		

Figure 2.7 *CTR Factorial Experiment Design, 8" Non-Overlaid*

		SOIL [SWELL]	LOW						HIGH					
		RAINFALL	L		M		H		L		M		H	
		TEMPERATURE [F]	L	H	L	H	L	H	L	H	L	H	L	H
SUBBASE TREAT.	AGG. TYPE	AGE [YRS]												
ASPHALT	SRG	< 15												2
		> 15	1			1		4						1
	LST	< 15												
		> 15	1		5	4		1						
CEMENT	SRG	< 15												2
		> 15	1					6					6	5
	LST	< 15	1		1	3						3		
		> 15			3		1	1	1			1	3	1
LIME	SRG	< 15	2											1
		> 15				1								3
	LST	< 15												
		> 15	4	1		5		3						
CRUSHED STONE	SRG	< 15												
		> 15	1											
	LST	< 15												
		> 15			3	1						1		

Figure 2.8 *CTR Factorial Experiment Design, 8" Overlaid*

		SOIL [SWELL]	LOW						HIGH					
		RAINFALL	L		M		H		L		M		H	
		TEMPERATURE [F]	L	H	L	H	L	H	L	H	L	H	L	H
SUBBASE TREAT.	AGG. TYPE	AGE [YRS]												
ASPHALT	SRG	< 15	4											
		> 15										1		
	LST	< 15	3											
		> 15												
CEMENT	SRG	< 15	1											
		> 15												
	LST	< 15												
		> 15												
LIME	SRG	< 15												
		> 15												
	LST	< 15												
		> 15												
CRUSHED STONE	SRG	< 15	1											
		> 15												
	LST	< 15												
		> 15												

Figure 2.9 *CTR Factorial Experiment Design, 9" Non-Overlaid*

		SOIL [SWELL]	LOW						HIGH					
		RAINFALL	L		M		H		L		M		H	
SUBBASE TREAT.	AGG. TYPE	TEMPERATURE [F] AGE [YRS]	L	H	L	H	L	H	L	H	L	H	L	H
ASPHALT	SRG	< 15												
		> 15												
	LST	< 15												
		> 15												
CEMENT	SRG	< 15												
		> 15												
	LST	< 15												
		> 15												
LIME	SRG	< 15												
		> 15												
	LST	< 15				1								
		> 15												
CRUSHED STONE	SRG	< 15				7								
		> 15												
	LST	< 15												
		> 15												

Figure 2.10 *CTR Factorial Experiment Design, 9" Overlaid*

		SOIL [SWELL]	LOW						HIGH					
		RAINFALL	L		M		H		L		M		H	
		TEMPERATURE [F]	L	H	L	H	L	H	L	H	L	H	L	H
SUBBASE TREAT.	AGG. TYPE	AGE [YRS]												
ASPHALT	SRG	< 15												
		> 15												
	LST	< 15												
		> 15												
CEMENT	SRG	< 15				2								
		> 15												
	LST	< 15												
		> 15												
LIME	SRG	< 15												
		> 15												
	LST	< 15				1						1		
		> 15												
CRUSHED STONE	SRG	< 15												
		> 15												
	LST	< 15												
		> 15												

Figure 2.11 *CTR Factorial Experiment Design, 13" Non-Overlaid*

		SOIL [SWELL]	LOW						HIGH					
		RAINFALL	L		M		H		L		M		H	
SUBBASE TREAT.	AGG. TYPE	AGE [YRS] / TEMPERATURE. [F]	L	H	L	H	L	H	L	H	L	H	L	H
ASPHALT	SRG	< 15												
		> 15												
	LST	< 15												
		> 15												
CEMENT	SRG	< 15												
		> 15												
	LST	< 15												
		> 15												
LIME	SRG	< 15												
		> 15												
	LST	< 15										1		
		> 15												
CRUSHED STONE	SRG	< 15												
		> 15												
	LST	< 15												
		> 15												

Figure 2.12 *CTR Factorial Experiment Design, 13" Overlaid*

2.4 LTPP Experiment Design for Jointed Plain Concrete Pavements

This type of pavement is defined as a non-reinforced portland cement concrete (PCC) slab over any number of base and subbase layers. The joints may or may not have dowel bars for the purpose of experiment design. Also, they have no reinforcement, as the name indicates; hence the joint spacing usually ranges from 3.05 to 6.10 meters (10 to 20 feet) (SHRP 86). The variables included in the factorial experiment design are as follows:

1. Moisture,
2. Temperature,
3. Subgrade,
4. Traffic,
5. Dowels,
6. PCC Thickness, and
7. Base Type.

The factor midpoints for these variables were also selected by LTPP personnel.

2.4.1 Moisture

As with the LTPP CRCP experiment design, the Thornthwaite Moisture Index (NOAA 82) in the United States is used to determine whether the test section is in the dry region or in the wet region. If the section has a positive Thornthwaite Moisture Index (that is, above zero), it is considered wet. If the section has a negative TMI, it is considered to be in the dry region.

2.4.2 Temperature

In the LTPP experiment design, all sections are classified, according to the Mean Freezing Index (NOAA 82), as belonging in either the "No-Freeze" region or the "Freeze" region.

2.4.3 Subgrade

Since the jointed plain concrete pavements (JPCP) have no reinforcement, the need for a subgrade not susceptible to swelling is very important. A test section can have either a granular subgrade (not susceptible to swelling) or a fine subgrade (susceptible to swelling) (Kier 89).

2.4.4 Traffic

Traffic is categorized as either high or low depending upon the estimated number of equivalent 18-kip ESAL per year in one direction on all the lanes. For LTPP experiment design the value of 200,000 18-kip ESAL / year is used to differentiate between the high and low traffic categories.

2.4.5 Dowels

In the LTPP factorial experiment, pavements both with and without dowels at the transverse joints are considered.

2.4.6 PCC Thickness

A slab thickness of 9.5 inches is used as the factor midpoint between the low and high pavement thickness. If the PCC thickness is greater than or equal to 24.13 cm (9.5 inches), then the slab thickness is high; otherwise, it is low.

2.4.7 Base Type

The need for a stable base for this type of pavement is well documented. Two base types are identified, either stabilized or non-stabilized. The stabilized bases may either be cement-treated or asphalt-treated.

2.4.8 LTPP JPCP Experiment Design

As was the case with LTPP CRCP experiment, the factorial experiment design is divided into two parts, namely the primary factorial experiment and the secondary factorial experiment, which when combined constitute the main factorial experiment design. Figure 2.13 shows the LTPP factorial experiment design for jointed plain concrete pavements.

Primary Factorial Design

Moisture		Wet		Dry	
Temperature		Freeze	NoFreeze	Freeze	NoFreeze
Traffic	Sub Grade				
Low	Fine				
	Coarse				
High	Fine				
	Coarse				

Secondary Factorial Design

Base Type	Granular		Stabilized	
Dowels ?	Yes	No	Yes	No
PCC Thk				
Low				
High				

Figure 2.13 *LTPP JPCP Factorial Experiment Design (SHRP 86)*

2.4.9 LTPP JPCP Test Sections in Texas

In Texas a total of three JPCP test sections are available; one of the three is in the "Dry – No-Freeze" region, and the remaining two are in the "Wet – No-Freeze" region, as shown in Figure 2.14.

The one in the "Dry – No-Freeze" region has a non-stabilized base with a pavement thickness greater than 25.4 cm (10 inches) and dowels for load transfer. The ones in the "Wet – No-Freeze" region have a stabilized base along with dowels.

2.5 CTR Factorial Experiment Design for Jointed Plain Concrete Pavements

Until recently no CTR factorial experiment design existed for JCP pavements, because an attempt was made to collect data on all jointed pavements in the state. In 1992, as an extension of Research Study 187 Tasl 7 ("Data Collection for Rigid Pavement Data Base"), Research Study 1342 was initiated to continue the data collection process. In January 1993 a factorial experiment design was adopted, as part of the data collection project, for the jointed plain concrete pavements (JPCP). The variables of this factorial experiment design are listed and discussed as follows:

1. Aggregate Type,
2. PCC Thickness,
3. Age,
4. Dowels, and
5. Climate.

It must be noted that slab length is not a variable in the factorial experiment design. The reason is that in Texas the slab length for JPCP is limited to 15 feet, and, according to TxDOT, no JPCP slabs have been constructed with a length greater than this.

2.5.1 Aggregate

This variable represents the coarse aggregate type. The effect of coarse aggregate on pavement performance has been documented in several of the studies conducted by the Center for Transportation Research (CTR) (CTR 92e and CTR 87b). It is based on the demonstrated effect of aggregate type on the continuous pavements and the assumption that there will be an effect on jointed pavements as well.

		Moisture	Wet								Dry							
		Temperature	Freeze				No Freeze				Freeze				No Freeze			
		Sub Grade	Fine		Coarse		Fine		Coarse		Fine		Coarse		Fine		Coarse	
		Traffic	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
Base Type	PCC Thickness	Dowels ?																
Granular	Low	Yes																
		No																
	High	Yes														1		
		No																
Stabilized	Low	Yes					1											
		No																
	High	Yes						1										
		No																

Factor Midpoints:

Traffic Rate	- 200,000 18-kip ESAL / Year
Joint Spacing	- 40 feet
PCC Thickness	- 9.5 inches

Figure 2.14 *LTPP JPCP Test Sections Existing in Texas as of Jan. '93*

2.5.2 PCC Thickness

Two levels of pavement thicknesses are considered in the factorial experiment. All those pavements having a thickness of greater than or equal to 25.4 cm (10 inches) are grouped together, and the remaining pavements are grouped that have a thickness of less than 25.4 cm (10 inches). The factor midpoint of 25.4 cm (10 inches) was selected after discussion with TxDOT officials.

2.5.3 Age

The effect of pavement age on pavement performance is difficult to quantify. It is included in the factorial experiment design because it functions as a measure of service life or performance. Pavement age is considered either high or low using a factor midpoint of 15 years. This factor midpoint is the median of ages of jointed pavements in the CTR database.

2.5.4 Dowels

This variable documents the presence of dowels as load transfer devices in the transverse joints. The presence of dowels is included in the experiment design.

2.5.5 Climate

The CTR factorial experiment design represents climate by dividing the state of Texas into four climatic regions as the dry freeze-thaw region, the wet freeze-thaw region, the dry no-freeze region, and the wet no-freeze region. Basically, the two separate variables, moisture and temperature, are combined into one.

2.5.6 CTR JPCP Experiment Design

The CTR JPCP experiment design incorporating climatic and construction variables is shown in Figure 2.15.

Aggregate		Limestone				Siliceous			
Thickness		< 10"		≥ 10"		< 10"		≥ 10"	
Age		L	H	L	H	L	H	L	H
Climate	Dowels?								
1	Y								
	N								
2	Y								
	N								
3	Y								
	N								
4	Y								
	N								

Figure 2.15 *CTR JPCP Factorial Experiment Design*

2.6 LTPP Experiment Design for Jointed Reinforced Concrete Pavements

This type of pavement in the LTPP factorial experiment design is specifically defined as a reinforced cement concrete slab placed over any number of base or subbase layers. The joints must contain dowel bars, and, since the concrete has reinforcement, the joint spacing ranges from 7.62 to 18.29 meters (25 to 60 feet) (SHRP 86). The variables in the LTPP factorial experiment design are moisture, temperature, subgrade, traffic, joint spacing, and PCC thickness.

For this type of pavement, all the variables have the same attributes, as discussed in the LTPP factorial experiment design for the JPCP, except for the joint spacing, which is discussed below.

2.6.1 Joint Spacing

For reinforced jointed pavements, joint spacing has increased from a range of 3.05 to 6.10 meters (10 to 20 feet), as was the case in JPCP, to a value which ranges between 7.62 to 18.29 meters (25 to 60 feet). The factor midpoint for joint spacing is 12.19 meters (40 feet).

2.6.2 LTPP JRCP Factorial Experiment

As before, the primary factorial experiment design remains the same; and, in the secondary factorial experiment design, two factors, the thickness of the PCC slab and the joint spacing, are considered, as shown in Figure 2.16.

2.6.3 LTPP JRCP Test Sections in Texas

TxDOT maintains a total of five JRCP test sections, and they all belong to the "Wet – No-Freeze" region. All five have a slab thickness of more than 24.13 cm (9.5 inches), and only two of the five have a joint spacing of less than 12.19 meters (40 feet), as shown in Figure 2.17.

2.7 CTR Factorial Experiment Design for Jointed Reinforced Concrete Pavements

As already stated, no factorial experiment design existed for jointed pavement until recently, when it was developed for use with CTR Research Study 1342, entitled "Maintaining and Updating the Rigid Pavement Data Base." The variables incorporated in the CTR factorial experiment for jointed reinforced concrete pavements (JRCP) are listed below:

1. Aggregate,
2. PCC Thickness,
3. Age,
4. Slab Length, and
5. Climate.

The presence of dowels for load transfer is not a variable in the experiment design because dowels are always present in this type of pavement owing to TxDOT design specifications.

The rest of the variables have the same attributes, as explained in the CTR factorial experiment design for JPCP, except for the slab length, which is described as follows.

Primary Factorial Design

	Moisture	Wet		Dry	
	Temperature	Freeze	NoFreeze	Freeze	NoFreeze
Traffic	Sub Grade				
Low	Fine				
	Coarse				
High	Fine				
	Coarse				

Secondary Factorial Design

	Joint Spacing	
PCC Thk	Low	High
High		
Low		

Figure 2.16 *LTPP JRCP Factorial Experiment (SHRP 86)*

	Moisture	Wet								Dry							
	Temperature	Freeze				No Freeze				Freeze				No Freeze			
	Sub Grade	Fine		Coarse		Fine		Coarse		Fine		Coarse		Fine		Coarse	
	Traffic	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
PCC Thickness	Joint Spacing																
Low	Low																
	High																
High	Low					2											
	High					1	1		1								

Factor Midpoints:

Traffic Rate - 200,000 18-kip ESAL / Year
Joint Spacing - 40 '
PCC Thickness - 9.5 "

Figure 2.17 *LTPP JRCP Test Sections Existing in Texas as of Jan. '93*

2.7.1 Slab Length

Two slab lengths are used in the construction of jointed reinforced concrete pavements (JRCP) in Texas. These two lengths are 9.14 meters (30 feet) and 18.29 meters (60 feet), which are incorporated in the factorial experiment design. It was found that TxDOT specifications limit the slab lengths for JRCP to the two incorporated lengths.

2.7.2 CTR JRCP Experiment Design

The CTR JRCP experiment design that incorporates climatic and construction variables is shown in Figure 2.18.

	Aggregate	Limestone				Siliceous			
	Thickness	< 10"		>= 10"		< 10"		>= 10"	
	Age	L	H	L	H	L	H	L	H
Climate	Slab Length								
1	30								
	60								
2	30								
	60								
3	30								
	60								
4	30								
	60								

Figure 2.18 *CTR JRCP Factorial Experiment*

2.8 Comparison Summary

After comparing the LTPP rigid pavement factorial experiment with the CTR rigid pavement factorial experiment, the following conclusions are drawn.

Nearly identical variables are used in both the LTPP and the CTR experiment designs. They may be defined a little differently but refer to the same variable or factor in the experiment design. For example, the CTR factorial design includes swelling activity of the subgrade soil, and, similarly, this variable is incorporated in the LTPP experiment design as fine or coarse, as there is generally a relationship between grain size and swelling activity. Fine-grained soils, such as clay, are very susceptible to swelling when they come in contact with water. On the other hand, coarse-grained materials, such as gravel, show no such tendency.

The CTR factorial considers the same experiment design for overlaid CRCP sections as for non-overlaid sections, whereas LTPP has a separate experiment design to study the effect of overlay design on performance.

In the CTR factorial experiment design, the type of aggregate used in the PCC mix and the type of stabilization used for the subbase are considered important factors and are included as variables in the experiment design. These are not present in the LTPP factorial experiment design.

Age is used as a factor in the CTR factorial experiment design but is not used in the LTPP experiment design.

The LTPP experiment design considers traffic and percentage of steel reinforcement in the PCC slab; these are not available in the CTR factorial experiment design, although traffic (ADT, ESAL, % trucks, etc.) is recorded in the database (CTR 89).

According to LTPP classification, Texas is in the "No-Freeze" region. This assumption may be valid when Texas is being considered in comparison with the whole country. But when proposing new test sections for use only in Texas, this assumption can no longer hold true, as explained in the recommendations.

2.9 Recommendations

In the light of the above discussion, the following general recommendations are made before the new factorial experiment designs are proposed for the long-term rigid pavement performance studies in Texas. Recommendations particular to one pavement type only are discussed when describing the proposed factorial experiment for that pavement type.

2.9.1 Freeze and No-Freeze Regions

First, as stated in the comparison summary, the LTPP experiments classify the state of Texas as being in the "No-Freeze" region. This is true when Texas is being considered in comparison with the whole country. But when new test sections are proposed only for Texas needs, this assumption can no longer be held true; therefore, "Freeze" and "No-Freeze" regions should be incorporated into the new factorial experiment.

Texas can be divided into four climatic regions as shown in Table 2.2, which clearly indicates that the whole of the Texas cannot be termed as a "No-Freeze" region.

The division of Texas into the four climatic regions is based on the zero Thornthwaite index line and the Freeze-Thaw line as given by the National Oceanic and Atmospheric Administration (NOAA 82). The above regions are also recommended by the AASHTO Pavement Design Guide 1986 (AASHTO 86). The geographic location of these regions is shown in Figure 2.19.

Table 2.2 *Four Texas Climatic Regions*

Region	Approximate Area (%)
I. Dry Freeze-Thaw Region	35
II. Wet Freeze-Thaw Region	15
III. Dry No-Freeze Region	30
IV. Wet No-Freeze Region	20

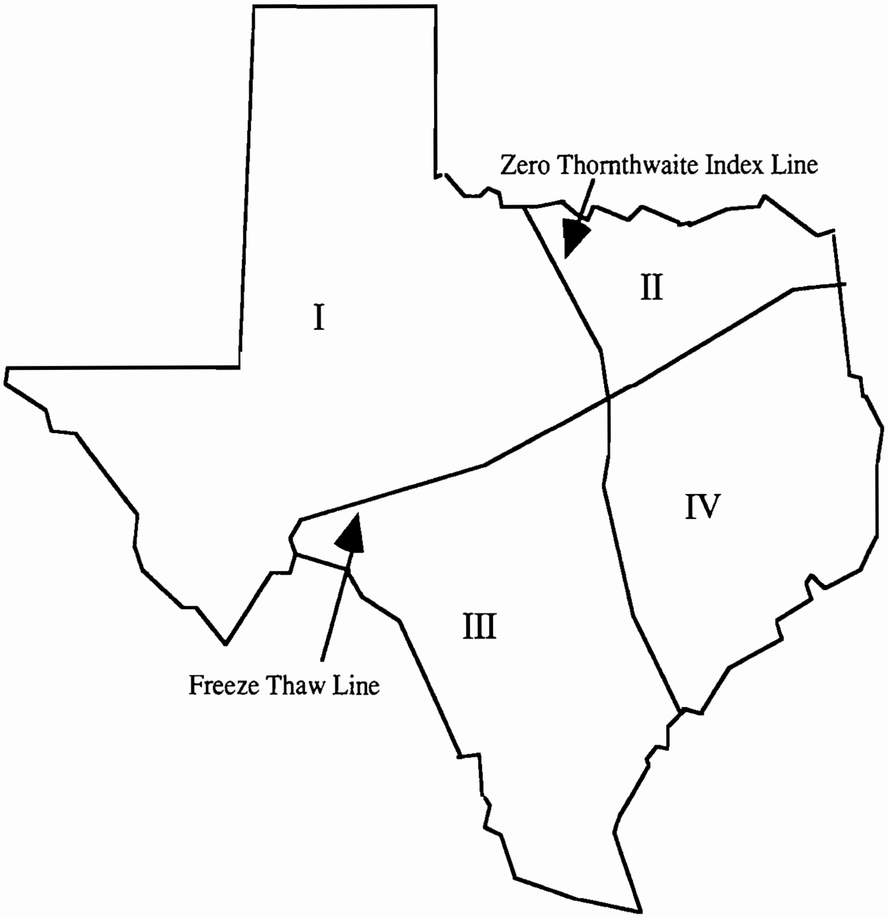


Figure 2.19 *Four Texas Climatic Regions*

2.9.2 *Pavement Age*

Age of the pavement must be made a part of the factorial design so that we have a reasonable mix of both new and old pavements.

The effect of age on pavement performance is difficult to quantify, since it acts as a measure of the accumulation of other distress-causing factors such as traffic, rainfall, and freeze-thaw cycles, etc. For this very reason it is an important principal factor to be included in the factorial experiment design. An age distribution analysis was conducted for the existing Texas CTR CRCP database, and the results are shown in Figure 2.20 (CTR 92a).

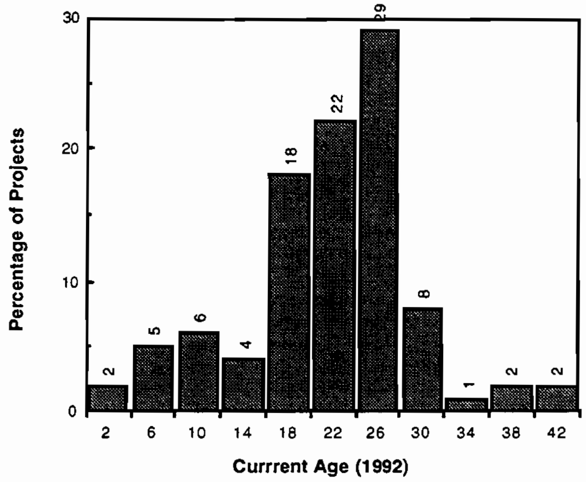


Figure 2.20 *Age Distribution of Pavements in Texas — CTR CRCP Database as of 1992*

Only 17 percent of the pavements are less than 15 years old. Design standards and maintenance and rehabilitation techniques have been updated many times in the last 15 years or so. For this reason alone, there is a great need for having more recent pavements in the database.

2.9.3 *Coarse Aggregate Type*

The effect of coarse aggregate type on pavement performance has been documented in several of the CTR studies, and most recently in phase one of CTR Research Study 1908 (CTR 87b, CTR 92a, CTR 92b, CTR 92d, and CTR 92e). Limestone and siliceous river gravel are the most widely used coarse aggregate types in Texas. It has been documented that cracking is more prevalent and more closely spaced in PCC slabs having siliceous river gravel as the coarse aggregate.

2.10 Proposed Factorial Experiments for Rigid Pavements

The 1986 AASHTO Design Guide clearly states that the pavement life, also represented as the number of 18-kip load applications, depends upon a number of design, climatic, and materials variables (AASHTO 86).

Upon further study of the AASHTO design methods it becomes evident that variables such as rainfall, temperature, coarse aggregate type, soil swelling characteristics, subbase type, and slab thickness have a great effect on the service life of the pavement.

Keeping all the above discussion in perspective, the foregoing variables should be made a part of the factorial experiment. It is once again stressed that the sole purpose of factorial experiment design is that of making the selection of rigid sections for condition surveys.

The intent here is not to make a recommendation as to what factors should be included in the database as covariates in addition to the principal factors listed below, but to have a sampling template in the form of a factorial experiment design to facilitate the selection of test sections for the purpose of pavement management. The proposed factorial experiment design consists of two separate experiments called the primary factorial experiment and the secondary factorial experiment.

The primary experiment involves climatic variables such as moisture and temperature, a construction variable in the form of coarse aggregate type, and the traffic load as represented by the number of 18-kip equivalent single axle loads per year. The primary factorial experiment design remains the same in both the continuously reinforced and the jointed pavements. The secondary experiment incorporates variables which vary between jointed and continuously reinforced pavements and which change even within the jointed pavement type category. The variables incorporated in the secondary experiment design are discussed separately for each pavement type.

The principal variables incorporated in the primary experiment are temperature and moisture conditions, traffic loading, and coarse aggregate type. These are discussed briefly and the possible sources for acquiring this information are also mentioned.

2.10.1 Moisture

The proposed factorial experiment has test sections belonging to either the wet region or the dry region. The Thornthwaite Moisture Index (NOAA 82) is used to determine whether the test section is in the dry region or in the wet region. If the section has a positive Thornthwaite Moisture Index (that is, above zero), it is considered to be wet. If the section has a negative TMI, it is considered to be in the dry region.

2.10.2 Temperature

Mean Freezing Index Values are used to determine whether the test section is in the "Freeze" or "No-Freeze" region. Mean Freezing Index Values are expressed in degree days below 0° C (32° F). One degree day represents one day with a mean air temperature of one degree (Fahrenheit) below freezing (NOAA 82, and SHRP 88).

2.10.3 Traffic

Test sections can belong to either the high-traffic category or the low-traffic category. Traffic is termed high or low depending upon the estimated number of equivalent 18-kip ESAL per year on all the lanes in one direction. For the experiment design, the value of 1.7 million 18-kip ESAL / year will be used to differentiate between the high and low traffic categories (TxDOT 91a, TxDOT 91b).

2.10.4 Coarse Aggregate Type

As already stated, a number of CTR studies have demonstrated the importance of coarse aggregate type on pavement performance. Siliceous river gravel and limestone are widely used in Texas and are incorporated in the experiment design.

2.10.5 Proposed CRCP Factorial Experiment Design

The secondary factorial experiment incorporates subgrade type, the age of the pavement, and the thickness of the PCC slab.

The secondary experiment design will have two types of pavements, those which are less than or 15 years old, and those which are more than 15 years of age. TxDOT maintains excellent records of construction dates, and the information can be obtained fairly easily.

The experiment design or the sampling template for CRCP is shown in Figure 2.21.

Primary Factorial Design

	Moisture	Wet		Dry	
	Temperature	Freeze	NoFreeze	Freeze	NoFreeze
Traffic	Coarse Agg.				
Low	L.S.				
	S.R.G.				
High	L.S.				
	S.R.G.				

Secondary Factorial Design

PCC Thk \ Age	≤ 15	> 15
> 8.5"		
<= 8.5"		

Figure 2.21 *Proposed CRCP Factorial Experiment Design*

2.10.6 Proposed JPCP Factorial Experiment Design

As was the case with the CRCP factorial experiment design, the primary experiment design incorporating moisture, temperature, traffic, and the coarse aggregate type remains the same for jointed plain pavements.

The secondary experiment design in the case of JPCP incorporates the thickness of the PCC slab and the presence of the dowel bars for load transfer across joints only.

Two PCC thickness levels are used. Pavements can be either less than 25.4 cm (10 inches thick) or greater than or equal to 25.4 cm (10 inches) thick. The presence or absence of dowel bars is recorded as a covariate, as shown in Figure 2.22. The JPCP pavements in Texas have a slab length of 4.57 meters (15 feet) according to TxDOT design specifications, so this factor is not included in the experiment design and is held constant throughout.

2.10.7 Proposed JRCP Factorial Experiment Design

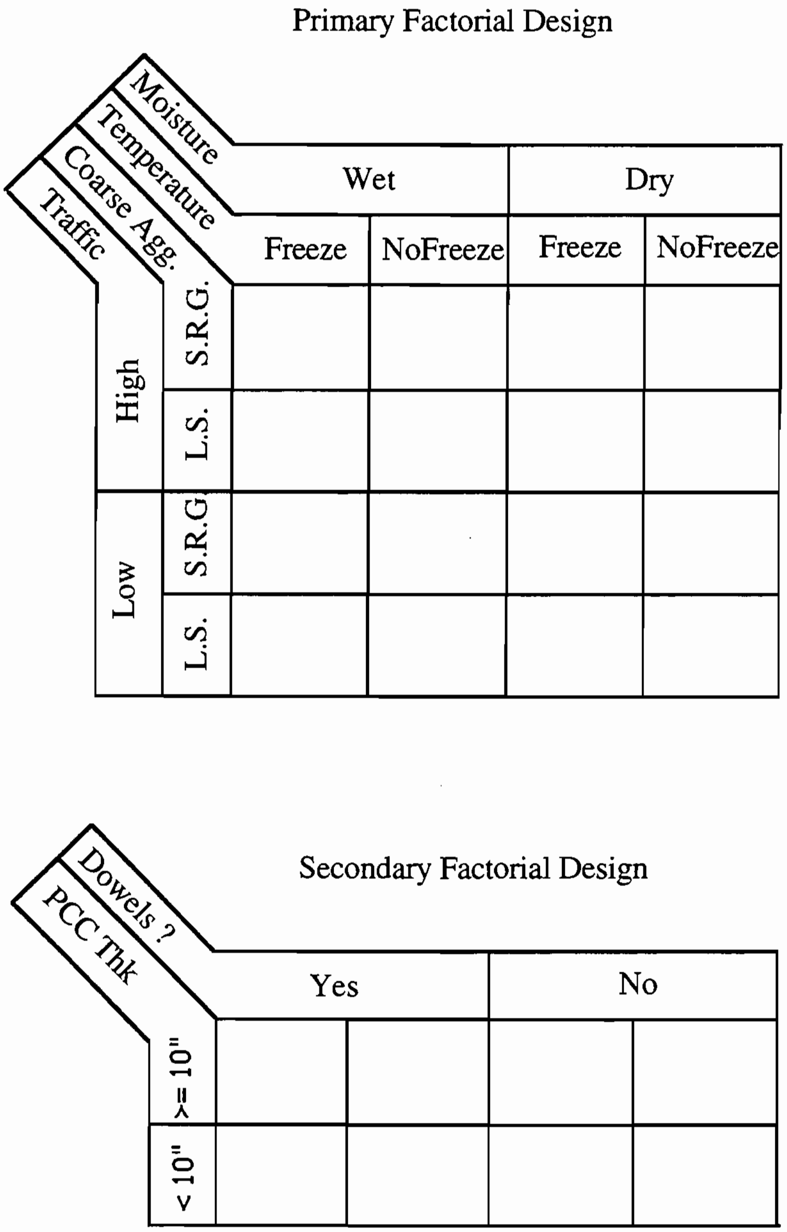
The primary factorial experiment design remains the same as CRCP experiment design once again. The secondary factorial experiment design incorporates the PCC slab thickness and the slab length or joint spacing.

The presence or absence of dowels for load transfer is not recorded but it is assumed that the dowels are always present, as stated in the definition of this type of pavement.

The JRCP are constructed such that each slab length or joint spacing is either 9.14 meters (30 feet) or 18.29 meters (60 feet). These measurements are incorporated in the experiment design, as shown in Figure 2.23.

2.11 Sampling Methodology

The three experiment designs each have a total of 64 cells, as shown in Table 2.3. The overall plan of the study is to limit the number of test sections to the minimum possible but still allow for sufficient degrees of freedom for various statistical analyses. A total of 200 test sections are proposed. A total of 100 CRCP test sections are proposed, with 50 each proposed for JPCP and JRCP. Research carried out under Project 1342 determined this sample size to be large enough statistically (CTR 94).



Primary Factorial Design

Traffic	Coarse Agg. \ Moisture	Wet		Dry	
	Temperature	Freeze	NoFreeze	Freeze	NoFreeze
High	S.R.G.				
	L.S.				
Low	S.R.G				
	L.S.				

Secondary Factorial Design

PCC Thk \ Dowels ?	Yes		No	
>= 10"				
< 10"				

Figure 2.22 *Proposed JPCP Factorial Experiment Design*

Primary Factorial Design

Moisture		Wet		Dry	
Temperature		Freeze	NoFreeze	Freeze	NoFreeze
Traffic	Coarse Agg.				
Low	SRG				
	L.S.				
High	SRG				
	L.S.				

Secondary Factorial Design

Slab Length	30'		60'	
PCC Thk				
>= 10"				
< 10"				

Figure 2.23 *Proposed JRCP Factorial Experiment Design*

Table 2.3 *Number of Cells per Experiment Design*

Pavement Type	Variables	Levels Each	Total # of Cells		Proposed Sections
CRCP	6	2	2^6	**64**	100
JPCP	6	2	2^6	**64**	50
JRCP	6	2	2^6	**64**	50

The existing CTR rigid pavement database is used to the extent possible to fill the various cells of the experiment design. If four or fewer than four test sections are in a cell, only one is selected; but if more than four sections fall in a cell, then two are selected. It is possible that all the factorial cells may not be filled using the CTR rigid pavement database. The TxDOT database is used in that case, and the remaining cells are filled. Appendices A and B list the SAS code used to set up the databases, and Appendices C and D list the proposed test sections by pavement type. Their various experimental attributes are also listed. Figures 2.24 through 2.26 show the partially filled proposed experiment designs.

Moisture		Wet								Dry							
Temperature		Freeze				No Freeze				Freeze				No Freeze			
CAT		LS		SRG		LS		SRG		LS		SRG		LS		SRG	
Traffic		L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
PCC Thickness	Age																
Low	≤15									1	2	2					
	>15	3			3	15	7	21	1	15	4	4	3		1	1	1
High	≤15					2	1		3	4	1	8			1		
	>15					1										1	

Factor Midpoints: Traffic 1.7 million 18-kip ESAL
Thickness 8.5 inches

Figure 2.24 *Proposed CRCP Test Sections for the Texas LTPP Program*

Moisture		Wet								Dry							
Temperature		Freeze				No Freeze				Freeze				No Freeze			
CAT		LS		SRG		LS		SRG		LS		SRG		LS		SRG	
Traffic		L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
PCC Thickness	Dowels present ?																
Low	No	8	3		2					6	2			10	2		
	Yes	2	4							2	4			4	4		
High	No	2	3		4			2		2	1			2	2		
	Yes	4	6							4	4						

Factor Midpoints: Traffic 1.7 million 18-kip ESAL
Thickness 10 inches

Figure 2.25 *Proposed JPCP Test Sections for the Texas LTPP Program*

PCC Thickness	Slab Length	Wet								Dry							
	Temperature	Freeze				No Freeze				Freeze				No Freeze			
	CAT	LS		SRG		LS		SRG		LS		SRG		LS		SRG	
	Traffic	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
Low	60'	4	9						1	1	2			8	2		
	30'	2	6				2			1				1		2	
High	60'					4	2	6	11					5	11		
	30'	2	4			2											

Factor Midpoints:	Traffic	1.7 million 18-kip ESAL
	Thickness	10 inches

Figure 2.26 *Proposed JRCP Test Sections for the Texas LTPP Program*

2.12 Predominant Rigid Pavement Types

Before trying to fill the factorial cells using the methodology described previously, it is necessary to facilitate test section selection by having available information concerning the manner in which a TxDOT district typically constructs each rigid pavement type and what pavement types are found in at district. For this purpose, an understanding of TxDOT is also required.

The Texas Department of Transportation (TxDOT) is a decentralized organization consisting of 24 geographical districts. Each of the 24 districts has authority to decide what pavement type will be designed and constructed following the guidelines set forth by the Design Section of the TxDOT. In recent years, urban areas and areas with high truck traffic corridors have used concrete pavements to a greater extent than previously (Wimsatt).

One of the objectives of Task 2 of Research Study 1908 is to find out which of the predominant pavement types present in Texas are not currently being represented in the LTPP database. A survey was conducted to determine what rigid pavement types are predominantly present in each of the 24 districts of TxDOT.

At the present time, TxDOT has standards for continuously reinforced concrete pavements (CRCP), plain dowel jointed concrete pavements (JPCP), skewed plain jointed concrete pavements (CPSJ), and jointed reinforced concrete pavements (JRCP) (THD 72 and SDHPT 82). These pavements are explained a little more in the following paragraphs.

The basic types of pavement used are CRCP (continuously reinforced concrete pavements) and the JCP (jointed concrete pavements), and the rest of them are derivatives of these two.

2.12.1 Continuously Reinforced Concrete Pavements

The most common pavement used in the Interstate program in Texas is continuously reinforced concrete pavement (CRCP). Thousands of miles of this type of pavement were constructed in the 1950's and 1960's by the Texas Highway Department. The design was simple — a pavement thickness of 20.32 cm (8 inches) and flexible shoulders were provided, consisting of a simple flexible base on which a thin wearing surface was provided (Wimsatt 89).

As far as the steel requirements are concerned, the majority of the sections were built using deformed reinforcing bars, and the percentage of longitudinal steel used, depending on the project, was either 0.5 percent or 0.6 percent. Another method to reinforce the pavements, used in some projects, was to use welded steel wire fabric, but these pavements did not perform well because cracks opened, allowing water to penetrate, causing damage to the subgrade. Sometimes incompressible foreign material entered into the cracks, giving rise to unwanted distresses.

It is interesting to report that the shoulders in such pavements were not tied to the concrete, and the resulting edge stresses that developed were very high. This problem occurred mostly on four-lane divided rural highways where truck traffic used to travel very close to the edge of the CRCP pavement in the outside lane. Also, warping and curling action was very significant on these relatively thin pavements. Distress appeared in the form of excessive punchouts. The distress was most severe in cases where siliceous river gravel was used. The use of this type of gravel resulted in closer crack spacing, with poor subbase support due to the lack of stabilization. Also, the subbase consisted of stabilized subbase, which bonded with CRCP and caused excessive transverse cracking.

To correct the situation, asphalt overlays were applied, and it was found that an overlay thickness in the range of 10.16 to 15.24 cm (4 to 6 inches) worked well. The application of the overlay and the correction (repair) of the significant distresses in the pavements led to an elimination of the distresses.

Another difference between CRCP and JPCP is the propagation of reflection cracks in the asphalt overlay. Unlike the case of JCP, reflection cracks almost never appear in CRCP, because the steel keeps the cracks tightly closed, and so CRCP is relatively easy to maintain and rehabilitate compared to JCP, which has led to the enormous popularity of CRC pavements.

The type of aggregate used and the subbase type present under the CRCP can have an effect on their performance. The crack spacing tends to be closer in CRCP using siliceous river gravel; this means that punchouts also appear at an early date, compared to those in CRCP constructed using limestone.

Many of the concrete pavements built during the Interstate program were built directly on cement-stabilized subbase. This caused a problem as explained earlier, in the case of CRCP as well as in JCP, resulting in excessive cracking. So a bond breaker was required to be incorporated between the subbase and the concrete pavement in case the pavement is built on a cement-stabilized subbase.

It is also required that all concrete pavements constructed and maintained by TxDOT use non-erosive, dense-graded, stabilized subbase, either asphalt or cement-stabilized. Neither lime-stabilized subbase nor flexible subbase is recommended in high-traffic areas, but exceptions could be made in low-traffic-volume areas.

2.12.2 Jointed Concrete Pavements

In the 1920's and up until the 1940's, many concrete pavements constructed in Texas by TxDOT had a thickness of 15.24 cm (6 inches) or 22.86 cm (9 inches), and the pavement slab was placed directly on the subgrade. Some of these early pavements are still in use, either as the riding surface or as composite pavements, where they are a part of the pavement structure after a number of overlays have been applied.

During the Interstate construction program it was normal to build a 25.4-cm-thick (10-inch-thick slab) with joints 4.57 meters (15 feet) apart. Most of these pavements were constructed in the cities of Houston, Dallas, and Fort Worth. The joints were constructed using wrinkled tin load transfer devices, which did not work successfully. As a result, the overall performance was bad, and the joints tended to spall and break up very seriously.

Another approach used slabs 25.4 cm (10 inches) thick with joints 9.14 meters (30 feet) to 18.29 meters (60 feet) apart and dowels for load transfer. This approach is still being used today, especially in District 12 (Houston). Cracks form within the slab, and are sometimes controlled by control joints, which force them to occur at that location; the cracks are then restricted in opening by the use of internal transverse steel.

AC overlays of such pavements have not been successful because of the formation of reflection cracks at the joints. A number of techniques have been used in an attempt to overcome this problem, such as fabric joint underseals. No method has provided a consistent level of service, so many districts have discontinued the use of AC overlays of jointed pavements as it is not cost-effective.

2.12.3 Predominant Rigid Pavement Types by Districts

The predominant rigid pavement types used in each district after 1983 are listed in Table 2.4. The records for key bid items were obtained for the ten-year period from the Division of Highway Design, Programming and Scheduling, instead of going to individual districts to get this information. From the tables provided, the information was selected and tabulated (Wimsatt).

Table 2.4 *Predominant Rigid Pavement Types in TxDOT Districts*

District #	Headquarters	Pavement Types
1	Paris	CPCD, CRCP
2	Fort Worth	CRCP, JRCP
3	Wichita Falls	CRCP, CPCD
4	Amarillo	CRCP
5	Lubbock	CRCP, CPCD
10	Tyler	CPCD, CRCP
11	Lufkin	JRCP
12	Houston	CRCP, JRCP
13	Yoakum	CRCP, JRCP
14	Austin	CRCP, JRCP
15	San Antonio	CRCP, JRCP
16	Corpus Christi	CRCP
18	Dallas	CRCP, CPCD, JRCP
19	Atlanta	CPCD [N.D.], CRCP
20	Beaumont	JRCP, CPSJ, CPCD
24	El Paso	CRCP
25	Childress	CPCD [N.D.]

Legend

CPCD	Concrete Pavements Contraction Joint
CRCP	Continuously Reinforced Concrete Pavements
JRCP	Jointed Reinforced Concrete Pavements
CPSJ	Concrete Pavement Skewed Jointed
[N.D.]	No Dowels

2.13 Summary

This chapter deals with the task of developing a new, improved factorial experiment design for a long-term pavement performance database to study the performance of rigid pavements in Texas. This was accomplished by taking into account previous efforts towards this goal in Texas, learning from the same and conforming to national standards.

Once the experiment design was agreed upon, a survey was conducted to determine the predominant rigid pavement types in each of the TxDOT districts. The test sections were selected based upon the sampling template or the factorial experiment design. The existing CTR rigid pavement database was used to the extent possible, and existing LTPP test sections in Texas were made a part of the database. This was done to have some reliable historical data readily available as soon as the database is created.

All this effort resulted in the creation of a list of test sections, which were selected by taking into account Texas long-term pavement performance needs, with a view toward facilitating better pavement management in Texas.

Maintaining and monitoring these test sections will require a major effort. But before monitoring the test sections, it is necessary to decide what data are required to practice better pavement management. The following chapter is devoted to determining the factors which affect the performance of rigid pavements so that those factors can be monitored and recorded in the database, in order to facilitate better management of pavements and safeguard this large investment.

CHAPTER 3

MAIN FACTORS AND VARIABLES FOR THE DATABASE

The manner in which a pavement performs in the field depends largely on the design concepts that were used, the construction quality, and maintenance and rehabilitation activities carried out after construction to assure a continuous level of performance comparable to that when the pavement was new.

The coordinated approach of combining all the activities related with planning, design, construction, maintenance and evaluation, and research of pavements is termed a Pavement Management System (PMS). Figure 3.1 shows a flow chart of major activities in a PMS and how they relate to each other (Haas & Hudson 82, Haas & Hudson 93).

The importance of acquiring data in a centrally coordinated manner, from all the PMS activities, is highlighted by identifying the data bank. The data bank serves as an information base for future research and serves to check the effectiveness of the actions taken in the past (Haas & Hudson 82, Haas & Hudson 93).

3.1 Purpose of a Pavement Management Database

The success of a pavement management system depends largely on the quality and the type of information and supporting technology available. The primary purpose of a pavement management database is to provide basic information for the evaluation of existing design methods and the development of pavement rehabilitation and maintenance design procedures (SHRP 88).

A properly designed database should provide the user with processed data and information. Most importantly, the database should be able to support the development of the desired mathematical equations or models to explain the relationship between significant independent variables and the occurrence of deterioration and distress in the pavements.

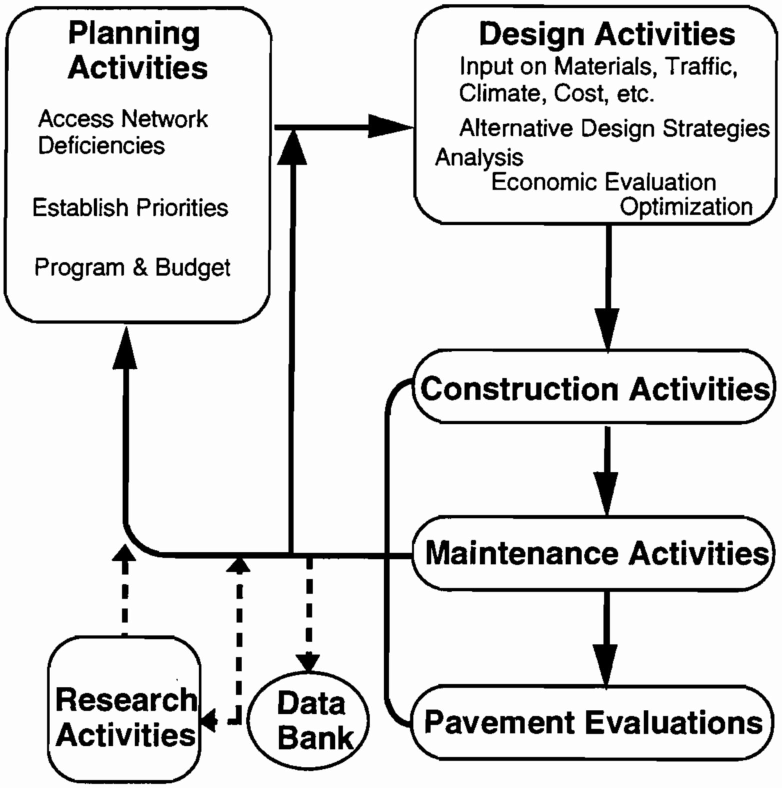


Figure 3.1 *Major Classes of Activities in a Pavement Management System (after Haas & Hudson)*

3.2 Pavement Management Database Characteristics

A pavement management database should have certain characteristics in order to support the development of mathematical models and to explain the occurrence of distress and deterioration in the pavement network. These characteristics are discussed briefly in the following paragraphs:

a) The Pavement Management Database (PMDB) must include data for all variables required for the prediction of distress or performance. These variables should also be able to predict the maintenance and rehabilitation requirements and the cost for these maintenance and rehabilitation activities.

b) It must have an adequate representation of pavement samples or test sections from each of the geographic and climatic regions in the network. An effort should be made to have a pavement sample from each of the various traffic levels and highway functional classifications. Various pavement types should be represented, and the pavements' age since construction should be a major component of the PMDB.

c) The PMDB must have reliable data, which can be ensured by employing various data quality control checks. Reliability of the data collected should be a major characteristic of the PMDB, and the uniformity of the data must be ensured for all the regions of the PMS or, in the case of a state Department of Transportation (DOT), for each district across the state.

d) Sufficient data should be collected so that statistical analyses of the data can produce relationships that are dependable with a high degree of confidence (SHRP 88).

3.3 Variable Determination

Once a database has been set up, incurring some major initial investment, it has to be maintained and updated on a regular basis. This effort requires considerable financial as well as human resources. Also, the hardware (computers) and the software (computer programs) required to set up the PMDB and operate it require continuous upkeep and maintenance in order to function properly.

Because of these constraints, the PMDB should not contain any extraneous variables. Conversely, the database should not omit any required variables. In fact, a very delicate balance exists between what variables should be included in the database and which ones should be excluded from it.

For the purpose of setting up a long-term database for Texas needs, it is necessary that all required variables be made a part of the database. To determine these required variables, both empirical and theoretical models are analyzed in the following sections. AASHTO design equations and mechanistic models (representing the two methods, respectively) are evaluated to determine the significant variables which affect the performance of the pavements.

Before one can proceed with the evaluation of the two methods described above, the difference between them should be fully understood. Statistical analyses are employed to develop empirical models and usually involve fitting an equation to field data. These models are limited by the range between the maximum and minimum value of the variables employed (CTR 88). On the other hand, existing mechanical principles and variables are used to determine a pavement response in theoretical or mechanistic models, and are limited by the usefulness of the hypothesis used in the derivation and its applicability to the real world.

3.3.1 AASHTO Equations

The AASHTO design equations are based primarily on the AASHO Road Test. In 1972, the AASHTO design committee revised the AASHO Interim Guide for the Design of Rigid and Flexible Pavements (1962) and issued the AASHTO Interim Guide for Design of Pavement Structures in 1972. Several modifications, based upon later research, were made in 1986. These modifications incorporate the concepts of reliability and climatic factors and such design and construction innovations as tied shoulders, subbase erosion, etc. (AASHTO 81 & AASHTO 86).

When the change in pavement serviceability is described by the number of equivalent 18-kip single axle load applications, then this change is a function of various design, climatic, and construction characteristics (AASHTO 86) as expressed in Equation 3.1.

$$W_{18} = f\left[\Delta\,\mathrm{PSI},\ S_c^{'},\ E_c,\ C_d,\ J,\ k,\ Z_R,\ S_o,\ D\right] \qquad (3.1)$$

Based on the above characteristics, the final AASHTO design equation for rigid pavements is given in Equation 3.2. However, it must be noted that the following is an empirical equation based on the AASHO Road Test. The empirical data were modified by using mechanistic models, and the equation is a best fit to the Road Test data.

$$\log W_{18} = Z_R * S_o + 7.35 \log(D + 1) - 0.06$$

$$+ \frac{\log\left(\frac{\Delta\,\mathrm{PSI}}{4.5 - 1.5}\right)}{1 + \left(\frac{1.624 \times 10^7}{(D + 1)^{8.46}}\right)}$$

$$+ (4.22 - 0.32P_t)\log\left[\left(\frac{S_c^{'} \times C_d}{215.63 \times J}\right)\left(\frac{D^{0.75} - 1.132}{D^{0.75} - \frac{18.42}{\left(\frac{E_c}{k}\right)^{0.25}}}\right)\right] \qquad (3.2)$$

where

Δ PSI = difference between the initial design serviceability, (P_i), and the final design serviceability, (P_t), (P_i - P_t). ,

S_c' = modulus of rupture of PCC (psi),

E_c = modulus of elasticity of PCC (psi),

C_d = coefficient of drainage,

J = coefficient of load transfer across joints,

k = modulus of subgrade reaction (psi),

Z_R = standard normal deviation,

S_o = combined standard error for traffic and performance prediction, and

D = thickness of the PCC slab (inches).

The above variables have a significant effect on pavement performance and are good candidates for performance estimation of pavements (AASHTO 86 & CTR 88). A list of candidate variables for inclusion in the TxDOT LTPP rigid database is given in Table 3.1.

Table 3.1 *List of Candidate Variables from AASHTO 1986 Design Guide*

Variable Type	Variable
Climatic	Temperature
	Moisture
Design	Coarse Agg. Type
	Soil Type
	Subbase Type
	Slab Thickness
	Traffic (18-kip ESAL)
Performance	Roughness
	Cracks
	Patches
	Traffic (18-kip ESAL)

3.3.2 Theoretical Models

A number of theoretical or mechanistic models are available for performance prediction of rigid pavements. NCHRP Report 1-15 and CTR Research Reports 177-9 and 472-6 (CTR 75, CTR 77, & CTR 89) discuss these models in great detail. These models are based upon pavement behavior and how pavements respond to internal and external stresses. The shrinkage of concrete during curing and changes in temperature give rise to internal stresses. External load applications, such as wheel loads and the friction between the subgrade or the supporting material and the PCC slab, give rise to external stresses.

Temperature variations and concrete shrinkage produce volume changes; if a concrete structure is free to have volume changes in all directions, then a uniform volume change should not result in cracking, although this is rarely the case. The PCC slab is restrained against volume changes both internally and externally.

Internally, the concrete structure is restrained by the presence of steel and the concrete itself. Internal restraint is dependent upon the type and quantity of steel, and upon its modulus of elasticity, coefficient of thermal expansion, bar diameter, and yield strength. The thickness of the PCC slab and its strength, modulus of elasticity, coefficient of thermal expansion, and creep also have an effect on the internal stresses. External restraints are due mainly to the frictional force between the PCC slab and the supporting structure, the frictional force arising due to the bond with the adjacent lane, and the distance from the edge of the pavement.

All of these restraints give rise to tensile forces. Since concrete is not strong in tension, transverse cracks form to relieve the tensile stresses. The PCC crack pattern is established as more transverse cracks form with time, due to temperature drop and shrinkage. The initial cracking is a function of internal restraints, while external restraints and applied wheel loads lead to subsequent fatigue-related cracking.

It can be safely concluded that the cracking and both steel and concrete stresses are functions of various design, material and climatic variables and of wheel load, as outlined in CTR Research Report 472-6 (CTR 89). The relationship is shown in Equation 3.3.

$$(\overline{X}, \Delta X, s_s, s_c) = f [E_c, E_s, S_c', \alpha_c\ \alpha_s, \Delta T, \Delta M, F, D_{slab}, W_{18}] \qquad (3.3)$$

where

$\overline{X}$ = mean crack spacing,

ΔX = crack width,

s_s = steel stress,

s_c = concrete stress,

E_c = modulus of elasticity of concrete,

E_s = modulus of elasticity of steel,

S_c' = modulus of rupture of concrete,

α_c = coefficient of thermal expansion of concrete,

α_s = coefficient of thermal expansion of steel,

ΔT = temperature drop, the difference between concrete placement temperature and the lowest temperature,

ΔM = moisture change,

F = coefficient of friction between the PCC slab and the supporting structure,

D_{slab} = slab thickness, and

W_{18} = 18-kip ESAL applications.

Modulus of elasticity of concrete (E_c), modulus of rupture of concrete (S_c'), and the coefficient of thermal expansion of concrete (α_c) are a function of the coarse aggregate type, the water cement ratio, and the cement content. On the other hand, the friction between the PCC slab and the supporting structure is a function of the subbase type. Considering all these factors, the list of candidate variables for inclusion in the TxDOT LTPP rigid pavement database is given in Table 3.2.

Finally, with regard to the performance of rigid pavements in Texas, the original objective of providing good performance with low maintenance cost over the service life is achieved in most of the cases. This leads to a higher level of service, because traffic interruptions due to maintenance and rehabilitation are reduced to a minimum. However, it must be noted that when a pavement becomes old, the factors which affect the performance become more and more evident.

Table 3.2 *List of Candidate Variables from Mechanistic Models*

Variable Type	Variable
Climatic	Temperature Drop
	Moisture Change
Design	Coarse Agg. Type
	Subbase Type
	Slab Thickness
	Traffic (18-kip ESAL)
	Steel Elastic Modulus
	Conc. Elastic Modulus
	Coef. of Load Transfer
Performance	Crack Width
	Crack Spacing
	Traffic (18-kip ESAL)

3.4 Data Items to Be Included in the Database

The data needs for a comprehensive database have been described in detail in the preceding discussion. All the data items have been listed which are believed to have statistical significance for the development of mathematical distress models. These data items can be reduced at a later date to collect data for only those factors which exhibit statistical importance in later analyses.

Looking closely at the candidate data item tables provided previously, one can easily infer that the data items belong to two broad categories. The first is the Inventory data items, and the second is Monitoring data items.

Inventory data include those data items which remain the same during the whole monitoring period. There is only a very slight probability that the inventory data will change during the life of the pavement. Monitoring data consist of those variables which change with time, require periodic evaluation and measurements during the monitoring period, and require constant updating to keep the database current (SHRP 88).

The inventory data include information required for the proper identification of the test section, construction material properties, geometric details, environmental conditions, previous accumulated traffic data since construction, construction dates, costs, and the accumulated costs involved with maintenance and rehabilitation. All these data remains constant, as already stated. But suppose that a rigid pavement is overlaid, as often is the case near the end of service life. The pavement type then changes to composite pavement, so the inventory data need to be updated to consider these changes (SHRP 88). Table 3.3 gives a list of inventory data required for the database.

Table 3.3 *Inventory Data Items to Be Collected*

Data Type	Data Items to Be Collected
Identification	Functional Class of Highway
	Number Designation, Direction
	Pavement Type
	Rural / Urban
	Test Section Location, No. of Lanes
	Construction Date
Geometric Details	No. and Width of Lanes
	Shoulder Presence, Type and Widths
	Drainage Effectiveness
	Joint Spacing
	Dowel Presence, Diameter, Spacing
	Severity and Extent of Existing Distress

Table 3.3 (Continued) *Inventory Data Items to Be Collected*

Data Type	Data Items to Be Collected
Climatic	General Type (Dry Freeze, etc.) Annual, Monthly Rainfall Highest, Lowest Mean Monthly Temperatures Freeze-Thaw Cycles per Year Freeze Index and Thornthwaite Index
Accumulated Traffic	Total and Mean AADT for previous years 18-kip ESAL, % Trucks No., Distribution of Tandem Axles No., Distribution of Single Axles No., Distribution of Triple Axles
Material Properties	Layer Thicknesses Subgrade Soil Type, Classification (especially swelling or not) Subbase Soil Type, Classification Stabilization Presence, Type PCC Moduli of Rupture & Elasticity PCC Steel Content, Steel Modulus of Elasticity, PCC Coarse Aggregate Type
Accumulated Costs	Initial Construction Cost Maintenance & Rehabilitation Type, Date Performed and Costs

Information concerning distress, serviceability, and deflection measurements is an integral part of the monitoring data, which also include traffic and axle load data. Maintenance and rehabilitation costs incurred during the monitoring period are included as well. Data are collected on an annual basis most of the time but may also be based on some other reasonable time period. This leads to the creation of a historical database required to study the relationship between distress, performance, age of the pavement, traffic and axle loading, and maintenance and rehabilitation costs in a number of ways. Table 3.4 gives a list of monitoring data required for the database.

Table 3.4 *Monitoring Data Items to Be Collected*

Data Type	Data Items to Be Collected
Distress, Performance	Transverse, Longitudinal and Slab Cracking, D-Cracking
	Joint Faulting, Pumping
	Roughness, Patches, Skid Resistance
	Joint, Crack Deterioration
	Lane - Shoulder Separation
Traffic	AADT, Percentage Trucks
	18-kip ESAL for the Time Period
	No., Distribution of Tandem Axles
	No., Distribution of Single Axles
	No., Distribution of Triple Axles
FWD / Deflection Tests	Mean Max. Deflection Under Load
	Deflection Observations, Basin,
	Loading
	Pavement Temperature

3.5 Conclusion

This chapter deals mainly with the type of data items required for inclusion into the database. The required data items were identified and divided into two broad general classes as being Inventory and Monitoring data items.

It is stressed that a great amount of data required both for research and pavement management, at both the network level and the project level, has been identified. It is quite possible that these data items may not be adequate for purposes other than those listed above. In that case the information can easily be modified to serve a specific need.

Now that the data items required for database have been identified, the cost associated with collecting all these data is a major issue due to the commitment and involvement of a considerable amount of both financial and human resources. The following chapter deals with the issue of determining the cost of data collection for the database.

CHAPTER 4

TEST SECTION IDENTIFICATION AND SECTION MONITORING COSTS

The previous three chapters of this document were devoted to clarifying the objectives, setting up an experiment design, selecting parameter test sections, and determining the type of data which should be collected for the database. Once all this has been done, the test sections must be physically located on the ground so that the data collection personnel can start the collection process immediately.

This chapter will address this process and the cost associated with the data collection efforts. Data collection costs can impose a financial burden on the research budget if not handled properly. Because of the financial constraints, priorities should be set to collect required data first and optional data later. Care should be taken not to collect any unnecessary data.

4.1 Test Section Identification

The identification and location of the test sections physically on the ground remains a problem. The test sections are identified in the CTR database by their Center For Transportation Research (CFTR) number and information identifying the start and the end of the test section. The CFTR number is comprised of five digits. The first two identify the TxDOT district in which the test section is located, and the remaining three identify the test section in that district.

The test sections are identified, on the ground, by a strip of white paint along with the CFTR number at the start of the test section, and ending after a thousand feet in the direction of travel. This strip of white paint has the tendency to fade over time as a result of the climatic conditions. Also, vehicles and overlays can eradicate the paint.

This observation highlighted the need for a more permanent form of test section identification. Since one of the purposes of this study is to modify and incorporate LTPP recommendations for Texas needs, the proposed new field section identification is based on LTPP specifications.

LTPP uses a 60.96-by-91.44-cm (24-by-36-inch) reflectorized sign, facing the traffic, 152.4 meters (500 feet) in advance of the test section. Another sign measuring 30.48 by 38.10 cm (12 by 15 inches), installed parallel to the traffic flow, is placed exactly at the beginning of the test section as shown in Figure 4.1. The first sign shows the SHRP logo, "Road Test," and the section ID number. The second sign, placed exactly at the beginning of the test section, parallel to the traffic flow, shows the SHRP section ID number.

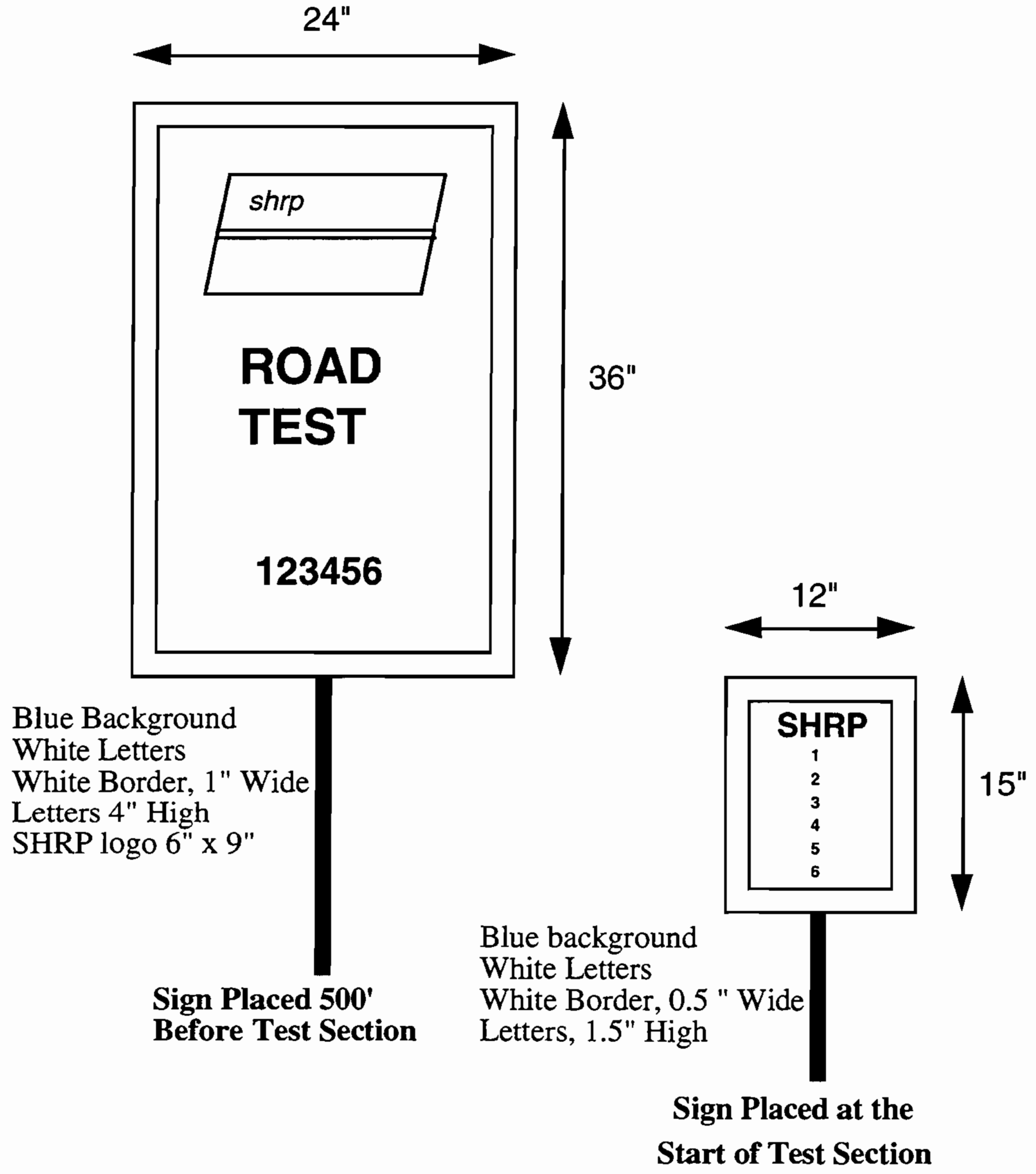
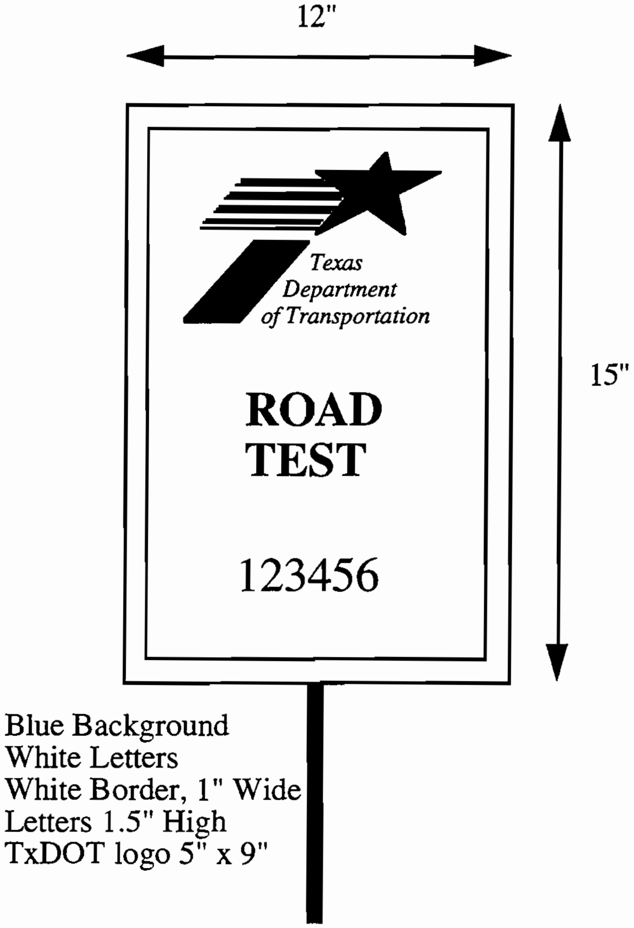


Figure 4.1 *LTPP Test Section Sign Details (SHRP 88b)*

4.1.1 Proposed Test Section Identification Sign

For the purpose of the TxDOT LTPP database, it is proposed to install one sign measuring 30.48 by 38.10 cm (12 by 15 inches) displaying the TxDOT logo and the section ID number exactly at the beginning of the test section facing the traffic, as shown in Figure 4.2.



Blue Background
White Letters
White Border, 1" Wide
Letters 1.5" High
TxDOT logo 5" x 9"

Sign Placed at the Beginning of the Test Section

Figure 4.2 *Proposed TxDOT Section ID Sign Details*

4.1.2 Marking Test Section Location and Details

It is recommended that the test sections be identified by two strips of white paint not less than 15.24 cm (6 inches) wide at the beginning of the test section adjacent to the sign and separated by a 7.62-cm (3-inch gap). Furthermore, the test section identification numbers should be painted on the pavement at the beginning of the test section near the outside shoulder, as shown in Figure 4.3.

Test sections should be divided into 30.48-meter (100-foot) subsections, marked by painting crosses, and numbered consecutively from 0 to 10, with 0 at the beginning of the test section and 10 at the end of the test section, as shown in Figure 4.3.

It is still possible to lose the sign and wear out the paint, so the start of the test section and the end should also be marked using monuments, spikes, or rebars installed in the shoulder, as shown in Figure 4.3. It takes a crew of two persons two hours to put the paint details on the test section and about one hour for a crew of two persons to maintain these details.

4.1.3 Section Identification Costs

To manufacture the proposed sign, the cost is approximately $6.00 for a sign measuring 30.48 by 38.10 cm (12 by 15 inches). To put on the white reflectorized paint the cost is usually $5.00. The lettering costs $1.50 per linear foot. Furthermore, it usually takes two persons half an hour to place the sign in the ground.

So, for test section identification purposes, the total cost is approximately $18.00, along with one man-hour for sign placement in the ground.

4.2 Section Monitoring Costs

As already identified in Chapter 3, the data items to be collected for the database are divided into two categories: (1) inventory data and (2) monitoring data.

Inventory data include such data as define the section and have a low probability of changing during the monitoring period of the test section. Inventory data items were grouped into six sub-categories, which dealt with test section identification, geometric details, environmental data, accumulated traffic, layer / material properties, and accumulated costs.

Monitoring data will include data items which change with time and require regular monitoring. Monitoring data to be collected relate to the distress and the performance of the pavement. These data also include traffic data and deflection measurements to evaluate behavior.

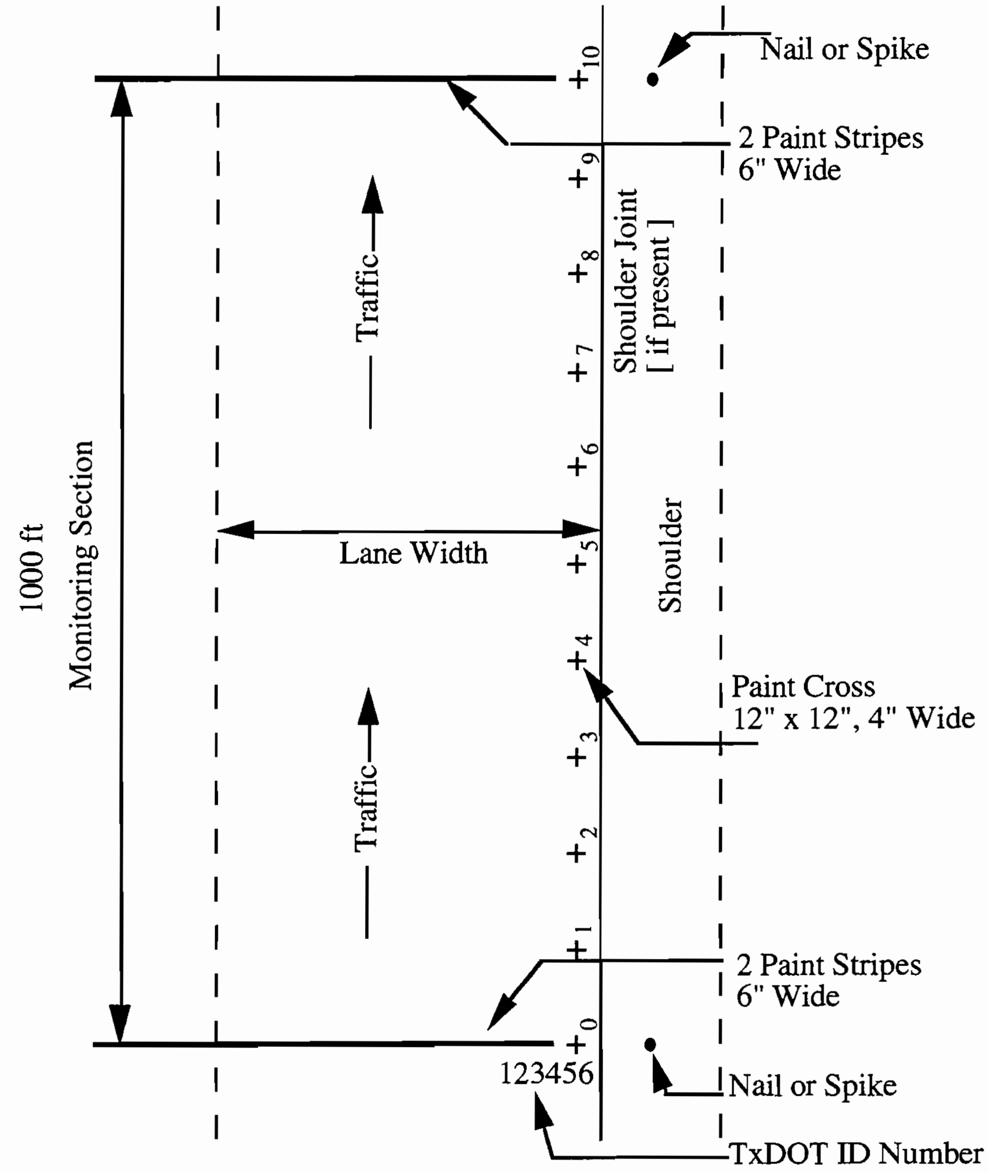


Figure 4.3 *Monitoring Site Paint Configuration Details*

TxDOT maintains a comprehensive set of project construction plans. Almost all the inventory data requirements can be met from these records, requiring little or no effort on part of the TxDOT personnel. Climatic data can be obtained from the Texas Department of Water Resources. Accumulated traffic data can be obtained from traffic reports published annually by TxDOT. The project completion data can be obtained from Project Identification Information Reports maintained by TxDOT. The information sources are summarized in Table 4.1 (CTR 88).

Table 4.1 *Inventory Data Sources*

Inventory Data Sub-Category	Sources
Identification	TxDOT Project Construction Plans
Geometric Details	TxDOT Project Construction Plans
Climatic	Texas Land Resources Weather and Climatic Section, Texas Department of Water Resources
Accumulated Traffic	Annual Traffic Reports, Tables 1 and 4, TxDOT
Material / Layer Properties	TxDOT Project Construction Plans Material Testing Reports, Folder # 5, Project Correspondence
Accumulated Costs	Design Division, Programming and Scheduling TxDOT

4.3 Monitoring Data Collection Costs

One of the major objectives of this study is to define costs associated with monitoring data collection, because both financial and personnel resources must be committed to collect the data.

The distress / performance data collection requires a visual distress survey. Deflection tests require testing with a falling weight deflectometer (FWD) or similar instrument. Traffic data are also to be collected on a regular basis. Traffic control is required when visual distress surveys and FWD tests are being conducted, and this adds to the cost.

An extensive literature search produced no literature or information on the time required to conduct visual surveys and FWD testing. Therefore a study was conducted to determine the time required to do the various monitoring tasks.

4.3.1 Case Study

This case study was conducted with the cooperation of CTR Research Study 1342. That study is involved with updating the visual distress and deflection data for the test sections which make up the CTR rigid pavement database.

At the time of writing, data collection had just been completed on the 29 test sections being maintained in District 13 of TxDOT by CTR. These included continuously reinforced pavements and jointed pavements.

The data collection team was requested to keep track of the time required to conduct its activities. On the data collection sheet, members were required to note the times when they started each of the three procedures and when each was finished. These values were averaged to find the mean.

Figures 4.4 through 4.6 show the average time required to conduct various activities. Table 4.2 shows the total man-hours required to conduct a visual distress survey and FWD testing after setting up the traffic control.

Figures 4.5 and 4.6 show the average time required to conduct a visual distress survey and FWD testing, independent of each other.

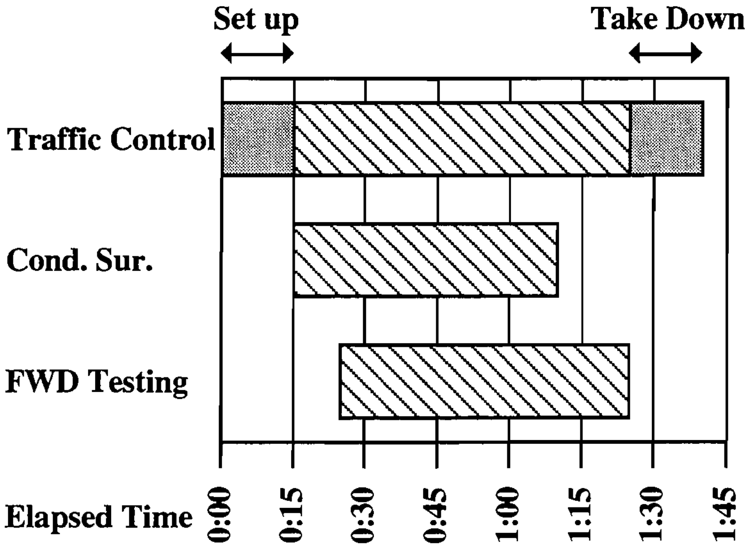


Figure 4.4 *Average Time Required to Conduct Visual Survey and FWD Testing*

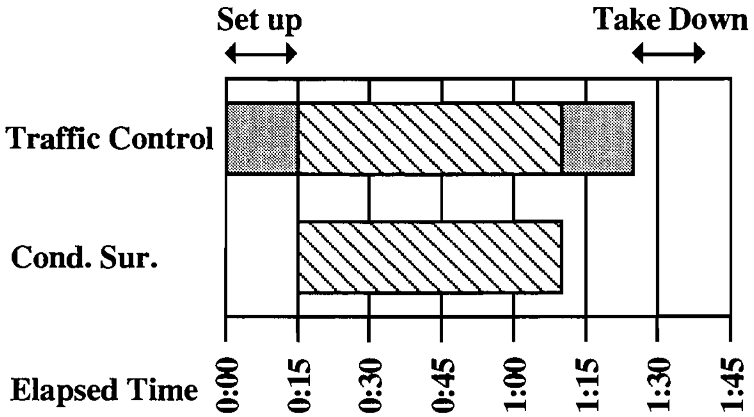


Figure 4.5 *Average Time Required to Conduct Visual Distress Survey Only*

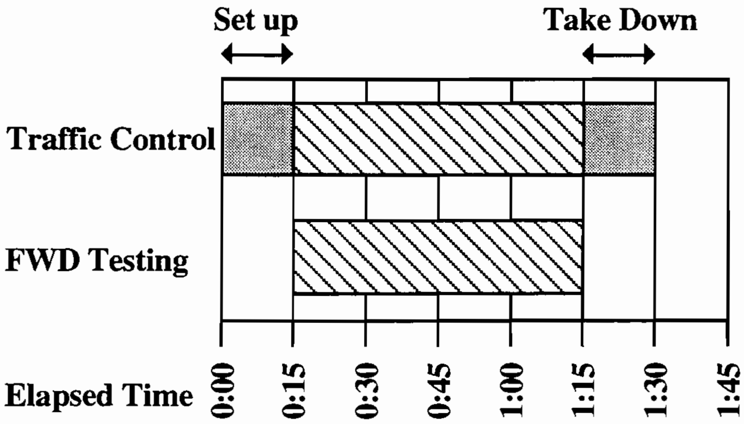


Figure 4.6 *Average Time Required to Conduct FWD Testing Only*

Table 4.2 *Man-Hours Required to Conduct Visual Distress Survey and FWD Testing*

Activity	Time Required	Persons Required
Traffic Control	0:30	3
Condition Survey	0:55	2
FWD Testing	1:00	2
Total	2:25	7
Total Cost	**2:25 x 7 =**	**16.92 man-hours**
		17.00 man-hours

Table 4.3 shows the man-hours required to carry out the visual distress survey only. Table 4.4 shows the man-hours required to conduct FWD testing only.

Table 4.3 *Man-Hours Required to Conduct Visual Distress Survey Only*

Activity	Time Required	Persons Required
Traffic Control	0:30	3
Condition Survey	0:55	2
Total	1:25	5
Total Cost	**1:25 x 5 =**	**7.08 man-hours** **7.00 man-hours**

Table 4.4 *Man-Hours Required to Conduct FWD Testing Only*

Activity	Time Required	Persons Required
Traffic Control	0:30	3
FWD Testing	1:00	2
Total	1:30	5
Total Cost	**1:30 x 5 =**	**7.50 man-hours**

4.4 Field Materials Sampling Locations and Sampling Costs

A comprehensive plan is followed by LTPP to obtain field material samples. Coring and augering are conducted at the test site to collect field material samples (SHRP 90b).

LTPP uses a total of 16 cores made at the beginning and end of each test section. The number of cores, their sizes, and their locations, with respect to the test sections, are given in Table 4.5. Figure 4.7 shows the same information graphically. Figure 4.8 shows the number of cores, their sizes, and their locations for the Texas LTPP.

Table 4.5 *Typical Core Sizes and Locations (SHRP 90 b)*

Location	Core Size	Total Number
00 - 65	4"	2
	6"	1
00 - 60	4"	2
	6"	1
00 - 55	6"	1
00 - 50	12"	1
00 - 45	12"	1
00 - 40	12"	1
	6"	1
05 + 40	6"	1
05 + 45	4"	2
	6"	1
05 + 50	4"	2
	6"	1

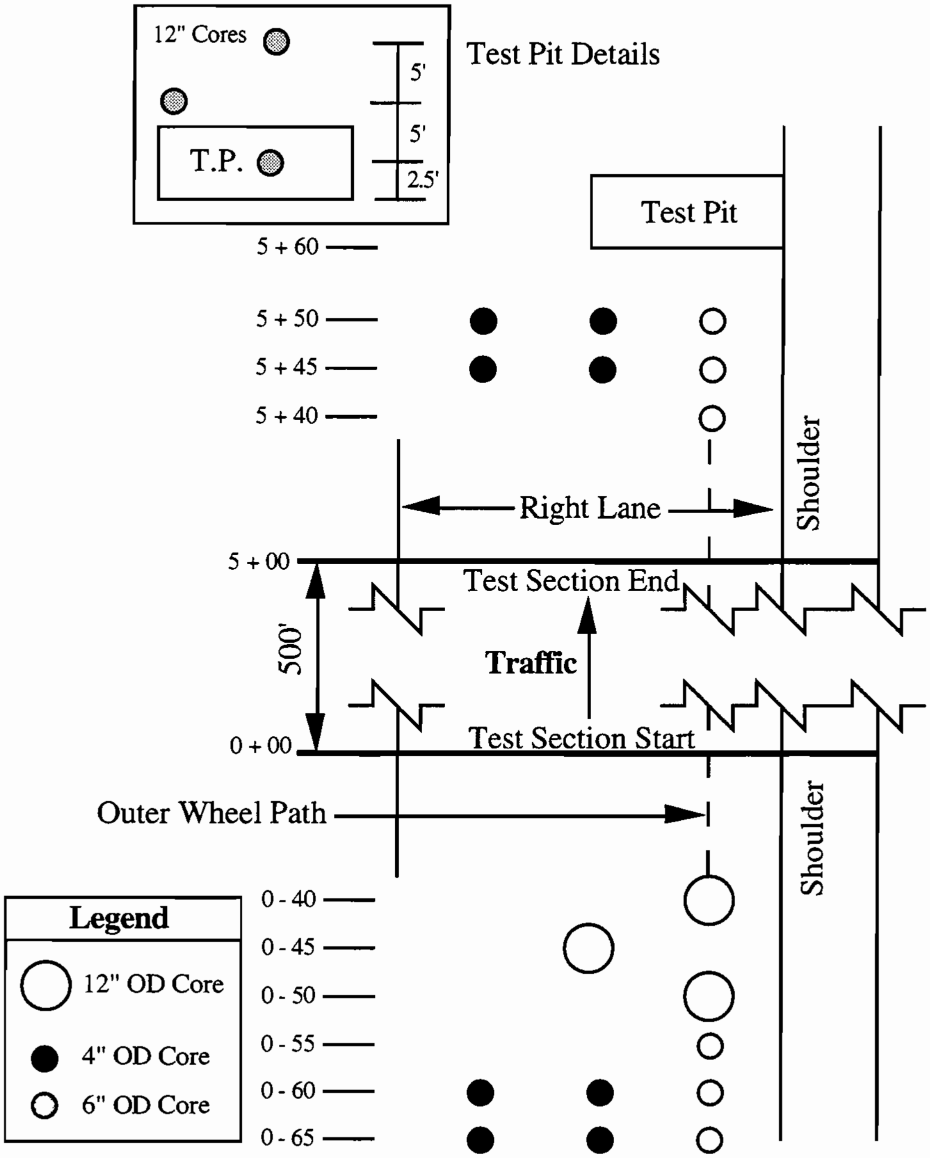


Figure 4.7 *Typical Sampling Point Locations (SHRP 90b)*

Also, a test pit, measuring 1.83 meters by 1.22 meters (6 feet by 4 feet) and 30.48 cm (12 inches deep), is excavated, and three auger holes are made, one inside and the two outside the excavated test pit, as shown in the previous figure. These three 30.48-cm (12-inch) auger holes are to retrieve bulk and moisture samples of unbound granular base, subbase, and untreated subbase (SHRP 90b).

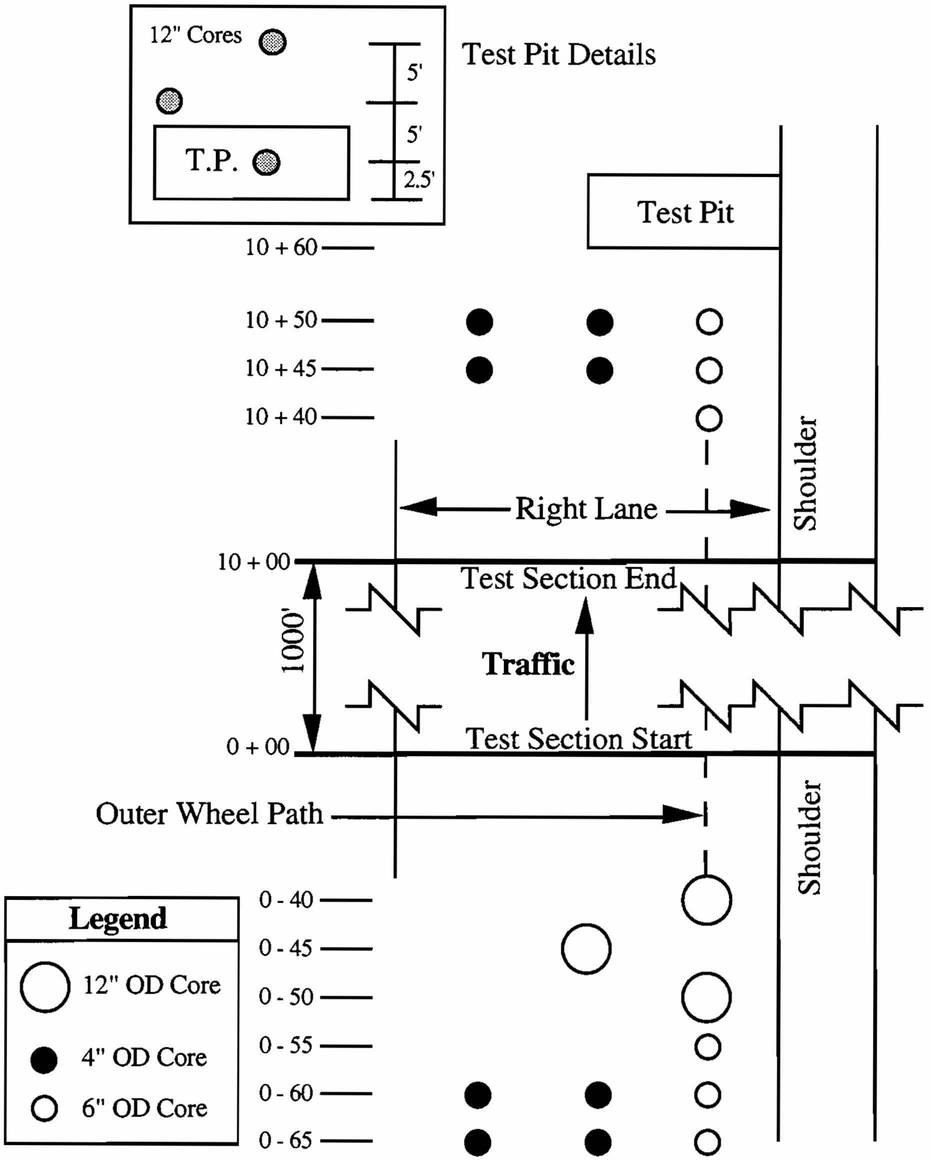


Figure 4.8 *Recommended Sampling Point Locations for Texas LTPP*

The time required to extract a PCC core depended on the diameter of the core and the thickness of the PCC slab. A core 10.16 cm (4 inches in diameter) and 20.32 cm (8 inches) in depth required, on the average, 45 minutes. This time increased to an hour if the PCC slab thickness was 13 inches.

Similarly, a 15.24-cm-diameter (6-inch-diameter) core required an hour to be extracted when the PCC thickness was 20.32 cm (8 inches). This time increased by half an hour when the PCC slab thickness increased to 33.02 cm (13 inches).

Irrespective of the thickness of the PCC slab, the coring time for a 30.48-cm-diameter (12-inch-diameter) core ranged between 1-3/4 hours and 2 hours.

Augering of the subbase and subgrade up to a depth of 30.48 cm (12 inches) required 30 to 40 minutes each with two persons working together. For a depth of 1.22 meters (4 feet), the time increased to 1-1/2 hours with two persons. The test pit, measuring 1.22 by 1.83 meters (4 by 6 feet) and 30.48 cm deep (12 inches deep), required 20 minutes for excavation. A backhoe with one operator was used to excavate the test pit.

Table 4.6 summarizes the times required to obtain the samples by each method. These times do not include the travel time to and from the test section, nor the time needed to locate the test section in the field.

Table 4.6 *Time and Persons Required to Perform Listed Activities*

Activity	**Time** [hr.]	**Persons**
I. Coring		
4" Dia., 8" / 13" Thick	0.75 / 1.00	1
6" Dia., 8" / 13" Thick	1.00 / 1.50	1
12" Dia, 8" / 13" Thick	2.00 / 2.00	1
II. Augering		
12" Deep	0.75	2
48" Deep	1.50	2
III. Test Pit Excavation*		
4' x 6' x 12"	0.33	1

*Backhoe used

Figure 4.9 shows the material sampling operation setup. The time, in man-hours, required to complete all the coring and augering on a single test section is calculated in Table 4.7.

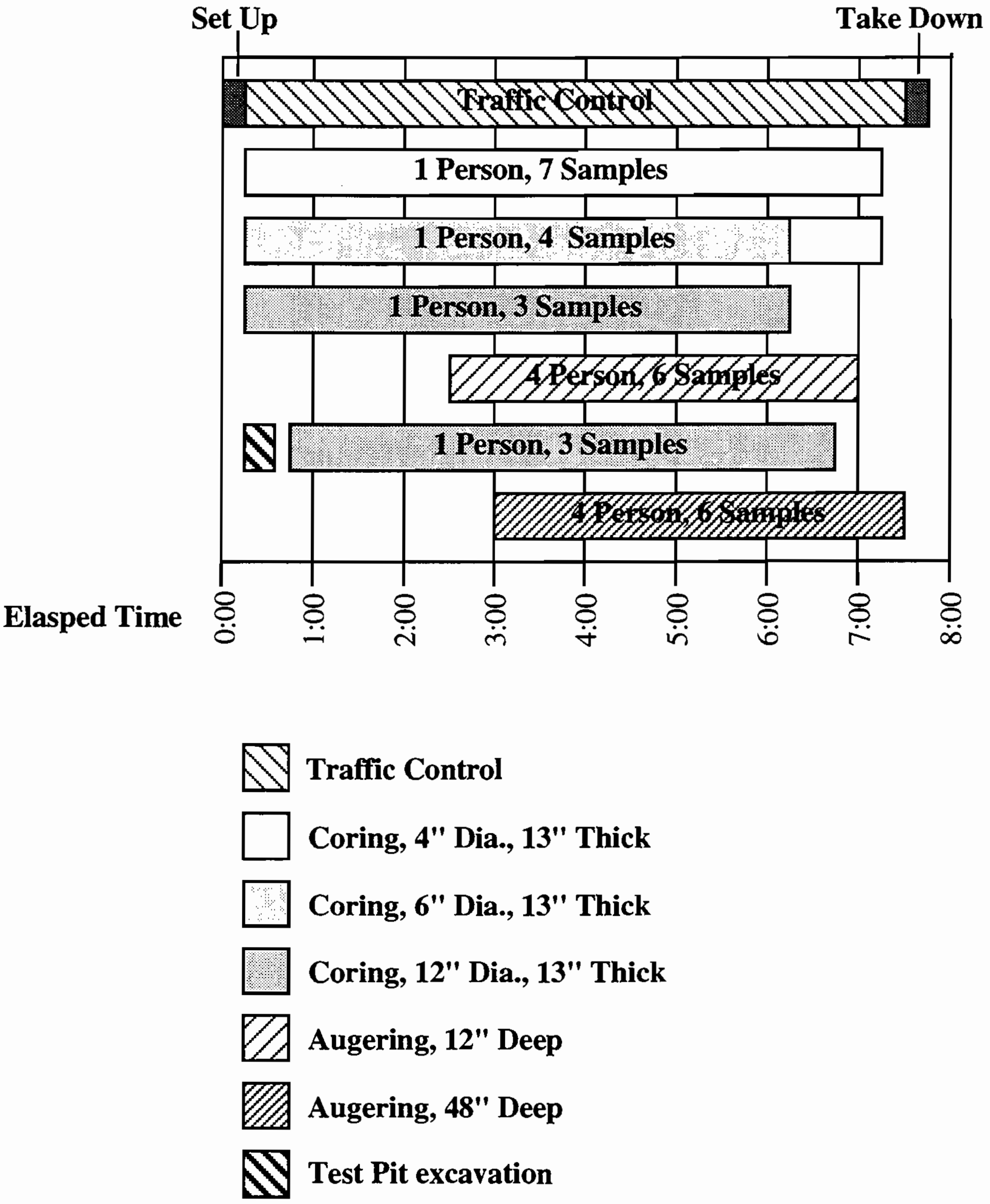


Figure 4.9 *Time and Persons Required to Obtain Field Material Samples*

Table 4.7 *Man-Hours Required to Conduct Materials Sampling*

Activity		Time Required	Persons Required
Traffic Control		8:00	3
Coring		8:00	4
Augering		8:00	8
	Total	8:00	15
	Total Cost	8:00 x 15 =	**120 man-hours**

4.5 Traffic Data Collection Costs

Traffic data form an essential basis for planning, designing, constructing, operating and managing the highways that make up any transportation network (Lee 90). Traffic is also the weakest link in the data collection chain for pavement management and research. For the last 30 years, the main concentration has been on determining traffic volumes, capacity, and destinations.

4.5.1 Traffic Data Required for Texas LTPP Program

Pavement performance analysis requires load, truck-type, and route-specific data. For this purpose, in addition to AADT, route-specific truck loading data are required. Simply put, an accurate estimate of the ESAL to which a pavement section is subjected is required.

Vehicle classification and weight data are of considerable use to agencies involved in almost any aspect of transportation planning and engineering. Pavement design and management, as well as the scheduling of resurfacing, reconditioning, and reconstruction of highways based on projected remaining pavement life, are impossible without accurate traffic data (FHWA 92).

4.5.2 Hierarchy of Traffic Data Collection

Because there are over 20,930 kilometers (13,000 miles) of rigid pavements in Texas, collection of necessary traffic data which adequately represent all possible highway - climatic - traffic density combinations is expensive.

The methodology outlined in the Traffic Monitoring Guide (FHWA 92) describes the sampling elements which account for the most common combinations of roadway and traffic conditions.

Currently the State of Texas uses approximately 3,500 accumulating count recorder (ACR) devices, which are moved among 75,000 sites (55,000 rural and 20,000 urban). The system is composed of a pneumatic tube placed perpendicular to the traffic stream with a battery-powered counter placed adjacent to the pavement shoulder to record the axle counts.

Two ACR schedules per week, with maps and special instructions, are prepared for 30 field operators who are responsible for 35 setups, on the average, per week. The resulting traffic counts are entered manually on the Department mainframe computer. Work is now underway to automate this procedure.

Up one level are the Automatic Traffic Recorder (ATR) devices, which are located at about 150 permanent sites. This system consists of an inductive loop presence detector, imbedded in the pavement and wired to a processing station adjacent to the pavement shoulder. Traffic data can be up-loaded to the Department mainframe computer using modems via telephone connections.

Automatic Vehicle Classifier (AVC) devices, at the next level, require no manpower, and data are obtainable via the Department mainframe using modems. Vehicle classifier counts are also made manually, usually for a period of 24 hours, by a team of three persons working in 8-hour shifts.

Weigh-In-Motion (WIM) devices are the most versatile traffic data collection tools available, though they are also the most expensive. These devices can count traffic, find its composition (classify it), and weigh each axle, besides recording a number of other parameters such as speed.

Portable WIM stations require six people working in shifts of two for a data collection period which usually lasts 48 hours. Two persons per shift are used to monitor the instrumentation installed in a van. Permanent WIM sites, on the other hand, require no operators, and data can be up-loaded to the Department mainframe via modems.

The other WIM sites are the Radian sites, named after the manufacturing company. These are seasonal sites which are visited at least four times annually. After replacing dummy load cells with active ones, data are collected for four consecutive days by four persons working in 8-hour shifts.

4.5.3 Traffic Data Collection Costs

A simple cost comparison of the hardware alone required for the three basic elements of the traffic data collection system is illustrative of the incentive to use less sophisticated data collectors where possible. The basic pneumatic tube short-duration volume counter costs approximately $200 (1993). Classification devices cost ten times as much, while WIM devices cost roughly 20 to 40 times more than the classification devices.

From previous discussion, it is clear that at least an ATR and AVC are required to collect detailed traffic data for Texas LTPP program, assuming that trucks don't exceed their legal load limits. But AVC devices are permanent in nature, so a WIM site is best suited for this purpose. The cost in man-hours required to monitor traffic at a test section is calculated in Table 4.8.

Table 4.8 *Traffic Data Collection Costs*

Method	Man-hours Required
I. Portable WIM Site	6 persons X 2 - 8-hour shifts
	Total 96 man-hours
II. Radian WIM Site	3 persons X 4 - 8-hour shifts
	Total 96 man-hours
III. Permanent WIM Site	Data down-loaded by the Department mainframe automatically

4.5.4 Equipment Costs

In order to collect detailed traffic data, WIM stations would be desirable at all the test sections. TxDOT currently is planning to install at least 46 additional WIM stations along the major routes in the state. Every effort has been made to select test sections close to the planned WIM sites.

Data from these WIM sites could be supplemented by installing an AVC device at those test sections which lack a WIM setup. The total cost for an AVC, including installation, is about $3,000. Detailed weight data are provided by the WIM station for each class of vehicle. Classification data from the AVC device are then supplemented using WIM data from nearby locations to estimate the ESAL on a particular site.

Another approach, which would not require any AVC devices, would be to develop models to calculate the ESAL from AADT based on data obtained from the WIM stations. These models may prove to be less expensive to develop, while still providing adequate accuracy within reasonable limits.

4.6 Travel Time

Test sections are not located in all of the TxDOT districts primarily because not every district has rigid pavements. The size of the state of Texas makes travel time an important consideration when scheduling personnel and equipment for data collection. Travel time needs to be considered only in case of centralized data collection. If this task is decentralized, then the districts will perform surveys, and travel time will not be a major concern.

When distances for travel time were calculated, it was assumed that the travel would be done along the most direct route. The total distance calculated is the round trip distance from Austin to the district and back. Table 4.9 lists these distances.

Table 4.9 *Round-Trip Distances from Austin to TxDOT District Head Office*

District		Distance Round Trip [miles]
1	Paris	602
2	Fort Worth	384
3	Wichita Falls	568
4	Amarillo	970
5	Lubbock	754
9	Waco	212
12	Houston	324
13	Yoakum	178
15	San Antonio	160
17	Bryan	206
18	Dallas	404
19	Atlanta	636
20	Beaumont	494
24	El Paso	1,166
	Total	**7,058**

The data collection party consisting of four persons, two for visual distress survey and two for FWD testing, must travel a total of 11,363 kilometers (7,058 miles) in order to collect data. The travel times are calculated at a constant 89 kph (55 mph), although most of these are on the interstate, to compensate for the brief stops, etc. The man-hours required are calculated below.

Total Distance	7,058	miles
Total Number of Districts	14	
Average Distance	504	miles
Time Required @ 55 mph	9.2	hours
Man-Hours Required	36.8	per Dist.

As a maximum, a total of 514 man-hours must be added to the total time required to complete all the tasks for the network to take into account the time spent in traveling to and from the districts.

Sometimes it may be possible to cover a second district without first returning to the main office (Austin). Generally, this has not proved to be the case in multi-district studies, since crews will need to return home for weekends, holidays, and other duties, etc. However, when this practice is used, costs may be reduced by slightly less than 50%, since it is less expensive to travel to a neighboring district instead of all the way back to the central office.

Certain other contingency factors — such as unforeseen weather, equipment breakdown, the effect of fatigue on personnel efficiency, and the time spent on locating the test section physically in the field upon arriving in the general area — could not be predicted accurately. To take into account all these factors, the estimated total time was increased by 5%.

4.7 Summary

This chapter deals with estimating test section setup, identification, maintenance, monitoring, and traffic data collection costs. Some of these costs are one-time expenses, such as the material sampling and testing and the costs incurred to set up signs for test section identification. Other expenses will be required periodically to maintain and monitor the test sections at regular intervals as selected by TxDOT. The initial setup costs and the cyclic monitoring costs are given in Table 4.10.

Table 4.10 *Man-Hours Required for Test Section Setup and Cyclic Monitoring*

Activity	Man-Hours Required per Test Section
I. Test Section Set Up Costs	
Identification signs manufacturing cost	$ 18.00
Installation of test section identification signs	1.00
Test section paint details marking	4.00
Test section material sampling	120.00
First time monitoring	17.00
Traffic data collection	96.00
Total **$ 18.00 plus 238.00 man-hours**	
II. Test Section Cyclic Monitoring Costs	
Test section monitoring	17.00
Traffic data collection	96.00
Test section maintenance	2.00
Total **115.00 man-hours**	

The costs associated with setting up 200 test sections and monitoring them on a yearly basis are calculated in Table 4.11.

Table 4.11 *Summary of Test Section Setup Costs and Annual Section Monitoring Costs in Terms of Man-Hours Required*

Activity		Man-Hours Required per Test Section	
Man-Hours Required for Test Section Setup			
200 Test Sections X 238	=	47,600	man-hours
200 Test Sections X $ 18	=	$ 3,600	
Travel Time	=	514	man-hours
Contingency Factors (5%)	=	2,406	man-hours
Total	=	**50,520**	**man-hours plus $ 3,600**
Man-Hours Required for Test Section Monitoring per Round			
200 Test Sections X 115	=	23,000	man-hours
Travel Time	=	514	man-hours
Contingency Factors (5%)	=	1,176	man-hours
Total	=	**24,690**	**man-hours**

The next and final chapter of this document lists conclusions and recommends further study to improve and expand the Texas LTPP to include flexible pavements and overlays.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this study was to develop a realistic experiment design to set up the appropriate test sections for a long-term pavement performance monitoring program for rigid pavements in Texas. The study was developed around existing LTPP test sections in Texas. Three experiment designs were established, one each for continuously reinforced concrete pavements (CRCP), jointed plain concrete pavements (JPCP), and jointed reinforced concrete pavements (JRCP). As requested by TxDOT personnel and advisors to CTR Research Project 1342, the number of test sections was limited to 100 for CRCP and 50 each for the two jointed pavement types. Various data items to be collected were determined and were classified as either (1) inventory data or (2) monitoring data. Estimated costs of setting up the test sections and then monitoring these sections were determined in terms of man-hours required.

5.1 Conclusions

As a result of the research study to develop a LTPP program for Texas, some specific conclusions were drawn as follows:

(1) Previous experience and literature review show that pavement thickness, moisture, temperature, traffic, age, and coarse aggregate type affect the long-term pavement performance of all concrete pavements. Therefore, these factors were included in the sampling plan.

(2) Previous work under this research project determined that the existing network-level PES database was inadequate for conducting project-level evaluations or research, primarily due to a lack of information on pavement age and on structural (thickness, etc.) and climatic variables.

(3) Some of the national-level LTPP test section specifications are not applicable to the state-level Texas LTPP program, so they were modified to accommodate the geographical and climatic needs of Texas.

(4) Study shows that traffic data in the form of AADT are inadequate to develop pavement performance models (CTR 93b). Based on this finding, detailed traffic data in terms of 18-kip ESAL are an item requested for the database.

(5) The current data collection strategy used on the national LTPP sections, which requires 18 core samples to be tested, in addition to several other tests, was found to be too expensive to follow for the Texas study. Based on previous levels of TxDOT spending (Projects 472, 187 Task 7, and 1342), funding would not be available at this higher level.

(6) There will be a significant decrease in man-hours required for test section monitoring if the data collection task can be decentralized (performed at the district level). However, there may also be a corresponding increase in variability of the data. Furthermore, there will also be an increase in training costs and travel for students to the training site.

(7) Maintenance and rehabilitation data, as well as the date on which M&R was performed, are absent in both the PES and the CTR databases (other than overlay dates). This should be remedied.

(8) The 1982 and 1984 CTR JCP database does not include information about pavement structure and materials, climatic conditions, and/or traffic.

(9) A total of 61 CRCP, 75 JPCP, and 60 JRCP projects meeting the requirements of the sampling templates were identified in this study. These are documented in Appendices C and D. Most of these are 20.3-cm-thick (8-inch-thick) pavements, but work is currently underway (Research Project 1342) to include thicker sections and newer designs such as double matted steel in the CTR rigid pavement database.

5.2 Recommendations

Several recommendations for future research, along with possible revisions of the proposed experiment designs, are presented below.

(1) Accurate traffic data for vehicle classification and axle weight should be collected and included in the database as one of the factors, because total traffic, vehicle type, and axle weight have a significant effect on pavement performance.

(2) This study and several other studies have shown that pavement thickness, coarse aggregate type, subbase treatment, etc., are all important to performance prediction models. Some of these variables are specified in the current PES database, and an effort should be made to collect this vitally important information.

(3) Recommendations for reduction in the current LTPP data collection strategy to reduce data collection costs are presented herein.

(4) This research developed a suggested LTPP test plan for rigid pavements only. It is recommended that the LTPP program be expanded to include flexible pavements also.

(5) The actual time required to perform various test section maintenance and monitoring activities should be recorded in the first year of the study. This will provide a better estimate of the man-hours required to conduct each activity.

(6) The type of maintenance and rehabilitation (M&R) performed on a test section should be recorded, along with the date it was performed. This information will facilitate better M&R performance models. Current LTPP procedures can be modified and used for this purpose.

(7) The accuracy of the initial performance / distress prediction models used in PMIS should be studied and improved through implementation of the Texas LTPP program and use of the data.

(8) Empty cells which appear in the factorial experiment designs should be examined to determine whether such pavements currently exist in Texas and/or if they are likely to be constructed. Unrealistic combinations should be ignored.

(9) Pavement test sections should be selected as close as possible to existing and proposed WIM stations. The need for accurate traffic models is so important to the TxDOT PMIS and to other ongoing research that a research study should be initiated to directly address the development of the models. These mathematical models will estimate 18-kip ESAL based on AADT, and classification data should be verified using actual data from WIM sites. To supplement the traffic data from existing or proposed WIM sites, a WIM station and an AVC device should be purchased and dedicated to this use for the duration of the study.

REFERENCES

[AASHTO 81] "AASHTO Interim Guide for Design of Pavement Structure, 1972, Chapter III Revised, 1981," American Association of State Highway and Transportation Officials, Washington, D.C., 1981.

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APPENDIX A

SAS PROGRAM FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

```
/**
     ************************************************
     *                                              *
     * THIS SAS PROGRAM TAKES THE CTR CRCP DATABASE *
     * AND ADDS THE CLIMATE VARIABLE AND THE        *
     * TEMPERATURE VARIABLE CREATING A NEW DATABASE. *
     * EXPERIMENT FACTORIALS ARE ALSO FILLED USING  *
     * THIS PROGRAM.                                *
     *                                              *
     ************************************************
                                                        **/

CMS FI SDS DISK DUMMY DUMMY Q;
DATA D; SET SDS.MASTER;
CLI="DRY";
IF COUNTY = "Franklin" THEN CLI ="WET";
IF COUNTY = "Grayson" THEN CLI ="WET";
IF COUNTY = "Hopkins" THEN CLI ="WET";
IF COUNTY = "Lamar" THEN CLI ="WET";
IF COUNTY = "Tarrant" THEN CLI ="WET";
IF COUNTY = "Falls" THEN CLI ="WET";
IF COUNTY = "Hill" THEN CLI ="WET";
IF COUNTY = "MCLennan" THEN CLI ="WET";
IF COUNTY = "Brazoria" THEN CLI ="WET";
IF COUNTY = "Fortbend" THEN CLI ="WET";
IF COUNTY = "Harris" THEN CLI ="WET";
IF COUNTY = "Montgomer" THEN CLI ="WET";
IF COUNTY = "Waller" THEN CLI ="WET";
IF COUNTY = "Colorado" THEN CLI ="WET";
```

```
IF COUNTY = "Fayette" THEN CLI ="WET";
IF COUNTY = "Gonzales" THEN CLI ="WET";
IF COUNTY = "Jackson" THEN CLI ="WET";
IF COUNTY = "Victoria" THEN CLI ="WET";
IF COUNTY = "Wharton" THEN CLI ="WET";
IF COUNTY = "Brazos" THEN CLI ="WET";
IF COUNTY = "Freestone" THEN CLI ="WET";
IF COUNTY = "Leon" THEN CLI ="WET";
IF COUNTY = "Madison" THEN CLI ="WET";
IF COUNTY = "Walker" THEN CLI ="WET";
IF COUNTY = "Dallas" THEN CLI ="WET";
IF COUNTY = "Denton" THEN CLI ="WET";
IF COUNTY = "Ellis" THEN CLI ="WET";
IF COUNTY = "Bowie" THEN CLI ="WET";
IF COUNTY = "Harrison" THEN CLI ="WET";
IF COUNTY = "Morris" THEN CLI ="WET";
IF COUNTY = "Titus" THEN CLI ="WET";
IF COUNTY = "Hardin" THEN CLI ="WET";
IF COUNTY = "Jefferson" THEN CLI ="WET";
IF COUNTY = "Liberty" THEN CLI ="WET";
OVLD="NO "; IF OV1 > . THEN OVLD="YES";
TEMPC="L"; IF TEMP>32 THEN TEMPC="H";
AGEC="HIGH"; IF (1993-CDATE)<=15 THEN AGEC="LOW";
IF OVLD="NO";  TC="HIGH" ; IF D<=8.5 THEN TC="LOW";
KEEP COUNTY CFTR TC AGEC  ADT85 CLI RAIN SOIL OVLD CAT TEMPC;
IF CAT < 3;
/*PROC SORT; BY D CAT CLI TEMPC SOIL OVLD; RUN;   */
DATA Q; MERGE D SSD.CUT2 ; BY CFTR;
PROC TABULATE DATA = Q;
```

```
VAR CFTR; CLASS T86 TC CAT CLI TEMPC SOIL AGEC;
TABLE TC*CAT*CLI*TEMPC*SOIL,T86*AGEC*CFTR*(N);
IF T86=' ' OR TC = ' ' OR CAT = ' ' OR SOIL = ' ' OR AGEC = ' '
THEN DELE
PROC SORT; BY  T86 TC CAT CLI TEMPC SOIL AGEC;
PROC PRINT; BY  T86 TC CAT CLI TEMPC SOIL AGEC; VAR CFTR;
PROC PRINT;*/
```

APPENDIX B

SAS PROGRAM FOR JOINTED CONCRETE PAVEMENTS

```
/**
      ******************************************************
      *                                                    *
      * THIS SAS PROGRAM TAKES THE CTR JOINTED DATA SET AND *
      * ADDS SUCH MISSING VARIABLES AS SLAB THICKNESS,     *
      * CAT, TRAFFIC, CLIMATE, RAINFALL, SLAB LENGTH, AND  *
      * DOWELS IF PRESENT OR NOT. IT FURTHER DIVIDES THE   *
      * DATA BASE INTO PLAIN JOINTED ( SDS.PLAIN ) AND     *
      * REINFORCED JOINTED ( SDS.REINF ). SDS.JCPFIN       *
      * CONTAINS ALL THE REQUIRED INFORMATION              *
      *                                                    *
      ******************************************************

**/

CMS FI SDS DISK DUMMY DUMMY A;
DATA SDS.JCPTEMP; SET SDS.JCP;
CLI="DRY";
IF COUNTY = "FRANKLIN" THEN CLI ="WET";
IF COUNTY = "GRAYSON" THEN CLI ="WET";
IF COUNTY = "HOPKINS" THEN CLI ="WET";
IF COUNTY = "LAMAR" THEN CLI ="WET";
IF COUNTY = "TARRANT" THEN CLI ="WET";
IF COUNTY = "FALLS" THEN CLI ="WET";
IF COUNTY = "HILL" THEN CLI ="WET";
IF COUNTY = "MC LENNAN" THEN CLI ="WET";
IF COUNTY = "BRAZORIA" THEN CLI ="WET";
IF COUNTY = "FORTBEND" THEN CLI ="WET";
IF COUNTY = "HARRIS" THEN CLI ="WET";
```

```
IF COUNTY = "MONTGOMER" THEN CLI ="WET";
IF COUNTY = "WALLER" THEN CLI ="WET";
IF COUNTY = "CLOLRADO" THEN CLI ="WET";
IF COUNTY = "FAYETTE" THEN CLI ="WET";
IF COUNTY = "GONZALES" THEN CLI ="WET";
IF COUNTY = "JACKSON" THEN CLI ="WET";
IF COUNTY = "Victoria" THEN CLI ="WET";
IF COUNTY = "WHARTON" THEN CLI ="WET";
IF COUNTY = "BRAZOS" THEN CLI ="WET";
IF COUNTY = "FREESTONE" THEN CLI ="WET";
IF COUNTY = "LEON" THEN CLI ="WET";
IF COUNTY = "MADISON" THEN CLI ="WET";
IF COUNTY = "WALKER" THEN CLI ="WET";
IF COUNTY = "DALLAS" THEN CLI ="WET";
IF COUNTY = "DENTON" THEN CLI ="WET";
IF COUNTY = "ELLIS" THEN CLI ="WET";
IF COUNTY = "BOWIE" THEN CLI ="WET";
IF COUNTY = "HARRISON" THEN CLI ="WET";
IF COUNTY = "MORRIS" THEN CLI ="WET";
IF COUNTY = "TITUS" THEN CLI ="WET";
IF COUNTY = "HARDIN" THEN CLI ="WET";
IF COUNTY = "JEFFERSON" THEN CLI ="WET";
IF COUNTY = "LIBERTY" THEN CLI ="WET";
DIST=INT ( CFTR / 1000 ) ;
TEMP="NOFREEZE";
IF DIST = 1 THEN TEMP ="FREEZE";
IF DIST = 2 THEN TEMP ="FREEZE";
IF DIST = 3 THEN TEMP ="FREEZE";
IF DIST = 4 THEN TEMP ="FREEZE";
```

```
IF DIST = 5 THEN TEMP ="FREEZE";
IF DIST = 8 THEN TEMP ="FREEZE";
IF DIST = 19 THEN TEMP ="FREEZE";
IF DIST = 18 THEN TEMP ="FREEZE";
IF DIST = 10 THEN TEMP ="FREEZE";
CAT ="LS";
IF COUNTY = "LAMAR" THEN CAT ="SRG" ;
IF COUNTY = "PARKER" THEN CAT ="SRG" ;
IF COUNTY = "CARSON" THEN CAT ="SRG" ;
IF COUNTY = "POTTER" THEN CAT ="SRG";
IF COUNTY = "GRAY" THEN CAT ="SRG";
IF COUNTY = "DONLEY" THEN CAT ="SRG"  ;
IF COUNTY = "HALE" THEN CAT = "SRG";
IF COUNTY = "SWISHER" THEN CAT ="SRG";
IF COUNTY = "MCLENNAN" THEN CAT ="SRG";
IF COUNTY = "VANZANDT" THEN CAT ="SRG";
IF COUNTY = "GREGG" THEN CAT ="SRG";
IF COUNTY = "HARRIS" THEN CAT ="SRG";
IF COUNTY = "FORTBEND" THEN CAT ="SRG";
IF COUNTY = "COLORADO" THEN CAT ="SRG";
IF COUNTY = "VICTORIA" THEN CAT ="SRG";
IF COUNTY = "FAYETTE" THEN CAT ="SRG";
IF COUNTY = "WHARTON" THEN CAT ="SRG";
IF COUNTY = "GONZALES" THEN CAT ="SRG";
IF COUNTY = "WHARTON" THEN CAT ="SRG";
IF COUNTY = "JACKSON" THEN CAT ="SRG";
IF COUNTY = "LEON" THEN CAT ="SRG";
IF COUNTY = "MADISON" THEN CAT ="SRG";
IF COUNTY = "FREESTON" THEN CAT ="SRG";
```

```
IF COUNTY = "BRAZOS" THEN CAT ="SRG";
IF COUNTY = "ELLIS" THEN CAT ="SRG";
IF COUNTY = "DENTON" THEN CAT ="SRG";
IF COUNTY = "HARRISON" THEN CAT ="SRG";
IF COUNTY = "BOWIE" THEN CAT ="SRG";
IF COUNTY = "TITUS" THEN CAT ="SRG";
IF COUNTY = "MORRIS" THEN CAT ="SRG";
IF COUNTY = "JEFFERSON" THEN CAT ="SRG";
IF COUNTY = "LIBERTY" THEN CAT ="SRG";
IF COUNTY = "WHEELER"  THEN CAT ="SRG"; PROC SORT; BY CFTR;
DATA SDS.JCPFIN;
MERGE SDS.JCPTEMP SDS.JR SDS.JP;
BY CFTR;
IF CFTR=. OR PTYPE=' ' THEN DELETE;
PROC SORT; BY CFTR;
PROC PRINT;VAR CFTR PTYPE TRCLASS CLI TEMP CAT THKC;
DATA SDS.PLAIN;SET SDS.JCPFIN;
IF PTYPE ='P';
PROC TABULATE DATA =SDS.PLAIN;VAR CFTR;
CLASS CLI TEMP TRCLASS CAT THKC LTRF;
TABLE CLI*TEMP*TRCLASS*CAT,THKC*LTRF*CFTR*(N);
PROC PRINT; VAR CFTR CONT SECT JOB START END;
PROC PRINT; VAR CFTR THKC LTRF CAT TRCLASS TEMP CLI;
DATA SDS.REINF;SET SDS.JCPFIN;IF PTYPE='R';PROC TABULATE
DATA=SDS.REINF;
VAR CFTR;
CLASS CLI TEMP TRCLASS CAT THKC SLABC;
TABLE CLI*TEMP*TRCLASS*CAT,THKC*SLABC*CFTR*(N);
PROC PRINT;
```

```
VAR CFTR DIST COUNTY CONT SECT JOB START END;
 PROC PRINT; VAR CFTR THKC SLABC CAT TRCLASS TEMP CLI;
PROC PRINT;
```

APPENDIX C

SELECTED OUTPUT —

CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

```
1The SAS System

12:11 Monday, June 7, 1993


 OBS     CFTR     TC      T86     CAT     TEMPC     CLI     AGEC

   1    12903    HIGH     HIG      1        H       WET     LOW

   2    12904    HIGH     HIG      1        H       WET     LOW

   3    12904    HIGH     HIG      1        H       WET     LOW

   4    15903    HIGH     HIG      2        H       DRY     LOW

   5    15901    HIGH     HIG      2        L       DRY     LOW

   6    12903    HIGH     HIG      2        H       WET     LOW

   7     2094    HIGH     HIG      2        L       WET     LOW

   8     9004    LOW      HIG      1        H       DRY     HIGH

   9     4003    LOW      HIG      1        L       DRY     HIGH

  10     4004    LOW      HIG      1        L       DRY     HIGH

  11     4009    LOW      HIG      1        L       DRY     HIGH

  12    20023    LOW      HIG      1        H       WET     HIGH

  13     9008    LOW      HIG      2        H       DRY     HIGH

  14    24003    LOW      HIG      2        L       DRY     HIGH

  15    24004    LOW      HIG      2        L       DRY     HIGH

  16    24006    LOW      HIG      2        L       DRY     HIGH

  17    24007    LOW      HIG      2        L       DRY     HIGH

  18    24031    LOW      HIG      2        L       DRY     HIGH

  19     2047    LOW      HIG      2        L       DRY     HIGH

  20     2048    LOW      HIG      2        L       DRY     HIGH

  21    24030    LOW      HIG      2        L       DRY     HIGH

  22    24027    LOW      HIG      2        L       DRY     LOW

  23    24028    LOW      HIG      2        L       DRY     LOW

  24    24029    LOW      HIG      2        L       DRY     LOW

  25    18065    LOW      HIG      2        H       WET     HIGH

  26    18069    LOW      HIG      2        H       WET     HIGH
```

```
1The SAS System

12:11 Monday, June 7, 1993


 OBS    CFTR    TC     T86    CAT    TEMPC    CLI    AGEC

  27    18107   LOW    HIG     2       H      WET    HIGH
  28    18040   LOW    HIG     2       H      WET    HIGH
  29    18058   LOW    HIG     2       H      WET    HIGH
  30    18061   LOW    HIG     2       H      WET    HIGH
  31    18062   LOW    HIG     2       H      WET    HIGH
  32    18064   LOW    HIG     2       H      WET    HIGH
  33    18066   LOW    HIG     2       H      WET    HIGH
  34    18073   LOW    HIG     2       H      WET    HIGH
  35    18078   LOW    HIG     2       H      WET    HIGH
  36    18081   LOW    HIG     2       H      WET    HIGH
  37    18093   LOW    HIG     2       H      WET    HIGH
  38    18100   LOW    HIG     2       H      WET    HIGH
  39    18101   LOW    HIG     2       H      WET    HIGH
  40    18103   LOW    HIG     2       H      WET    HIGH
  41    18106   LOW    HIG     2       H      WET    HIGH
  42     2056   LOW    HIG     2       L      WET    HIGH
  43     2060   LOW    HIG     2       L      WET    HIGH
  44     2075   LOW    HIG     2       L      WET    HIGH
  45     2093   LOW    HIG     2       L      WET    HIGH
  46     2022   LOW    HIG     2       L      WET    HIGH
  47     2030   LOW    HIG     2       L      WET    HIGH
  48     2033   LOW    HIG     2       L      WET    HIGH
  49     2034   LOW    HIG     2       L      WET    HIGH
  50     2039   LOW    HIG     2       L      WET    HIGH
  51     2045   LOW    HIG     2       L      WET    HIGH
  52     2068   LOW    HIG     2       L      WET    HIGH
```

```
1The SAS System

12:11 Monday, June 7, 1993


OBS    CFTR   TC     T86   CAT   TEMPC   CLI   AGEC

 53    2096   LOW    HIG    2      L     WET   HIGH
 54    2098   LOW    HIG    2      L     WET   HIGH
 55    2097   LOW    HIG    2      L     WET   LOW
 56   12107   HIGH   LOW    1      H     DRY   HIGH
 57    4021   HIGH   LOW    1      L     DRY   LOW
 58    4022   HIGH   LOW    1      L     DRY   LOW
 59    4027   HIGH   LOW    1      L     DRY   LOW
 60    4028   HIGH   LOW    1      L     DRY   LOW
 61    5002   HIGH   LOW    1      L     DRY   LOW
 62    5005   HIGH   LOW    1      L     DRY   LOW
 63    5008   HIGH   LOW    1      L     DRY   LOW
 64    5009   HIGH   LOW    1      L     DRY   LOW
 65   15911   HIGH   LOW    2      L     DRY   LOW
 66   15912   HIGH   LOW    2      L     DRY   LOW
 67   15914   HIGH   LOW    2      L     DRY   LOW
 68    5004   HIGH   LOW    2      L     DRY   LOW
 69    5006   HIGH   LOW    2      L     DRY   LOW
 70    5007   HIGH   LOW    2      L     DRY   LOW
 71   15902   HIGH   LOW    2      L     DRY   LOW
 72   20013   HIGH   LOW    2      H     WET   HIGH
 73   12905   HIGH   LOW    2      H     WET   LOW
 74   12905   HIGH   LOW    2      H     WET   LOW
 75    9009   LOW    LOW    1      H     DRY   HIGH
 76    4005   LOW    LOW    1      L     DRY   HIGH
 77    4006   LOW    LOW    1      L     DRY   HIGH
 78    4011   LOW    LOW    1      L     DRY   HIGH
```

```
1The SAS System

12:11 Monday, June 7, 1993


OBS    CFTR    TC     T86    CAT   TEMPC    CLI    AGEC

 79   24022   LOW    LOW     1      L      DRY    HIGH

 80    4023   LOW    LOW     1      L      DRY    LOW

 81    4025   LOW    LOW     1      L      DRY    LOW

 82    1012   LOW    LOW     1      H      WET    HIGH

 83    1013   LOW    LOW     1      H      WET    HIGH

 84   13011   LOW    LOW     1      H      WET    HIGH

 85   13013   LOW    LOW     1      H      WET    HIGH

 86   13022   LOW    LOW     1      H      WET    HIGH

 87   13025   LOW    LOW     1      H      WET    HIGH

 88   13026   LOW    LOW     1      H      WET    HIGH

 89   13027   LOW    LOW     1      H      WET    HIGH

 90   13028   LOW    LOW     1      H      WET    HIGH

 91   19007   LOW    LOW     1      H      WET    HIGH

 92   20014   LOW    LOW     1      H      WET    HIGH

 93   20017   LOW    LOW     1      H      WET    HIGH

 94   20018   LOW    LOW     1      H      WET    HIGH

 95   20021   LOW    LOW     1      H      WET    HIGH

 96   13014   LOW    LOW     1      H      WET    HIGH

 97   13030   LOW    LOW     1      H      WET    HIGH

 98   13032   LOW    LOW     1      H      WET    HIGH

 99   13033   LOW    LOW     1      H      WET    HIGH

100   17007   LOW    LOW     1      H      WET    HIGH

101   17009   LOW    LOW     1      H      WET    HIGH

102   20022   LOW    LOW     1      H      WET    HIGH

103    2028   LOW    LOW     2      L      DRY    HIGH

104    3019   LOW    LOW     2      L      DRY    HIGH
```

```
1The SAS System

12:11 Monday, June 7, 1993

OBS     CFTR    TC     T86    CAT    TEMPC    CLI    AGEC

105    24002    LOW    LOW     2       L      DRY    HIGH

106    24008    LOW    LOW     2       L      DRY    HIGH

107    15913    LOW    LOW     2       L      DRY    LOW

108    24032    LOW    LOW     2       L      DRY    LOW

109     2051    LOW    LOW     2       L      DRY    HIGH

110     2052    LOW    LOW     2       L      DRY    HIGH

111     2054    LOW    LOW     2       L      DRY    HIGH

112     2058    LOW    LOW     2       L      DRY    HIGH

113     2059    LOW   LOW     2       L      DRY    HIGH

114     2078    LOW   LOW     2       L      DRY    HIGH

115     3007    LOW   LOW     2       L      DRY    HIGH

116     3010    LOW   LOW     2       L      DRY    HIGH

117     3011    LOW   LOW     2       L      DRY    HIGH

118     3012    LOW   LOW     2       L      DRY    HIGH

119     3014    LOW   LOW     2       L      DRY    HIGH

120     3015    LOW   LOW     2       L      DRY    HIGH

121     3017    LOW   LOW     2       L      DRY    HIGH

122     3018    LOW   LOW     2       L      DRY    HIGH

123     1002    LOW   LOW     2       H      WET    HIGH

124    13015    LOW   LOW     2       H      WET    HIGH

125    13016    LOW   LOW     2       H      WET    HIGH

126    13021    LOW   LOW     2       H      WET    HIGH

127    18072    LOW   LOW     2       H      WET    HIGH

128    18080    LOW   LOW     2       H      WET    HIGH

129    18086    LOW   LOW     2       H      WET    HIGH

130    18088    LOW   LOW     2       H      WET    HIGH
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1The SAS System

12:11 Monday, June 7, 1993


 OBS     CFTR     TC     T86     CAT    TEMPC    CLI    AGEC

 131    20019    LOW    LOW      2       H      WET    HIGH
 132    20020    LOW    LOW      2       H      WET    HIGH
 133     1015    LOW    LOW      2       H      WET    HIGH
 134    13017    LOW    LOW      2       H      WET    HIGH
 135    13020    LOW    LOW      2       H      WET    HIGH
 136    17008    LOW    LOW      2       H      WET    HIGH
 137    18074    LOW    LOW      2       H      WET    HIGH
 138    18079    LOW    LOW      2       H      WET    HIGH
 139     2041    LOW    LOW      2       L      WET    HIGH
 140     2049    LOW    LOW      2       L      WET    HIGH
 141     2050    LOW    LOW      2       L      WET    HIGH
 142*   12915    LOW    LOW      2       H      WET    LOW
 143*   18120    LOW    LOW      2       H      WET    LOW
 144*   16001    LOW    LOW      2       H      WET    HIGH
 145*    2099    LOW    LOW      2       L      WET    HIGH
 146*    6001    LOW    HIG      2       H      WET    HIGH
 147*    2100    HIGH   LOW      2       L      WET    LOW
 148*    2101    LOW    LOW      2       L      WET    LOW
 149*    2102    LOW    LOW      2       L      WET    HIGH
 150*    2103    HIGH   LOW      2       L      WET    LOW
 151*    2104    HIGH   LOW      2       L      WET    LOW
 152*    2105    LOW    LOW      2       L      WET    LOW
 153*    4029    HIGH   LOW      2       L      DRY    LOW
 154*    3024    LOW    LOW      2       L      DRY    HIGH
 155*   25006    LOW    LOW      1       H      DRY    HIGH
 156*    2103    HIGH   LOW      2       L      WET    LOW
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1The SAS System

12:11 Monday, June 7, 1993


 OBS     CFTR     TC     T86     CAT     TEMPC     CLI     AGEC

 157*    4030     HIGH   LOW      2        L       DRY     LOW

 158*    4031     LOW    LOW      2        L       DRY     HIGH


        VARIABLES

           CFTR       CENTER FOR TRANSPORTATION NUMBER
             TC       THICKNESS CLASS
            T86       TRAFFIC CLASS
            CAT       1 - SRG
                      2 - LS
          TEMPC       TEMPERATURE CLASS
            CLI       CLIMATE
           AGEC       AGE CLASS
              *       LTPP TEST SECTION
```

APPENDIX D

SELECTED OUTPUT —

JOINTED CONCRETE PAVEMENTS

```
1The SAS System

11:18 Tuesday, June 1, 1993


 OBS     CFTR    PTYPE   TRCLASS    CLI      TEMP      CAT    THKC

   1     1551      R        L       DRY     FREEZE     LS     LOW

   2     1552      R        H       DRY     FREEZE     LS     LOW

   3     1552      R        H       DRY     FREEZE     LS     LOW

   4     1553      R        H       WET     FREEZE     LS     HIGH

   5     1553      R        H       WET     FREEZE     LS     HIGH

   6     1554      R        H       WET     FREEZE     LS     HIGH

   7     1554      R        H       WET     FREEZE     LS     HIGH

   8     2501      R        L       WET     FREEZE     LS     HIGH

   9     2501      R        L       WET     FREEZE     LS     HIGH

  10     2505      R        H       WET     FREEZE     LS     LOW

  11     2505      R        H       WET     FREEZE     LS     LOW

  12     2506      P        L       WET     FREEZE     LS     HIGH

  13     2506      P        L       WET     FREEZE     LS     HIGH

  14     2537      R        L       WET     FREEZE     LS     LOW

  15     2537      R        L       WET     FREEZE     LS     LOW

  16     2576      R        H       WET     FREEZE     LS     LOW

  17     2576      R        H       WET     FREEZE     LS     LOW

  18     3397      R        L       DRY     FREEZE     LS     LOW

  19     3577      P        L       DRY     FREEZE     LS     LOW

  20     3577      P        L       DRY     FREEZE     LS     LOW

  21     3578      P        L       DRY     FREEZE     LS     LOW

  22     3578      P        L       DRY     FREEZE     LS     LOW

  23     3579      P        H       DRY     FREEZE     LS     LOW

  24     3579      P        H       DRY     FREEZE     LS     LOW

  25     3581      P        H       DRY     FREEZE     LS     LOW
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1The SAS System

11:18 Tuesday, June 1, 1993

OBS    CFTR   PTYPE   TRCLASS   CLI     TEMP      CAT   THKC

 26    3581     P        H      DRY   FREEZE      LS    LOW
 27    3584     P        H      DRY   FREEZE      LS    HIGH
 28    3584     P        H      DRY   FREEZE      LS    HIGH
 29    3586     P        H      DRY   FREEZE      LS    HIGH
 30    3586     P        H      DRY   FREEZE      LS    HIGH
 31    3588     P        L      DRY   FREEZE      LS    LOW
 32    3588     P        L      DRY   FREEZE      LS    LOW
 33    3589     P        L      DRY   FREEZE      LS    HIGH
 34    3589     P        L      DRY   FREEZE      LS    HIGH
 35    3590     P        L      DRY   FREEZE      LS    HIGH
 36    3590     P        L      DRY   FREEZE      LS    HIGH
 37    3592     P        L      DRY   FREEZE      LS    HIGH
 38    3592     P        L      DRY   FREEZE      LS    HIGH
 39    3593     P        H      DRY   FREEZE      LS    HIGH
 40    3598     P        H      DRY   FREEZE      LS    LOW
 41    3598     P        H      DRY   FREEZE      LS    LOW
 42    9553     P        L      DRY   NOFREEZE    LS    LOW
 43    9553     P        L      DRY   NOFREEZE    LS    LOW
 44   10564     P        L      DRY   FREEZE      LS    LOW
 45   10564     P        L      DRY   FREEZE      LS    LOW
 46   12105     R        H      WET   NOFREEZE    SR    LOW
 47   12505     R        L      WET   NOFREEZE    LS    HIGH
 48   12505     R        L      WET   NOFREEZE    LS    HIGH
 49   12509     P        H      DRY   NOFREEZE    LS    LOW
 50   12509     P        H      DRY   NOFREEZE    LS    LOW
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1The SAS System
11:18 Tuesday, June 1, 1993

OBS    CFTR    PTYPE    TRCLASS    CLI      TEMP       CAT    THKC
 51    12513     P         H       DRY    NOFREEZE     LS     HIGH
 52    12513     P         H       DRY    NOFREEZE     LS     HIGH
 53    12526     R         H       WET    NOFREEZE     SR     HIGH
 54    12526     R         H       WET    NOFREEZE     SR     HIGH
 55    12527     R         H       DRY    NOFREEZE     LS     HIGH
 56    12527     R         H       DRY    NOFREEZE     LS     HIGH
 57    12535     P         H       DRY    NOFREEZE     LS     LOW
 58    12535     P         H       DRY    NOFREEZE     LS     LOW
 59    12535     P         H       DRY    NOFREEZE     LS     LOW
 60    12535     P         H       DRY    NOFREEZE     LS     LOW
 61    12536     P         H                                 HIGH
 62    12537     R         H       WET    NOFREEZE     SR     HIGH
 63    12537     R         H       WET    NOFREEZE     SR     HIGH
 64    12540     R         H       DRY    NOFREEZE     LS     HIGH
 65    12540     R         H       DRY    NOFREEZE     LS     HIGH
 66    12541     R         H                                 HIGH
 67    12548     R         L       WET    NOFREEZE     SR     HIGH
 68    12548     R         L       WET    NOFREEZE     SR     HIGH
 69    12549     R         L       WET    NOFREEZE     SR     HIGH
 70    12549     R         L       WET    NOFREEZE     SR     HIGH
 71    12553     R         L       WET    NOFREEZE     LS     HIGH
 72    12553     R         L       WET    NOFREEZE     LS     HIGH
 73    12554     R         L       WET    NOFREEZE     LS     HIGH
 74    12554     R         L       WET    NOFREEZE     LS     HIGH
 75    12561     R         H       WET    NOFREEZE     LS     HIGH
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1The SAS System

11:18 Tuesday, June 1, 1993

OBS    CFTR    PTYPE    TRCLASS    CLI     TEMP       CAT    THKC

 76    12561     R         H       WET    NOFREEZE    LS     HIGH
 77    12563     R         H       WET    NOFREEZE    SR     HIGH
 78    12563     R         H       WET    NOFREEZE    SR     HIGH
 79    12563     R         H       WET    NOFREEZE    SR     HIGH
 80    12563     R         H       WET    NOFREEZE    SR     HIGH
 81    12564     R         L       WET    NOFREEZE    SR     HIGH
 82    12564     R         L       WET    NOFREEZE    SR     HIGH
 83    12576     R         H       WET    NOFREEZE    LS     LOW
 84    12576     R         H       WET    NOFREEZE    LS     LOW
 85    12590     R         L       DRY    NOFREEZE    LS     HIGH
 86    12590     R         L       DRY    NOFREEZE    LS     HIGH
 87    12591     P         L       WET    NOFREEZE    SR     HIGH
 88    12591     P         L       WET    NOFREEZE    SR     HIGH
 89    13501     R         L       DRY    NOFREEZE    LS     HIGH
 90    13504     P         L       DRY    NOFREEZE    LS     LOW
 91    13504     P         L       DRY    NOFREEZE    LS     LOW
 92    13506     R         L       DRY    NOFREEZE    LS     LOW
 93    13506     R         L       DRY    NOFREEZE    LS     LOW
 94    13509     R         H       DRY    NOFREEZE    LS     HIGH
 95    13509     R         H       DRY    NOFREEZE    LS     HIGH
 96    13510     R         H       DRY    NOFREEZE    LS     HIGH
 97    13510     R         H       DRY    NOFREEZE    LS     HIGH
 98    13512     R         L       DRY    NOFREEZE    LS     HIGH
 99    13512     R         L       DRY    NOFREEZE    LS     HIGH
100    13513     R         H       DRY    NOFREEZE    LS     HIGH
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1The SAS System

11:18 Tuesday, June 1, 1993

OBS    CFTR    PTYPE    TRCLASS    CLI    TEMP        CAT    THKC

101    13514     R         H       DRY    NOFREEZE    LS     HIGH
102    13514     R         H       DRY    NOFREEZE    LS     HIGH
103    16570     P         L       DRY    NOFREEZE    LS     LOW
104    16570     P         L       DRY    NOFREEZE    LS     LOW
105    17560     R         L       DRY    NOFREEZE    SR     LOW
106    17560     R         L       DRY    NOFREEZE    SR     LOW
107    17561     P         L       DRY    NOFREEZE    LS     LOW
108    17561     P         L       DRY    NOFREEZE    LS     LOW
109    18120     P         L       WET    FREEZE      LS     LOW
110    18120     P         L       WET    FREEZE      LS     LOW
111    18164     P         L       WET    FREEZE      LS     LOW
112    18164     P         L       WET    FREEZE      LS     LOW
113    18165     R         H       WET    FREEZE      LS     LOW
114    18166     P         H       WET    FREEZE      LS     LOW
115    18166     P         H       WET    FREEZE      LS     LOW
116    18167     P         L       WET    FREEZE      LS     LOW
117    18167     P         L       WET    FREEZE      LS     LOW
118    18168     P         H       WET    FREEZE      LS     LOW
119    18168     P         H       WET    FREEZE      LS     LOW
120    18170     P         L       WET    FREEZE      LS     LOW
121    18170     P         L       WET    FREEZE      LS     LOW
122    18171     R         L       WET    FREEZE      LS     LOW
123    18171     R         L       WET    FREEZE      LS     LOW
124    18501     R         H       WET    FREEZE      LS     LOW
125    18501     R         H       WET    FREEZE      LS     LOW
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1The SAS System

11:18 Tuesday, June 1, 1993


OBS    CFTR    PTYPE    TRCLASS    CLI      TEMP     CAT    THKC

126    18502     R         H       WET     FREEZE    LS     LOW

127    18502     R         H       WET     FREEZE    LS     LOW

128    18503     R         L       WET     FREEZE    LS     LOW

129    18503     R         L       WET     FREEZE    LS     LOW

130    18506     R         H       WET     FREEZE    LS     LOW

131    18506     R         H       WET     FREEZE    LS     LOW

132    18507     R         H       WET     FREEZE    LS     LOW

133    18507     R         H       WET     FREEZE    LS     LOW

134    18508     R         H       WET     FREEZE    LS     LOW

135    18508     R         H       WET     FREEZE    LS     LOW

136    18523     P         H       WET     FREEZE    LS     HIGH

137    18523     P         H       WET     FREEZE    LS     HIGH

138    18525     P         H       WET     FREEZE    LS     HIGH

139    18525     P         H       WET     FREEZE    LS     HIGH

140    18526     P         L       WET     FREEZE    LS     HIGH

141    18526     P         L       WET     FREEZE    LS     HIGH

142    18530     P         H       WET     FREEZE    SR     HIGH

143    18530     P         H       WET     FREEZE    SR     HIGH

144    18531     P         H       WET     FREEZE    LS     HIGH

145    18531     P         H       WET     FREEZE    LS     HIGH

146    18532     P         H       WET     FREEZE    SR     HIGH

147    18532     P         H       WET     FREEZE    SR     HIGH

148    18535     P         H       WET     FREEZE    LS     HIGH

149    18535     P         H       WET     FREEZE    LS     HIGH

150    18536     P         L       WET     FREEZE    LS     HIGH
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1The SAS System

11:18 Tuesday, June 1, 1993

 OBS    CFTR    PTYPE   TRCLASS   CLI     TEMP       CAT   THKC

 151    18536     P        L      WET   FREEZE       LS    HIGH
 152    18541     P        L      WET   FREEZE       LS    LOW
 153    18541     P        L      WET   FREEZE       LS    LOW
 154    18547     P        H      WET   FREEZE       LS    HIGH
 155    18556     P        H      WET   FREEZE       LS    LOW
 156    18556     P        H      WET   FREEZE       LS    LOW
 157    18557     P        H      WET   FREEZE       LS    LOW
 158    20573     P        H      WET   NOFREEZE     LS    LOW
 159    20573     P        H      WET   NOFREEZE     LS    LOW
 160    20574     R        L      DRY   NOFREEZE     LS    LOW
 161    20574     R        L      DRY   NOFREEZE     LS    LOW
 162    20575     R        L      DRY   NOFREEZE     LS    LOW
 163    20575     R        L      DRY   NOFREEZE     LS    LOW
 164    20576     R        L      DRY   NOFREEZE     LS    LOW
 165    20576     R        L      DRY   NOFREEZE     LS    LOW
 166    20577     R        L      DRY   NOFREEZE     LS    LOW
 167    20578     P        L      DRY   NOFREEZE     LS    HIGH
 168    20578     P        L      DRY   NOFREEZE     LS    HIGH
 169    20579     P        L      DRY   NOFREEZE     LS    LOW
 170    20579     P        L      DRY   NOFREEZE     LS    LOW
 171    20584     R        H      DRY   NOFREEZE     LS    LOW
 172    20584     R        H      DRY   NOFREEZE     LS    LOW
 173    20586     P        L      DRY   NOFREEZE     LS    LOW
 174    20586     P        L      DRY   NOFREEZE     LS    LOW
 175    20587     P        L      DRY   NOFREEZE     LS    LOW
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1The SAS System

11:18 Tuesday, June 1, 1993


OBS    CFTR    PTYPE    TRCLASS    CLI      TEMP       CAT     THKC

176    20587     P         L       DRY    NOFREEZE     LS      LOW

177    20588     R         H       WET    NOFREEZE     SR      HIGH

178    20590     R         H       WET    NOFREEZE     SR      HIGH

179    20590     R         H       WET    NOFREEZE     SR      HIGH



       VARIABLES

          CFTR          CENTER FOR TRANSPORTATION NUMBER

         PTYPE          PAVEMENT TYPE

                        P - PLAIN JOINTED

                        R - REINFORCED JOINTED

       TRCLASS          TRAFFIC CLASS

           CLI          CLIMATE

          TEMP          TEMPERATURE

           CAT          COARSE AGGREGATE TYPE

                        LS - LIME STONE

                        SR - SELICIOUS RIVER GRAVEL

          THKC          THICKNESS CLASS
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1The SAS System

11:18 Tuesday, June 1, 1993


OBS     CFTR    CONT    SECT    JOB    START    END

  1     2506     172       1     13     23.0   21.2

  2     2506     172       1     13     21.2   23.0

  3     3577     156       4     38     10.6    8.8

  4     3577     156       4     38      8.6   10.4

  5     3578     156       4     45      8.6    6.2

  6     3578     156       4     45      6.8    8.4

  7     3579     156       4     35      6.0    5.8

  8     3579     156       4     35      5.6    5.8

  9     3581      44       1     34     15.4   14.8

 10     3581      44       1     34     14.6   15.2

 11     3584      44       3     21     13.2   13.6

 12     3584      44       3     21     14.0   13.6

 13     3586      45       1     16     20.0   21.4

 14     3586      45       1     16     22.0   20.0

 15     3588      43       9     48     14.2   12.2

 16     3588      43       9     48     12.0   14.0

 17     3589     156       3     15     39.2   35.6

 18     3589     156       3     15     35.4   38.8

 19     3590     685       1      9     12.0   13.0

 20     3590     685       1      9     13.2   12.2

 21     3592     283       3     12      0.0    0.2

 22     3592     283       3     12      0.4    0.2

 23     3593      43       5     37     13.5   12.7

 24     3598     124       3     13     18.0   15.8

 25     3598     124       3     13     15.8   18.0
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1The SAS System

11:18 Tuesday, June 1, 1993

OBS     CFTR    CONT    SECT    JOB    START     END

 26     9553     419       2     21      1.2     0.2

 27     9553     419       2     21        .     1.0

 28    10564    1163       2      2      0.4     3.4

 29    10564    1163       2      2      3.6     1.2

 30    12509     110       4     36     80.0    84.2

 31    12509     110       4     36     84.2    80.0

 32    12513     110       4     37     80.0    73.6

 33    12513     110       4     37     73.6    80.0

 34    12535     675       8      3     91.0    84.2

 35    12535     675       8      3     84.0    90.8

 36    12535     177       5      3     17.8     0.0

 37    12535     177       5      3      0.0    17.6

 38    12536       .       .      .        .       .

 39    12591     502       1     73      0.0     1.6

 40    12591     502       1     73      1.6     0.0

 41    13504     179       7     10     29.6    29.6

 42    13504     179       7     10     29.6    29.6

 43    16570    1069       1      3      0.0    11.0

 44    16570    1069       1      3     11.2     0.0

 45    17561     315      12      4      0.0     4.4

 46    17561     315      12      4      4.6     0.2

 47    18120      48       1     22      7.2     9.6

 48    18120      48       1     22      9.8     7.4

 49    18164     430       1     19      2.6     9.6

 50    18164     430       1     19      5.6     2.6
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1The SAS System

11:18 Tuesday, June 1, 1993


 OBS     CFTR    CONT    SECT    JOB    START     END

  51    18166       9     11      78     52.2    50.0

  52    18166       9     11      78     50.8    52.0

  53    18167     581      1      57     10.8    11.8

  54    18167     581      1      57     12.0    11.0

  55    18168       9      2      22     12.0     5.6

  56    18168       9      2      22      5.6     6.6

  57    18170     353      5      42      0.0      2.8

  58    18170     353      5      42      3.0      0.2

  59    18523     196      3      29    426.4   426.2

  60    18523     196      3      29    426.0   426.2

  61    18525     196      3      30    429.4   428.6

  62    18525     196      3      30    428.4   429.2

  63    18526     196      3      36    427.2   426.6

  64    18526     196      3      36    426.4   427.0

  65    18530     195      2      14    471.6   472.4

  66    18530     195      2      14    472.2   471.6

  67    18531     196      3      31    428.4   427.4

  68    18531     196      3      31    427.2   428.2

  69    18532     195      2      16    472.6   482.6

  70    18532     195      2      16    482.6   472.4

  71    18535     196      3      34    431.2   429.6

  72    18535     196      3      34    429.4   431.0

  73    18536     196      3      38    431.8   431.4

  74    18536     196      3      38    431.2   431.6

  75    18541       9     11      19     50.6    52.8
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1The SAS System

11:18 Tuesday, June 1, 1993


OBS     CFTR     CONT     SECT     JOB     START      END

 76     18541       9      11       19      52.2      50.8

 77     18547     442       2       24     412.0     413.0

 78     18556     196       3       44     434.8     436.8

 79     18556     196       3       44     437.0     435.0

 80     18557     196       3       47     433.2     434.6

 81     20573     339       4        5       0.0       0.6

 82     20573     339       4        5       0.8       0.2

 83     20578     508       4       18      20.2      23.2

 84     20578     508       4       18      23.4      20.0

 85     20579     508       6        2      31.4      30.6

 86     20579     508       6        2      30.4      31.2

 87     20586     932       1       39      33.8      35.8

 88     20586     932       1       39      36.0      34.0

 89     20587     667       2        1       7.0       0.2

 90     20587     667       2        1       0.0       7.6

 91*    18558     353       4        30

 92*    20588     389       2        32

 93*     3599      43       6        25
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1The SAS System

11:18 Tuesday, June 1, 1993


OBS     CFTR     THKC     LTRF     CAT     TRCLASS      TEMP        CLI

  1     2506     HIGH     NO       LS         L         FREEZE      WET

  2     2506     HIGH     NO       LS         L         FREEZE      WET

  3     3577     LOW      YES      LS         L         FREEZE      DRY

  4     3577     LOW      YES      LS         L         FREEZE      DRY

  5     3578     LOW      NO       LS         L         FREEZE      DRY

  6     3578     LOW      NO       LS         L         FREEZE      DRY

  7     3579     LOW      NO       LS         H         FREEZE      DRY

  8     3579     LOW      NO       LS         H         FREEZE      DRY

  9     3581     LOW      YES      LS         H         FREEZE      DRY

 10     3581     LOW      YES      LS         H         FREEZE      DRY

 11     3584     HIGH     YES      LS         H         FREEZE      DRY

 12     3584     HIGH     YES      LS         H         FREEZE      DRY

 13     3586     HIGH     YES      LS         H         FREEZE      DRY

 14     3586     HIGH     YES      LS         H         FREEZE      DRY

 15     3588     LOW      NO       LS         L         FREEZE      DRY

 16     3588     LOW      NO       LS         L         FREEZE      DRY

 17     3589     HIGH     NO       LS         L         FREEZE      DRY

 18     3589     HIGH     NO       LS         L         FREEZE      DRY

 19     3590     HIGH     YES      LS         L         FREEZE      DRY

 20     3590     HIGH     YES      LS         L         FREEZE      DRY

 21     3592     HIGH     YES      LS         L         FREEZE      DRY

 22     3592     HIGH     YES      LS         L         FREEZE      DRY

 23     3593     HIGH     NO       LS         H         FREEZE      DRY

 24     3598     LOW      YES      LS         H         FREEZE      DRY

 25     3598     LOW      YES      LS         H         FREEZE      DRY
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1The SAS System
11:18 Tuesday, June 1, 1993

OBS    CFTR   THKC   LTRF   CAT   TRCLASS     TEMP       CLI
 26    9553   LOW    NO     LS       L      NOFREEZE     DRY
 27    9553   LOW    NO     LS       L      NOFREEZE     DRY
 28   10564   LOW    NO     LS       L      FREEZE       DRY
 29   10564   LOW    NO     LS       L      FREEZE       DRY
 30   12509   LOW    NO     LS       H      NOFREEZE     DRY
 31   12509   LOW    NO     LS       H      NOFREEZE     DRY
 32   12513   HIGH   NO     LS       H      NOFREEZE     DRY
 33   12513   HIGH   NO     LS       H      NOFREEZE     DRY
 34   12535   LOW    YES    LS       H      NOFREEZE     DRY
 35   12535   LOW    YES    LS       H      NOFREEZE     DRY
 36   12535   LOW    YES    LS       H      NOFREEZE     DRY
 37   12535   LOW    YES    LS       H      NOFREEZE     DRY
 38   12536   HIGH   YES             H
 39   12591   HIGH   NO     SR       L      NOFREEZE     WET
 40   12591   HIGH   NO     SR       L      NOFREEZE     WET
 41   13504   LOW    NO     LS       L      NOFREEZE     DRY
 42   13504   LOW    NO     LS       L      NOFREEZE     DRY
 43   16570   LOW    YES    LS       L      NOFREEZE     DRY
 44   16570   LOW    YES    LS       L      NOFREEZE     DRY
 45   17561   LOW    NO     LS       L      NOFREEZE     DRY
 46   17561   LOW    NO     LS       L      NOFREEZE     DRY
 47   18120   LOW    NO     LS       L      FREEZE       WET
 48   18120   LOW    NO     LS       L      FREEZE       WET
 49   18164   LOW    NO     LS       L      FREEZE       WET
 50   18164   LOW    NO     LS       L      FREEZE       WET
 51   18166   LOW    YES    LS       H      FREEZE       WET
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1The SAS System
11:18 Tuesday, June 1, 1993

OBS    CFTR    THKC    LTRF    CAT    TRCLASS     TEMP      CLI
 52    18166   LOW     YES     LS        H       FREEZE     WET
 53    18167   LOW     YES     LS        L       FREEZE     WET
 54    18167   LOW     YES     LS        L       FREEZE     WET
 55    18168   LOW     NO      LS        H       FREEZE     WET
 56    18168   LOW     NO      LS        H       FREEZE     WET
 57    18170   LOW     NO      LS        L       FREEZE     WET
 58    18170   LOW     NO      LS        L       FREEZE     WET
 59    18523   HIGH    NO      LS        H       FREEZE     WET
 60    18523   HIGH    NO      LS        H       FREEZE     WET
 61    18525   HIGH    YES     LS        H       FREEZE     WET
 62    18525   HIGH    YES     LS        H       FREEZE     WET
 63    18526   HIGH    YES     LS        L       FREEZE     WET
 64    18526   HIGH    YES     LS        L       FREEZE     WET
 65    18530   HIGH    NO      SR        H       FREEZE     WET
 66    18530   HIGH    NO      SR        H       FREEZE     WET
 67    18531   HIGH    YES     LS        H       FREEZE     WET
 68    18531   HIGH    YES     LS        H       FREEZE     WET
 69    18532   HIGH    NO      SR        H       FREEZE     WET
 70    18532   HIGH    NO      SR        H       FREEZE     WET
 71    18535   HIGH    YES     LS        H       FREEZE     WET
 72    18535   HIGH    YES     LS        H       FREEZE     WET
 73    18536   HIGH    YES     LS        L       FREEZE     WET
 74    18536   HIGH    YES     LS        L       FREEZE     WET
 75    18541   LOW     NO      LS        L       FREEZE     WET
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1The SAS System

11:18 Tuesday, June 1, 1993


 OBS     CFTR     THKC     LTRF     CAT     TRCLASS      TEMP       CLI

  76     18541    LOW      NO       LS         L       FREEZE       WET

  77     18547    HIGH     NO       LS         H       FREEZE       WET

  78     18556    LOW      YES      LS         H       FREEZE       WET

  79     18556    LOW      YES      LS         H       FREEZE       WET

  80     18557    LOW      NO       LS         H       FREEZE       WET

  81     20573    LOW      NO       LS         H       NOFREEZE     WET

  82     20573    LOW      NO       LS         H       NOFREEZE     WET

  83     20578    HIGH     NO       LS         L       NOFREEZE     DRY

  84     20578    HIGH     NO       LS         L       NOFREEZE     DRY

  85     20579    LOW      NO       LS         L       NOFREEZE     DRY

  86     20579    LOW      NO       LS         L       NOFREEZE     DRY

  87     20586    LOW      YES      LS         L       NOFREEZE     DRY

  88     20586    LOW      YES      LS         L       NOFREEZE     DRY

  89     20587    LOW      NO       LS         L       NOFREEZE     DRY

  90     20587    LOW      NO       LS         L       NOFREEZE     DRY

  91*    18558    LOW      YES      LS         L       FREEZE       WET

  92*    20588    HIGH     YES      LS         L       NOFREEZE     DRY

  93*     3599    HIGH     YES      LS         H       FREEZE       DRY


        VARIABLES

           CFTR          CENTER FOR TRANSPORTATION NUMBER
        TRCLASS          TRAFFIC CLASS
           LTRF          LOAD TRANSFER
                         YES - DOWELS PRESENT
                         NO  - DOWELS ABSENT
           THKC          THICKNESS CLASS
              *          LTPP TEST SECTION
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1The SAS System
Tuesday, June 1, 1993


 OBS    CFTR    CONT    SECT    JOB    START      END

   1    1551     400       1     11      8.8      8.4

   2    1552     45        7      1      0.4      0.2

   3    1552     45        7      1      0.0      0.2

   4    1553     47        3     21      8.4      6.4

   5    1553     47        3     21      6.2      8.2

   6    1554     47        3     24      6.2      1.6

   7    1554     47        3     24      1.4      6.0

   8    2501     13       10      5      0.0      0.8

   9    2501     13       10      5      1.0      0.2

  10    2505     14       16     20     44.8     46.4

  11    2505     14       16     20     46.4     44.8

  12    2537   2208        1     11     12.2     10.8

  13    2537   2208        1     11     10.8     12.2

  14    2576      8        4     12      0.0      3.0

  15    2576      8        4     12      3.4      0.2

  16    3397    146        7      3      4.2      5.4

  17   12105    271        6      4    734.0    733.4

  18   12505    179        1     14     35.2     41.4

  19   12505     79        1     14     41.4     35.4

  20   12526    110        5     18     60.0     66.2

  21   12526    110        5     18     66.4     60.0

  22   12527    675        8      1     98.2    100.8

  23   12527    675        8      1    110.8     98.4

  24   12537    110        5     17     66.8     72.8

  25   12537    110        5     17     72.8     66.8

  26   12540    675        8      1     91.0     98.0

  27   12540    675        8      2     98.2     91.2
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1The SAS System
Tuesday, June 1, 1993

OBS     CFTR    CONT    SECT      JOB     START      END

 28    12541       .                    .

 29    12548     502       1       22       3.6      3.4

 30    12548     502       1       22       3.2      3.6

 31    12549     502       1       21       3.8      3.6

 32    12549     502       1       21       3.6      3.8

 33    12553     178       2       23      13.0     10.8

 34    12553     178       2       23      10.8     13.6

 35    12554     178       3       46      13.6     16.0

 36    12554     178       3       46      15.4     13.0

 37    12561     271       4       17     727.8    738.8

 38    12561     271       4       17     727.7    733.0

 39    12563     271       6       12     741.8    744.4

 40    12563     271       6       12     744.0    742.0

 41    12563     271       6       12     741.8    744.4

 42    12563     271       6       12     744.0    742.0

 43    12564     502       1       35       3.2      1.6

 44    12564    502        1       35       1.6      3.2

 45    12576    276        4       13     733.2    727.6

 46    12576    271        4       13     733.2    727.6

 47    12590    389        6       30       0.0      0.8

 48    12590    389        6       30       1.0      0.2

 49    13501    179        4       30      15.2     13.8

 50    13506    179        6       18      29.6     28.2

 51    13506    179        6       18      27.8     29.6

 52    13509    271        2       13     711.8    718.0

 53    13509    271        2       14     718.0    712.2

 54    13510    271        2       15     718.2    720.6
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1The SAS System
Tuesday, June 1, 1993


 OBS     CFTR    CONT    SECT     JOB    START      END

  55    13510    271       2       15    720.6    718.2

  56    13512    271       3       11    720.8    721.6

  57    13512    271       3       11    721.6    720.8

  58    13513    271       3       12    721.8    727.2

  59    13514    271       3       13    727.4    727.6

  60    13514    271       3       13    727.8    727.6

  61    17560    426       1        2      0.0      0.6

  62    17560    426       1        2      1.0      0.2

  63    18165    430       1       21     10.2      5.8

  64    18171      9       2       29     12.0     13.4

  65    18171      9       2       29     13.4     12.0

  66    18501     47       7       16     14.2     14.0

  67    18501     47       7       16     14.0     14.8

  68    18502     47       7       14     13.8     13.2

  69    18502     47       7       14     13.2     13.8

  70    18503     47       7       17     13.0     12.0

  71    18503     47       7       17     12.0     13.0

  72    18506     47       7       12     10.2      9.2

  73    18506     47       7       12      9.2     10.2

  74    18507     47       7       24     10.4     11.4

  75    18507     47       7       24     11.4     10.4

  76    18508     47       7       26     11.6     11.4

  77    18508     47       7       26     11.6     11.8

  78    20574     64       8       24      6.2     11.0

  79    20574     64       8       24     11.2      6.8

  80    20575     64       8       16     11.2     16.0

  81    20575     64       8       16     16.2     11.4
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1The SAS System
Tuesday, June 1, 1993


OBS    CFTR    CONT    SECT    JOB    START      END

 82    20576    306      3      55      3.6      2.6

 83    20576    306      3      55      2.4      3.4

 84    20577     28     13      12    855.4    854.0

 85    20584    200     14      29     13.6     11.4

 86    20584    200     14      29     11.2     13.4

 87    20588    177      3      36      5.2      0.6

 88    20590     28      3      59      0.8      7.4

 89    20590     28      3      59      7.6      0.8

 90*   20591     64      8      24

 91*   20592     28      6      39

 93*   20593   3187      2       3

 94*   20594    388      3      47
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1The SAS System

11:18 Tuesday, June 1, 1993


OBS    CFTR    THKC    SLABC    CAT    TRCLASS      TEMP       CLI

  1    1551    LOW      HIG     LS        L        FREEZE      DRY

  2    1552    LOW      HIG     LS        H        FREEZE      DRY

  3    1552    LOW      HIG     LS        H        FREEZE      DRY

  4    1553    HIGH     LOW     LS        H        FREEZE      WET

  5    1553    HIGH     LOW     LS        H        FREEZE      WET

  6    1554    HIGH     LOW     LS        H        FREEZE      WET

  7    1554    HIGH     LOW     LS        H        FREEZE      WET

  8    2501    HIGH     LOW     LS        L        FREEZE      WET

  9    2501    HIGH     LOW     LS        L        FREEZE      WET

 10    2505    LOW      LOW     LS        H        FREEZE      WET

 11    2505    LOW      LOW     LS        H        FREEZE      WET

 12    2537    LOW      HIG     LS        L        FREEZE      WET

 13    2537    LOW      HIG     LS        L        FREEZE      WET

 14    2576    LOW      HIG     LS        H        FREEZE      WET

 15    2576    LOW      HIG     LS        H        FREEZE      WET

 16    3397    LOW      LOW     LS        L        FREEZE      DRY

 17   12105    LOW      HIG     SR        H        NOFREEZE    WET

 18   12505    HIGH     LOW     LS        L        NOFREEZE    WET

 19   12505    HIGH     LOW     LS        L        NOFREEZE    WET

 20   12526    HIGH     HIG     SR        H        NOFREEZE    WET

 21   12526    HIGH     HIG     SR        H        NOFREEZE    WET

 22   12527    HIGH     HIG     LS        H        NOFREEZE    DRY

 23   12527    HIGH     HIG     LS        H        NOFREEZE    DRY

 24   12537    HIGH     HIG     SR        H        NOFREEZE    WET

 25   12537    HIGH     HIG     SR        H        NOFREEZE    WET
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1The SAS System

11:18 Tuesday, June 1, 1993


OBS    CFTR    THKC    SLABC    CAT    TRCLASS      TEMP      CLI

 26    12540   HIGH     HIG     LS        H       NOFREEZE    DRY

 27    12540   HIGH     HIG     LS        H       NOFREEZE    DRY

 28    12541   HIGH     HIG               H

 29    12548   HIGH     HIG     SR        L       NOFREEZE    WET

 30    12548   HIGH     HIG     SR        L       NOFREEZE    WET

 31    12549   HIGH     HIG     SR        L       NOFREEZE    WET

 32    12549   HIGH     HIG     SR        L       NOFREEZE    WET

 33    12553   HIGH     HIG     LS        L       NOFREEZE    WET

 34    12553   HIGH     HIG     LS        L       NOFREEZE    WET

 35    12554   HIGH     HIG     LS        L       NOFREEZE    WET

 36    12554   HIGH     HIG     LS        L       NOFREEZE    WET

 37    12561   HIGH     HIG     LS        H       NOFREEZE    WET

 38    12561   HIGH     HIG     LS        H       NOFREEZE    WET

 39    12563   HIGH     HIG     SR        H       NOFREEZE    WET

 40    12563   HIGH     HIG     SR        H       NOFREEZE    WET

 41    12563   HIGH     HIG     SR        H       NOFREEZE    WET

 42    12563   HIGH     HIG     SR        H       NOFREEZE    WET

 43    12564   HIGH     HIG     SR        L       NOFREEZE    WET

 44    12564   HIGH     HIG     SR        L       NOFREEZE    WET

 45    12576   LOW      LOW     LS        H       NOFREEZE    WET

 46    12576   LOW      LOW     LS        H       NOFREEZE    WET

 47    12590   HIGH     HIG     LS        L       NOFREEZE    DRY

 48    12590   HIGH     HIG     LS        L       NOFREEZE    DRY

 49    13501   HIGH     HIG     LS        L       NOFREEZE    DRY

 50    13506   LOW      HIG     LS        L       NOFREEZE    DRY
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1The SAS System

11:18 Tuesday, June 1, 1993

OBS     CFTR    THKC    SLABC    CAT    TRCLASS      TEMP       CLI

 51    13506    LOW      HIG     LS        L       NOFREEZE     DRY
 52    13509    HIGH     HIG     LS        H       NOFREEZE     DRY
 53    13509    HIGH     HIG     LS        H       NOFREEZE     DRY
 54    13510    HIGH     HIG     LS        H       NOFREEZE     DRY
 55    13510    HIGH     HIG     LS        H       NOFREEZE     DRY
 56    13512    HIGH     HIG     LS        L       NOFREEZE     DRY
 57    13512    HIGH     HIG     LS        L       NOFREEZE     DRY
 58    13513    HIGH     HIG     LS        H       NOFREEZE     DRY
 59    13514    HIGH     HIG     LS        H       NOFREEZE     DRY
 60    13514    HIGH     HIG     LS        H       NOFREEZE     DRY
 61    17560    LOW      LOW     SR        L       NOFREEZE     DRY
 62    17560    LOW      LOW     SR        L       NOFREEZE     DRY
 63    18165    LOW      HIG     LS        H       FREEZE       WET
 64    18171    LOW      LOW     LS        L       FREEZE       WET
 65    18171    LOW      LOW     LS        L       FREEZE       WET
 66    18501    LOW      LOW     LS        H       FREEZE       WET
 67    18501    LOW      LOW     LS        H       FREEZE       WET
 68    18502    LOW      LOW     LS        H       FREEZE       WET
 69    18502    LOW      LOW     LS        H       FREEZE       WET
 70    18503    LOW      HIG     LS        L       FREEZE       WET
 71    18503    LOW      HIG     LS        L       FREEZE       WET
 72    18506    LOW      HIG     LS        H       FREEZE       WET
 73    18506    LOW      HIG     LS        H       FREEZE       WET
 74    18507    LOW      HIG     LS        H       FREEZE       WET
 75    18507    LOW      HIG     LS        H       FREEZE       WET
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1The SAS System

11:18 Tuesday, June 1, 1993

 OBS    CFTR   THKC    SLABC    CAT   TRCLASS     TEMP       CLI

  76   18508   LOW      HIG     LS       H      FREEZE       WET
  77   18508   LOW      HIG     LS       H      FREEZE       WET
  78   20574   LOW      HIG     LS       L      NOFREEZE     DRY
  79   20574   LOW      HIG     LS       L      NOFREEZE     DRY
  80   20575   LOW      HIG     LS       L      NOFREEZE     DRY
  81   20575   LOW      HIG     LS       L      NOFREEZE     DRY
  82   20576   LOW      HIG     LS       L      NOFREEZE     DRY
  83   20576   LOW      HIG     LS       L      NOFREEZE     DRY
  84   20577   LOW      LOW     LS       L      NOFREEZE     DRY
  85   20584   LOW      HIG     LS       H      NOFREEZE     DRY
  86   20584   LOW      HIG     LS       H      NOFREEZE     DRY
  87   20588   HIGH     HIG     SR       H      NOFREEZE     WET
  88   20590   HIGH     HIG     SR       H      NOFREEZE     WET
  89   20590   HIGH     HIG     SR       H      NOFREEZE     WET
  90*  20591   LOW      HIG     LS       L      NOFREEZE     WET
  91*  20592   HIGH     HIG     SR       L      NOFREEZE     WET
  92*  20593   HIGH     HIG     LS       L      NOFREEZE     WET
  93*  20594   HIGH     LOW     SR       L      NOFREEZE     WET
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VARIABLES

CFTR	CENTER FOR TRANSPORTATION NUMBER
THKC	THICKNESS CLASS
TRCLASS	TRAFFIC CLASS
CAT	SR - SELICIOUS RIVER GRAVEL LS - LIME STONE
TEMP	TEMPERATURE CLASS
CLI	CLIMATE
SLABC	SLAB CLASS
*	LTPP TEST SECTION