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16. Abstract

This report outlines the research and recommendations concerning the rehabilitation of IH-10 through the downtown area of El Paso. The project of isolating an appropriate rehabilitation method was broken into three tasks. Task 1 included collecting background information such as traffic data and environmental information, documenting current pavement conditions, and determining District 24's long-term objectives. Task 2 included using the background information collected to consider the various methods of rehabilitation that would be appropriate to use in the downtown area of El Paso. Task 3 included developing a preliminary set of bonded concrete overlay design plans that are cost-effective and meet the district's needs for a long-term rehabilitation plan.

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FEASIBILITY STUDY FOR A FULL-SCALE BONDED CONCRETE OVERLAY ON IH-10 IN EL PASO, TEXAS

by

Brent T. Allison
B. Frank McCullough
David W. Fowler

Research Report 1957-1F

Full-Scale Bonded Concrete Overlay on IH-10 in El Paso

Research Project 3-24D-92-1957

conducted for the

Texas Department of Transportation

by the

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

January 1993

IMPLEMENTATION STATEMENT

A viable rehabilitation procedure for continuously reinforced concrete pavement is the bonded concrete overlay. This rehabilitation procedure is especially attractive on such heavily traveled urban freeways as IH-10 through the downtown area of El Paso. Through the use of background information, laboratory testing, on-site testing, and previous research from various sources, CTR has developed a rehabilitation design recommendation to meet the needs of District 24. In this report various remaining life models and thickness design methods are used to isolate the best recommendation for rehabilitation. The recommendation that was isolated includes placing a bonded concrete overlay on the observed research sections.

Prepared in cooperation with the Texas Department of Transportation

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There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

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Research Supervisors

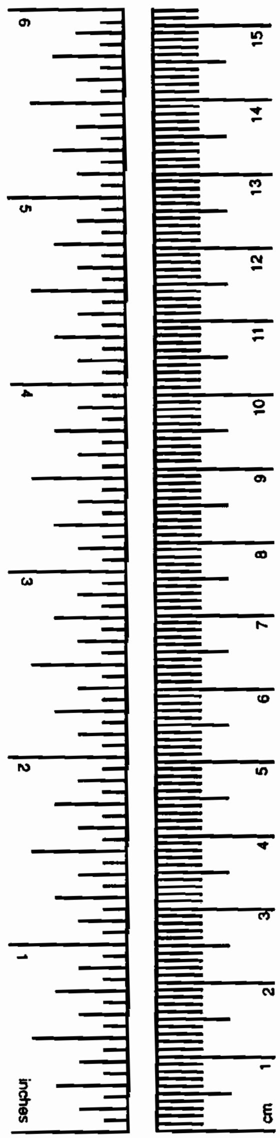
METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.0765	meters cubed	m^3

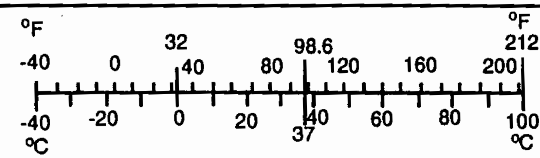
NOTE: Volumes greater than 1,000 L shall be shown in m^3.

Symbol	When You Know	Multiply by	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.20	square yards	yd^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1,000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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SUMMARY

This report outlines the research and recommendations concerning the rehabilitation of a section of IH-10 running through downtown El Paso. The effort to isolate an appropriate rehabilitation method was broken into three tasks. Task 1 included collecting background information (such as traffic data and environmental information), documenting current pavement conditions, and determining District 24's long-term objectives. Task 2 included using the background information collected to consider the various methods of rehabilitation that would be appropriate to use in the downtown area of El Paso. Task 3 included developing a preliminary set of bonded concrete overlay design plans that are cost-effective and which meet the district's needs for a long-term rehabilitation plan.

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

In large metropolitan areas, such as Houston and Dallas, many sections of the interstate highway system are nearing the end of their design life. Their structural and functional capability can be improved with routine maintenance, by rehabilitation, or by new construction. Nowadays, rehabilitation is proving to be a viable method for maintaining the interstate highways in a cost-effective manner. Rehabilitation improves riding quality and structural strength at a cost relatively lower than that of alternative methods.

One rehabilitation method, applied successfully on Loop 610 in Houston, is bonded concrete overlays. Under contract with the El Paso District (District 24)of the Texas Department of Transportation (TxDOT), the Center for Transportation Research (CTR) is conducting a feasibility study to identify a successful and cost-effective rehabilitation strategy, such as bonded concrete overlays. This report documents all aspects of the data collection and engineering analysis relative to the rehabilitation of the IH-10 section running through downtown El Paso.

1.2 OBJECTIVE

The purpose of this project is to characterize the existing pavement and its support materials, and to recommend a bonded concrete overlay (BCO) design. Other rehabilitation alternatives that satisfy basic pavement design criteria and are economically feasible will also be considered.

1.3 SCOPE

The proposed rehabilitation section is approximately 1.5 miles long and includes an overpass, several underpasses, and a depressed section. Figure 1.1 shows the location of the proposed rehabilitation section.

In order to characterize the existing pavement structure, it is necessary to gather all available background information pertaining to this section. This information includes environmental factors, pavement condition, traffic data, and original construction information. The following background information has been gathered:

(1) *Deflections:* The falling weight deflectometer (FWD) measurements were taken in the eastbound and westbound inside lanes, along the entire length of the proposed section. The measurements were taken in the right-hand wheel path, going with the flow of traffic. Two FWD measurements were taken every 100 feet. The first FWD measurement was taken across a crack. The crack ran between the first and the second sensor of the FWD. The second measurement was taken a few feet down the road; there were no cracks within the seven sensors. By comparing the two measurements, load transfer can be calculated. This information is useful for determining the pavement material properties, evaluating the performance of the existing BCO, and correlating future FWD measurements.

(2) *Condition Survey:* A detailed condition survey was conducted in order to locate the existing cracks, punchouts, spalls, and repairs. The results of the condition survey were recorded—or "mapped"—on a survey form provided by CTR. The survey forms also include the locations of all testing (e.g., FWD and coring) which has taken place in gathering the background information. The forms are useful for determining crack spacing and for documenting the pavement's condition. They also make it possible to compare the current pavement condition with data to be collected in future condition surveys.

(3) *Traffic Data:* Traffic data are some of the most important aspects to consider in rehabilitation design development. The proposed study section is known as the "depressed" section of IH-10 through downtown El Paso because the section goes from four lanes in each direction to three lanes, without a decrease in the amount of traffic. As traffic increases, subsequent damage to the pavement will likewise

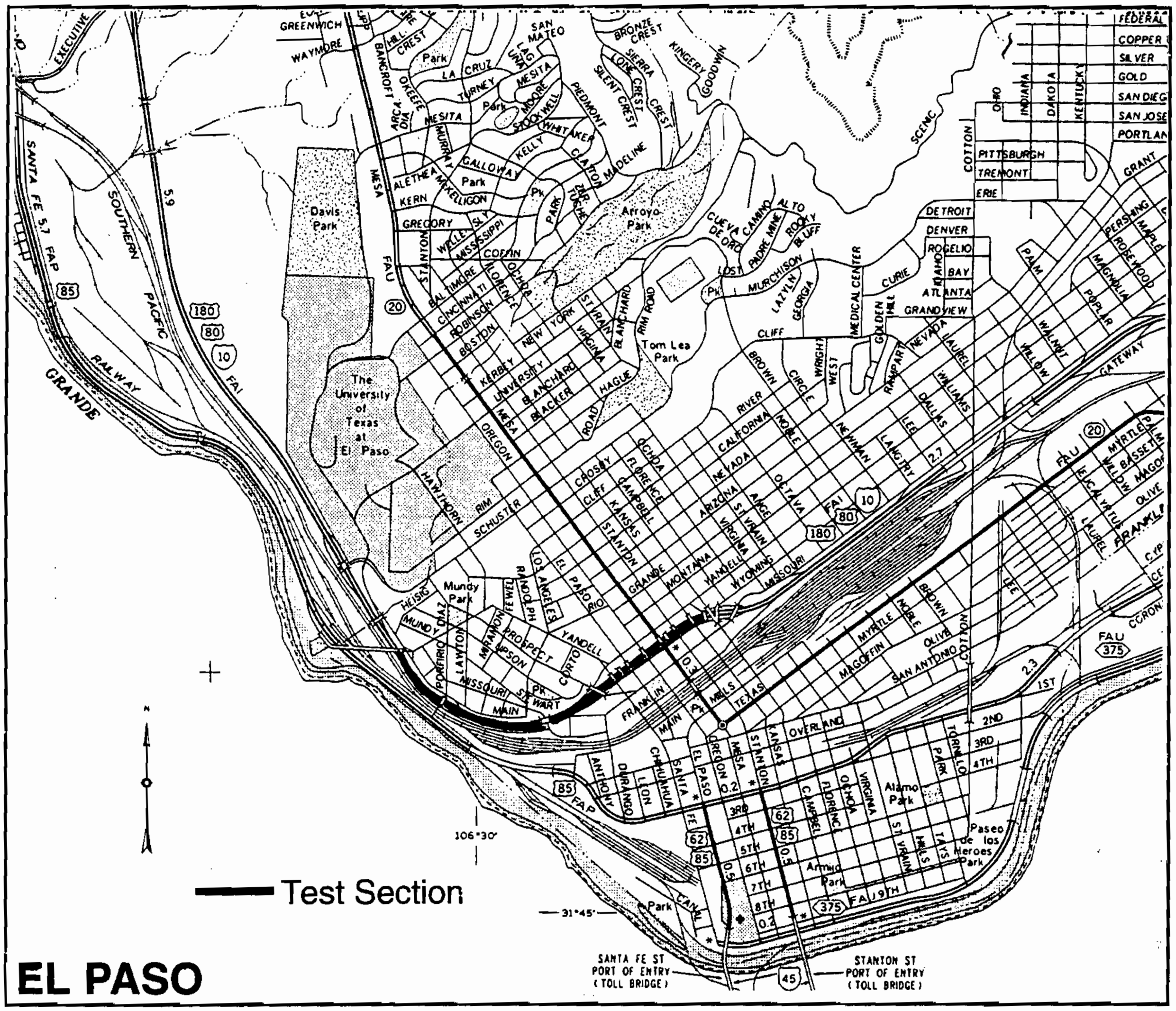


Figure 1.1 Location of proposed rehabilitation section on IH-10

increase. The AASHTO guide offers a mixed stream of different axle loads and axle configurations into a design traffic volume that is the summation of an equivalent number of 18-kip single-axle loads (18-kip ESAL) over the design period. The historic traffic data were used to predict future traffic numbers.

(4) *Cores:* Sixteen cores were obtained from the proposed rehabilitation section's existing continuously reinforced concrete pavement. Eight cores were taken in each direction, one every 1,000 feet. The cores were used to verify the original pavement thickness and physical characteristics (splitting tensile strength and modulus of elasticity).

(5) *Economic Variables:* For overlay design, a consideration of the economic factors used to choose optimal design strategy is very important. Economic factors are the key to choosing the most cost-effective method under given conditions. Some economic variables to consider are construction cost, user cost, design lives, life-cycle cost, and maintenance cost. Another economic variable which may be considered in the future is the possible need for lane expansion. With the amount of traffic congestion flowing through the downtown area, it may be necessary to consider the feasibility of expanding the depressed section to four lanes.

CHAPTER 2. FIELD OBSERVATION

2.1 DESCRIPTION OF PROJECT SECTION

Interstate Highway 10 was constructed with CRCP across the downtown area of El Paso in 1965. The selected project is located between mileposts 18.5 and 20.0 in the eastbound and westbound lanes. This section is approximately 8,000 feet in each direction. At this location, the roadway consists of three lanes in each direction, expanding to four lanes at both approach ends to the depressed section. Coring, deflection measurements, and condition surveys were all taken from the inside lane or from the lane closest to the concrete median barrier. The widths of main lanes are 12 feet and the widths of the outside shoulders are 10 feet. A typical cross-section from the proposed rehabilitation area is displayed in Figure 2.1.

2.2 DEFLECTION DATA ANALYSIS

2.2.1 Background

When a major rehabilitation project is being considered, some pavement testing activities must be conducted in order to determine the existing pavement properties. These activities include deflection testing, condition surveys to identify surface distress, and coring to determine the physical characteristics of the existing pavement layers.

Results from the data collected show some variation in pavement condition along the roadway. The test sections were divided according to the detectable variations in deflection measurements (Ref 1). This was accomplished by analyzing the data from the FWD and combining the Standard Judgment Method and the AASHTO Guide Method for dividing the sections.

The ability to determine the general boundary location of each unit is critical in analyzing the pavement design. These units form the basis on which more specific analyses are conducted.

Historical information about pavements, such as pavement type, construction history, traffic, and pavement condition, can be used to help determine the length of each analysis unit. However, it is difficult to obtain all the needed historical data and to determine their accuracy. For this project, the "Measured Pavement Response" approach was selected to analyze the deflection data and to isolate specific analysis units.

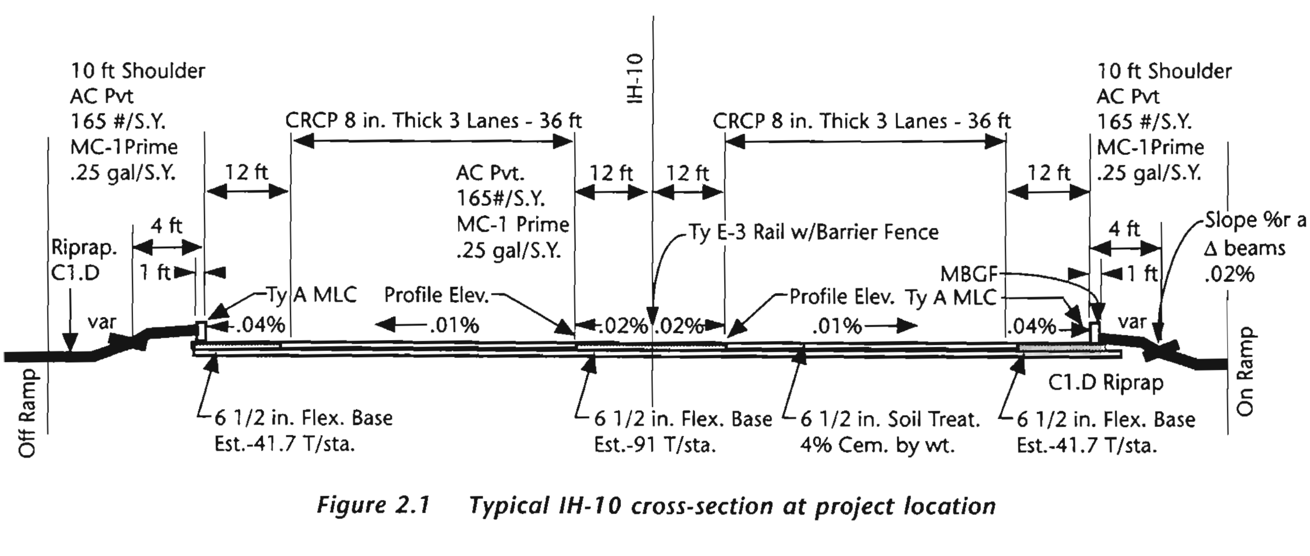


Figure 2.1 Typical IH-10 cross-section at project location

Figure 2.2 Falling weight deflectometer (FWD)

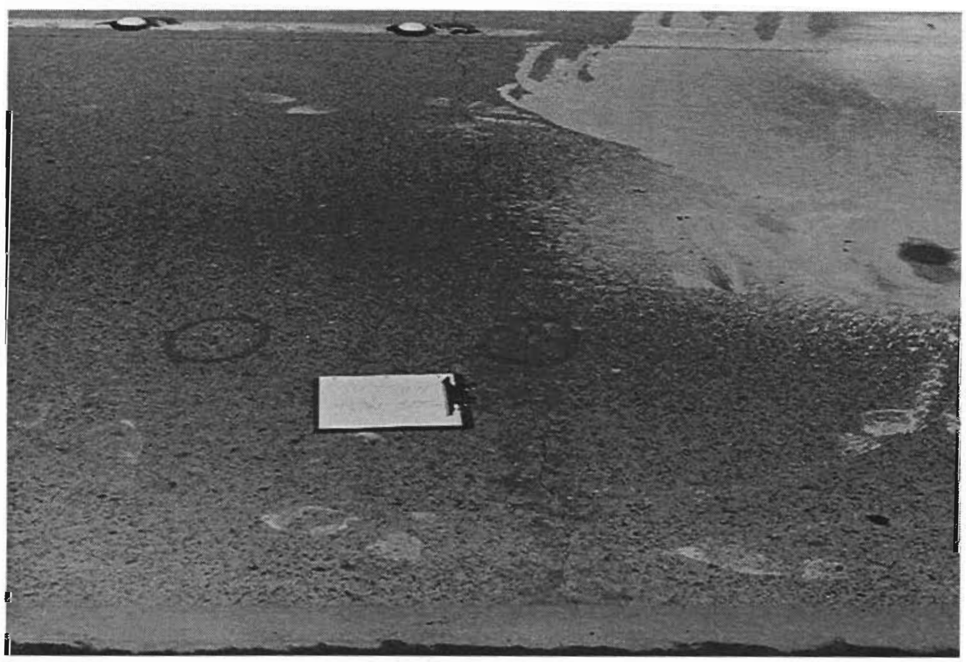


Figure 2.3 FWD markings on a crack and downstream from the crack

Two deflection measurements were taken every 100 feet. The first deflections were taken across a crack and the second on a section having no cracks within the seven sensors. The mean of both deflection measurements was analyzed and compared. This testing was accomplished and coupled with statistical testing to ensure the accuracy of the measurements.

Comparing a deflection across a crack with one from a section having no crack within its sensors allows a comparison of the population means of the two deflection measurements. The null hypothesis states that there should be no significant difference between the mean of the two populations. The tests were conducted as follows:

(1) *Hypothesis:*

Null hypothesis	Ho: u1 = u2
Alternative hypothesis	H1: u1 > u2 *or* u1 < u2

(2) *Statistics:* Because the number in this sample is greater that 30, the Z test must be used.

$$Z = \frac{\text{Mean Difference}}{\frac{\text{S.V.}}{\sqrt{n}}}$$

(3) *Statistical Significance Level:* (alpha) = 0.05

(4) *Test Results*

The test results are shown in Appendix A. In the individual seventh deflection sensor there was found to be little variation between groups. In comparing the individual first deflection sensors in each group, we found a large amount of variability. Because of these results, the mean value for the first sensor cannot be used to determine the unit parameters.

2.2.2 Development of Homogeneous Units

In order to accurately identify homogeneous sections based on deflection data, we used the following two methods.

(1) *Standard Judgment Method:* This method may be the simplest way to determine the unit parameters. The method is completed by using the following steps:
   - Plot sensors 1 and 7 versus station number, using the third and fourth drop of FWD data.
   - Divide plot into homogeneous units according to the fluctuation in the graphed line.
   - Perform test to verify the sections are statistically different at the significance level established (alpha = 0.05).

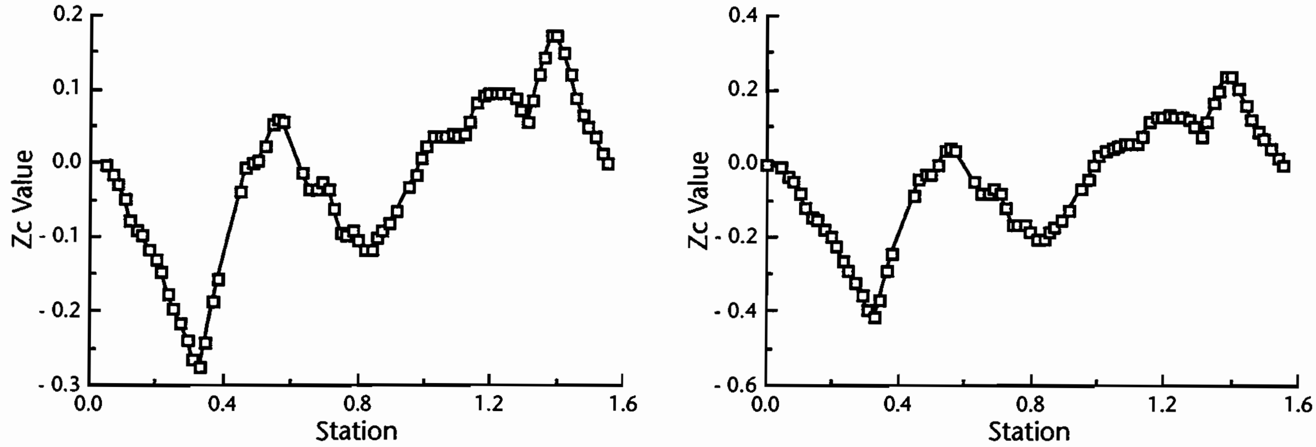
Appendix B includes an example of a short section of the deflection profile which illustrates the unit limits along the wheel path. The standard judgment method is simple, is quick, and shows definite unit limits when given data exhibit different properties at every possible unit. When the properties are similar it is difficult to identify unit parameters. Because this method relies on the operator to distinguish the unit parameters, it is subject to the judgment of the operator.

(2) *AASHTO Guide Method:* The AASHTO guide method relies on the variable Zc to analyze homogeneous unit limits (Ref 1). This method includes the following steps:
   - Using the average of sensor 7 at every test point, Zc variable can be determined.
   - For w1, before-and-after cracking measurements were used to determine Zc variable.
   - Plot each Zc variable versus station number using the third and fourth drops; the unit limits will be automatically placed according to the graphed line fluctuation.

The unit limits defined by the AASHTO guide method utilize the third and fourth drop load from the falling weight deflectometer. The eastbound and westbound results appear to be similar. With sensors 1 or 7, the results are a little different, as shown in the graphs in Figures 2.4 through 2.7. The final decision of unit boundaries is made by combining the standard judgment method and the AASHTO guide method. By comparing the plots that come from these two methods, the final unit parameters can be selected as shown in Table 2.1.

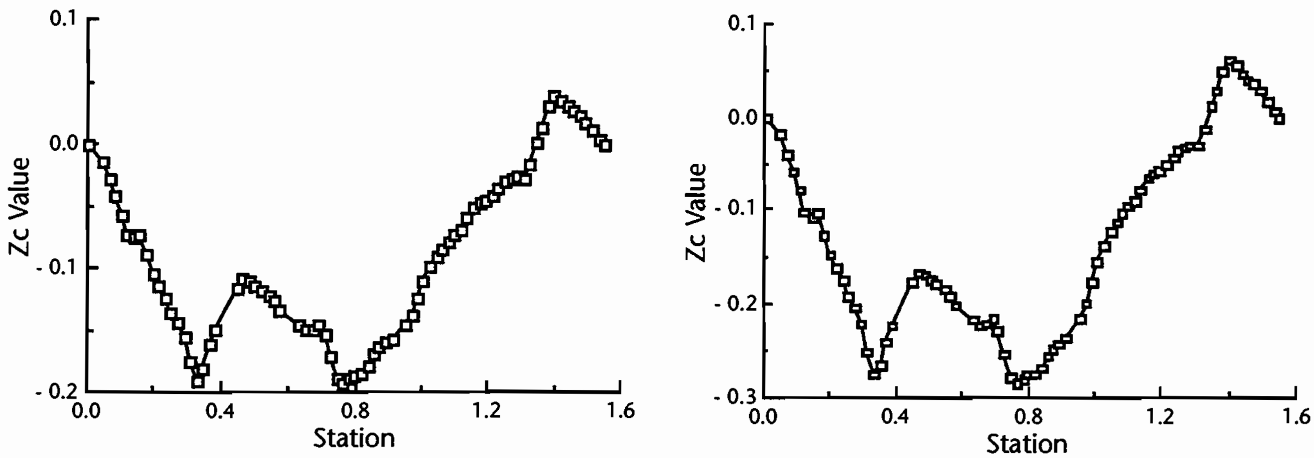
2.2.3 Deflection Analysis

To enable the FWD measurements to be taken in the same locations after the overlay was placed, the deflection locations were mapped on condition survey forms. Tables 2.2 and 2.3 represent the means and standard deviations of deflections of all sensors in the midspan area (deflections with no cracks within the sensors). Figures 2.8 and 2.9 are the plots of Tables 2.2 and 2.3. These data provide important information for the pavement engineer. Each sensor provides information about the performance of the various layer characteristics. The first sensor generally shows the properties of the surface layer. The last sensor provides the properties of the subgrade pavement structure (Ref 2). The PCC layers of sections



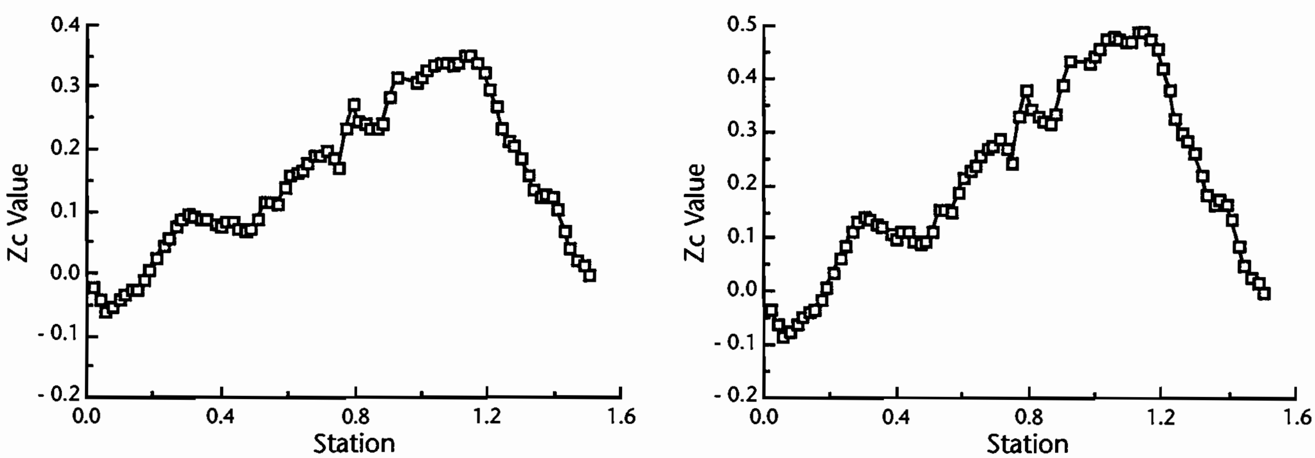
a) Third drop *b) Fourth drop*

Figure 2.4 Using W1 of eastbound direction, third and fourth drops



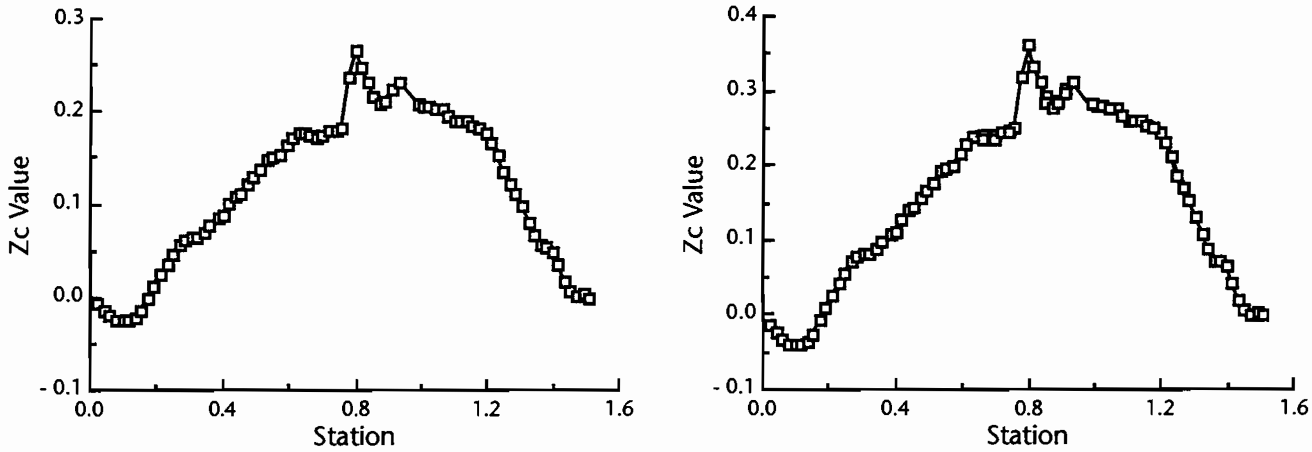
a) Third drop *b) Fourth drop*

Figure 2.5 Using W7 of eastbound direction, third and fourth drops



a) Third drop *b) Fourth drop*

Figure 2.6 Using W1 of westbound direction, third and fourth drops



a) Third drop *b) Fourth drop*

Figure 2.7 Using W7 of westbound direction, third and fourth drops

Table 2.1 Homogenous section delineation

	Eastbound Section Number				
	1	2	3	4	5
Mile	0 – 0.34	0.34 – 0.54	0.54 – 0.795	0.795 – 1.360	1.360 – End
Feet	(0 – 1,800)	(1,800 – 2,850)	(2,850 – 4,200)	(4,200 – 7,200)	(7,200 – 8,000)

	Westbound Section Number				
	1	2	3	4	5
Mile	0 – 0.160	0.160 – 0.568	0.568 – 0.925	0.925 – 1.174	1.174 – End
Feet	(0 – 850)	(850 – 3,000)	(3,000 – 5,000)	(5,000 – 6,200)	(6,200 – 8,000)

Table 2.2 Means and standard deviations (third drop eastbound)

	Sensors						
Sections	1	2	3	4	5	6	7
1	4.51	3.89	3.17	2.47	1.86	1.39	1.03
	(0.77)	(0.77)	(0.73)	(0.67)	(0.62)	(0.57)	(0.50)
2	6.88	6.24	5.36	4.35	3.39	2.58	1.95
	(1.22)	(1.09)	(1.02)	(0.95)	(0.78)	(0.65)	(0.55)
3	4.94	4.43	3.70	2.93	2.28	1.72	1.33
	(1.22)	(1.14)	(0.96)	(0.75)	(0.64)	(0.52)	(0.45)
4	5.82	5.23	4.55	3.83	3.12	2.53	2.03
	(0.63)	(0.60)	(0.54)	(0.45)	(0.39)	(0.34)	(0.30)
5	5.18	4.63	3.94	3.28	2.69	2.17	1.77
	(1.22)	(1.15)	(1.00)	(0.83)	(0.70)	(0.59)	(0.48)

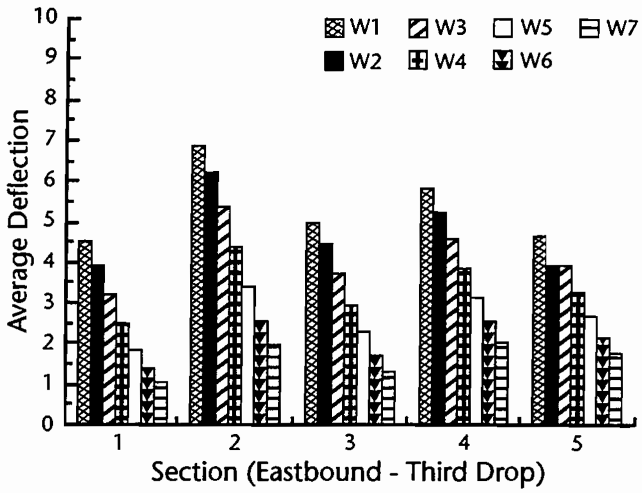


Figure 2.8 *Means and standard deviations of deflections*

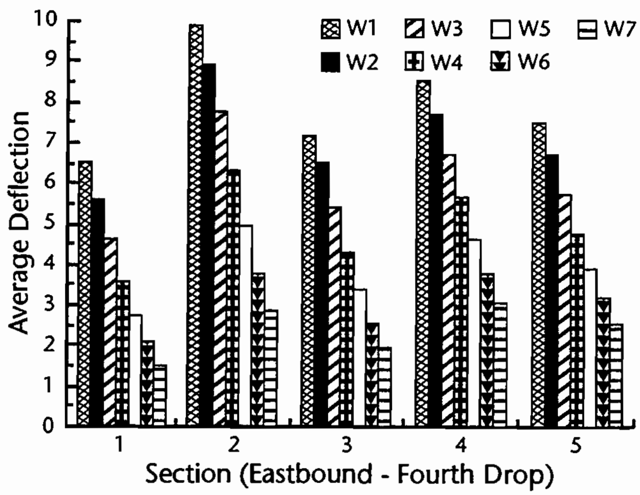


Figure 2.9 *Means and standard deviations of deflections*

Table 2.3 *Means and standard deviations of deflections*

	Sensors						
Sections	1	2	3	4	5	6	7
1	6.54 (1.05)	5.65 (1.10)	4.62 (1.03)	3.61 (0.95)	2.74 (0.89)	2.06 (0.79)	1.53 (0.71)
2	9.91 (1.69)	8.96 (1.55)	7.76 (1.45)	6.32 (1.29)	4.96 (1.09)	3.78 (0.91)	2.86 (0.77)
3	7.20 (1.71)	6.53 (1.58)	5.43 (1.33)	4.29 (1.07)	3.37 (0.88)	2.56 (0.78)	1.96 (0.68)
4	8.53 (0.95)	7.69 (0.92)	6.71 (0.81)	5.69 (0.67)	4.63 (0.56)	3.78 (0.46)	3.04 (0.40)
5	7.54 (1.72)	6.73 (1.60)	5.74 (1.41)	4.77 (1.19)	3.90 (1.00)	3.17 (0.84)	2.57 (0.69)

2 and 4 of the eastbound direction are as good as those of the other sections. Sections 2 and 4 show much higher deflections, but section 2 shows more severe distress than section 4. This is due to the larger standard deviation found in section 2, compared with that in section 4. The condition survey results, to be shown in the next chapter, show a higher number of cracks in sections 2 and 4.

In the westbound sections, deflection measurements show relatively lower values than those of the eastbound. The second, third, and fourth sections have similar mean values, while the standard deviations (which show the dispersion of their samples) are different. This means that each of the three sections consists of various unique pavement characteristics which must be considered carefully. Tables 2.4 and 2.5 represent the means and standard deviations of deflections of all sensors in the midspan area (deflections with no cracks within the sensors). Figures 2.10 and 2.11 are the plots of Tables 2.4 and 2.5.

2.3 Condition Survey

Condition surveys are generally conducted in order to monitor various distress types before the overlay construction, and to estimate the remaining life of existing pavement sections. A detailed condition survey mapping the severity and magnitude of distress was conducted over all test sections, running from milepost 20 to milepost 18.4 in both the eastbound and westbound lanes. This is approximately 8,000 feet in each direction. The maps include the locations of all testing, distress, repairs, and landmarks (such as bridge decks and overpasses). In general, eastbound lanes tended to have more cracking and distress than westbound lanes. The cracks seem to meander more and be less transverse than those in westbound lanes. Figures 2.12 and 2.13 show the typical cracking in each direction.

In general, the pavement is in good shape, considering the number of years the pavement has been in place. (Most sections of IH-10 in downtown El Paso were placed 27 years ago.) There is relatively little distress visible within the 8,000 feet of pavement that were surveyed for this study. Some distresses, such as patching, spalling, failed joints, and popouts, were found and recorded on the condition surveys. Examples of these failures are illustrated in Figures 2.14 through 2.17. The condition survey maps were computerized upon return to CTR. The condition surveys provided information about crack spacing and crack severity.

In order to index the types of distress, we divided them into separate categories and then subdivided them by severity. Patching, for example, was considered severe if it covered more than 1 square yard on the surface of the pavement. Tables 2.6 and 2.7 summarize various distress types separately.

2.4 Cores

Sixteen 4-inch-diameter cores were taken in order to identify the material characteristics. Figure 2.18 shows the portable coring rig being operated by TxDOT testing personnel from Odessa.

A general description of the cores is given in Tables 2.8 and 2.9 according to direction. Four of the 16 cores were taken with a crack running through the middle of the core. This allowed the crack configuration to be examined through the pavement to the base. The detailed laboratory core testing results will be discussed in Chapter 3.

2.5 Traffic Data

Traffic data were obtained through the planning division. Because traffic volume is directly related to the long-term performance of pavements, it is very important to get accurate information about traffic loadings. The percentage of truck traffic is especially important for the pavement design engineer. General information about the IH-10 traffic volume and its typical user type was obtained from the El Paso District. In order to accurately estimate the percentage of trucks using IH-10, the arithmetic mean of three sample records was adapted for the calculation. As shown in Table 2.11, about 35 percent of total traffic volume is made up of truck traffic. The high percentage of truck traffic comes from the regional characteristics of El Paso. El Paso is located on the border of Mexico and the United States. Because it is a major border city, large amounts of freight pass through IH-10 downtown. The target sections are located in the downtown area and thus experience heavy amounts of traffic. The largest body of traffic consists primarily of passenger cars and buses. A target point near El Paso was fixed and analyzed to obtain a detailed analysis of traffic volume. It is assumed that the same number of trucks is presently moving on the target section. According to the AASHTO guidelines, all traffic volume should be transformed into equivalent single-axle loads (ESALs). For this analysis, it is assumed that the portion of distribution in vehicle type will be continuous in the future and that the general growth rate of traffic will be 4 percent for the 20-year analysis period. Table 2.10 is an estimation of slab thickness versus time.

Table 2.4 Means and standard deviations of deflections

	Sensors						
Sections	1	2	3	4	5	6	7
1	4.74 (0.98)	4.10 (0.91)	3.44 (0.76)	2.80 (0.59)	2.22 (0.46)	1.74 (0.31)	1.37 (0.22)
2	5.32 (0.74)	4.72 (0.65)	4.08 (0.61)	3.47 (0.54)	2.87 (0.44)	2.35 (0.38)	1.93 (0.32)
3	5.55 (1.81)	4.96 (1.83)	4.25 (1.79)	3.53 (1.70)	2.84 (1.56)	2.23 (1.39)	1.74 (1.25)
4	5.15 (0.63)	4.48 (0.58)	3.82 (0.56)	3.11 (0.50)	2.43 (0.41)	1.89 (0.35)	1.43 (0.26)
5	3.95 (0.76)	3.37 (0.72)	2.77 (0.67)	2.22 (0.62)	1.69 (0.52)	1.28 (0.44)	0.97 (0.36)

Table 2.5 Means and standard deviations of deflections

Sections	Sensors 1	2	3	4	5	6	7
1	6.85 (1.35)	5.96 (1.31)	4.99 (1.07)	4.03 (0.82)	3.18 (0.58)	2.51 (0.41)	1.97 (0.26)
2	7.65 (1.07)	6.81 (0.94)	5.88 (0.88)	4.96 (0.78)	4.12 (0.62)	3.39 (0.52)	2.77 (0.44)
3	7.98 (2.53)	7.13 (2.57)	6.11 (2.49)	5.08 (2.34)	4.09 (2.16)	3.24 (1.95)	2.55 (1.74)
4	7.45 (0.94)	6.63 (0.97)	5.63 (0.85)	4.60 (0.72)	3.61 (0.62)	2.81 (0.49)	2.18 (0.41)
5	5.74 (1.08)	4.94 (1.08)	4.09 (0.99)	3.27 (0.87)	2.53 (0.74)	1.94 (0.63)	1.47 (0.54)

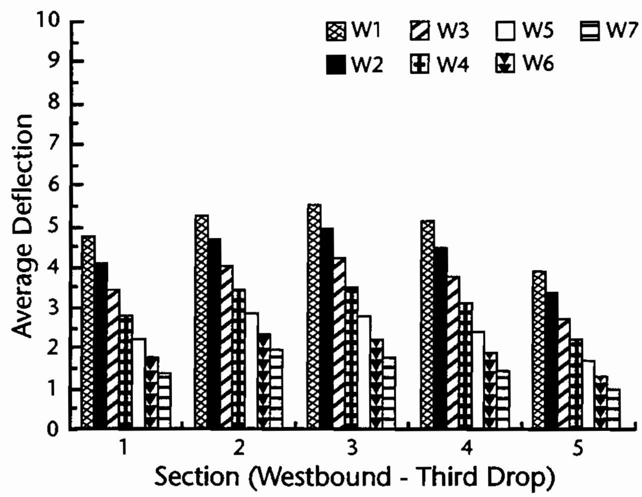


Figure 2.10 Means and standard deviations of deflections

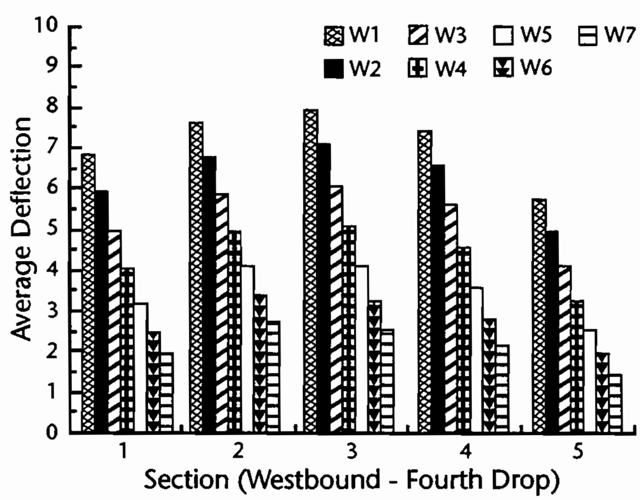


Figure 2.11 Means and standard deviations of deflections

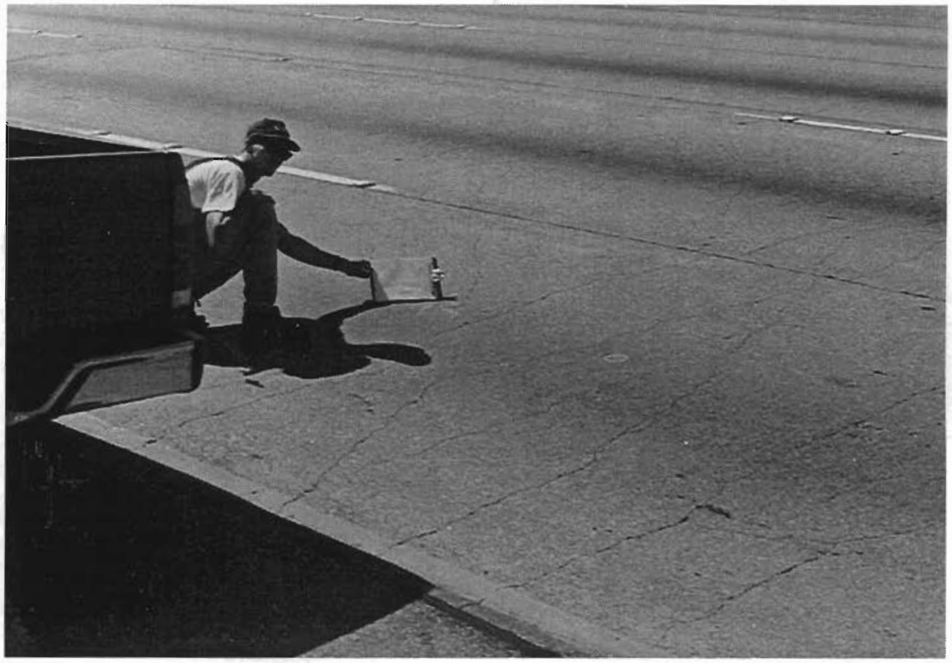


Figure 2.12 Typical cracking of eastbound lanes

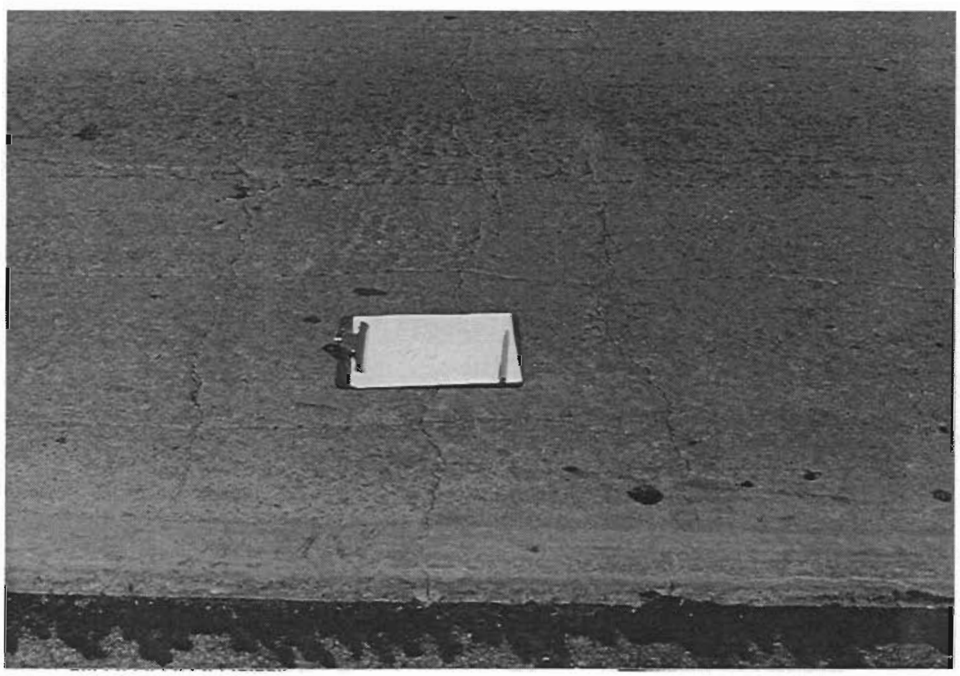


Figure 2.13 Typical cracking of westbound lanes

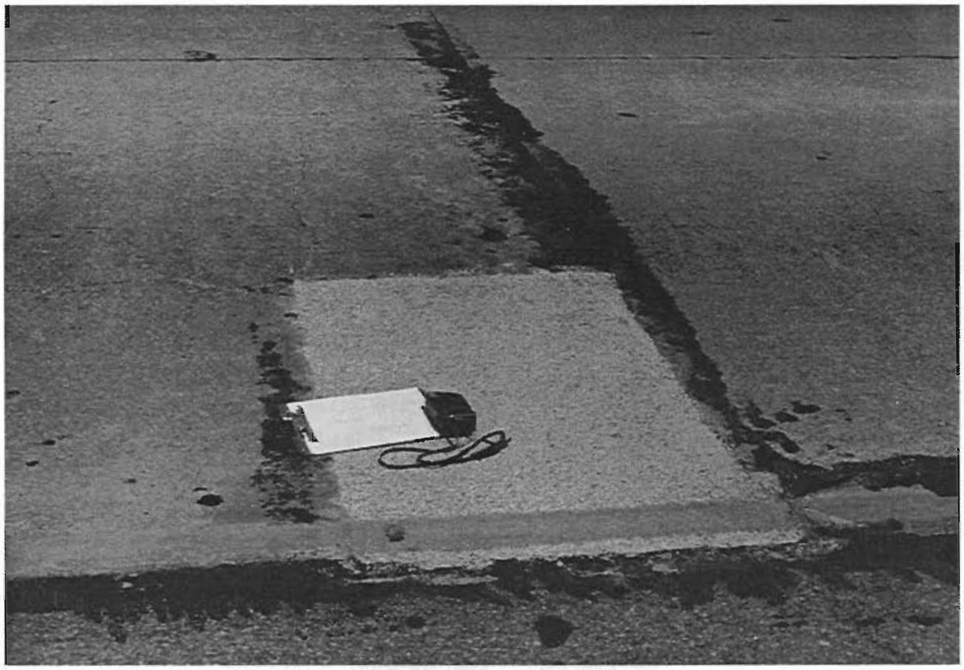


Figure 2.14 Example of patching on IH-10

Figure 2.15 Example of spalling on IH-10

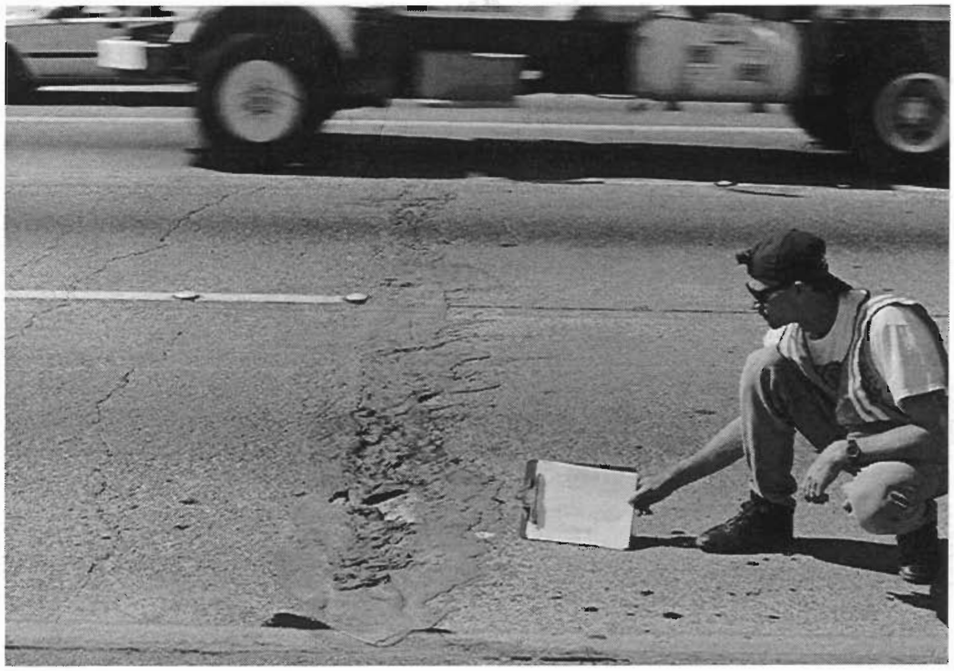


Figure 2.16 Example of a failed joint on IH-10

Figure 2.17 Example of popout on IH-10

Table 2.6 Condition survey distress in eastbound direction

Section	Vertical: Total Number of Cracks	Vertical: Average Crack Spacing (ft)	Patching: Severe	Patching: Minor	Holes Remaining Unpatched	Punchout
1	334	5.39	1	0	0	13
2	186	5.65	0	0	0	7
3	169	6.92	0	0	3	6
4	617	4.86	2	0	6	25
5	97	8.25	0	2	2	2

Table 2.7 Condition survey distress in westbound direction

Section	Vertical: Total Number of Cracks	Vertical: Average Crack Spacing (ft)	Patching: Severe	Patching: Minor	Holes Remaining Unpatched	Punchout
1	137	6.20	0	0	0	0
2	451	4.77	0	1	11	11
3	334	5.62	1	0	4	7
4	209	7.48	0	0	3	4
5	303	5.94	0	0	0	7

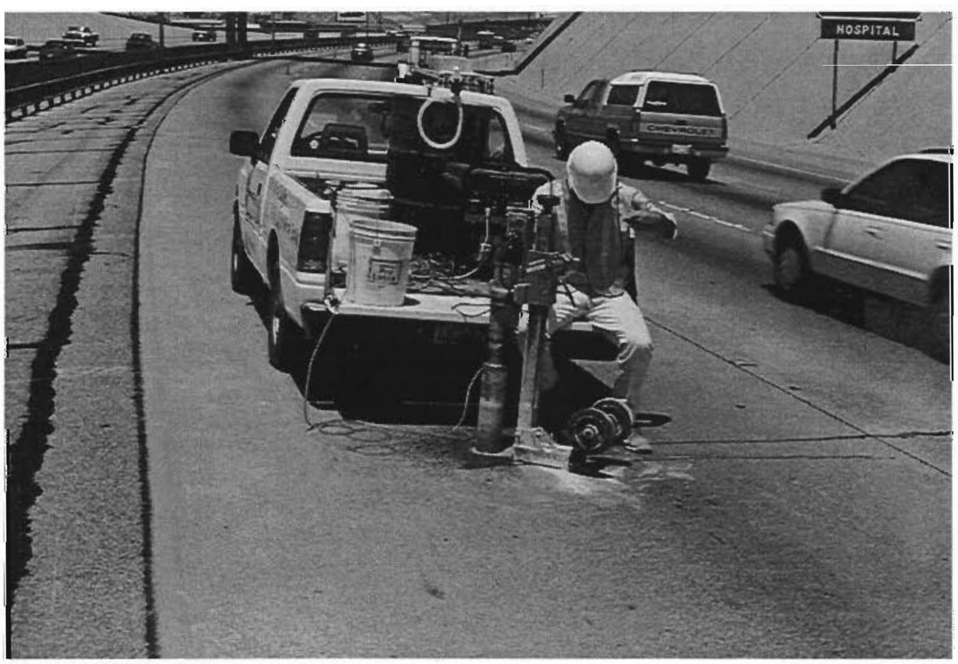


Figure 2.18 Coring on IH-10 westbound

Table 2.8 Core descriptions in westbound direction

Specimen	Height (in.)	Width (in.)	Description
W1	8.34 to 8.67	4.00	Small voids; rebar; not vertical
W2	7.78 to 8.00	3.94	Small void; rebar; not vertical; cracked throughout
W3	7.81 to 8.34	3.94	Small voids; no rebar; not vertical
W4	7.94 to 8.09	3.97	Tiny voids; rebar; not vertical
W5	8.17 to 8.44	3.95	Tiny voids; rebar; not vertical
W6	7.97 to 8.13	3.97	Small voids; rebar; not vertical
W7	8.34 to 8.59	3.97	Walls not straight due to coring; rebar; not vertical; cracks throughout
W8	8.50 to 8.75	3.97	Branching cracks; several voids; rebar; not vertical

Table 2.9 Core descriptions in eastbound direction

Specimen	Height (in.)	Width (in.)	Description
E1	8.88 to 9.16	4.00	3 large voids; rebar; not vertical
E2	8.44 to 8.63	4.00	1 void; rebar; not vertical; cracks throughout
E3	8.41 to 8.56	4.00	Small crack; rebar; not vertical; 1 void
E4	8.19 to 8.47	3.95	No large voids; no rebar; not vertical
E5	7.50 to 7.88	3.97	Rebar; not vertical
E6	7.59 to 7.89	3.95	Small voids; no rebar; not vertical
E7	7.78 to 7.89	4.00	Small voids; rebar; cracks throughout
E8	8.19 to 8.69	3.95	3 large voids; no rebar; not vertical

Table 2.10 Slab thickness versus time

Slab Thickness (in.)	Years 1992 – 2002	Years 1992 – 2007	Years 1992 – 2012
8	1,430,000	23,800,000	35,500,000
9	1,460,000	24,400,000	36,300,000
10	1,480,000	24,700,000	36,700,000
11	1,490,000	24,800,000	36,900,000
12	1,490,000	24,900,000	37,100,000
13	1,490,000	24,900,000	37,100,000
14	1,490,000	24,900,000	37,100,000

Equivalent Single Axle Load ($P_t = 2.5$)
Direction distribution = 50:50
Lane distribution factor = 0.5

Table 2.11 Approximate vehicle classification data on IH-10

	IH-10 (MS-117)	Traffic Volume (%)	IH-10 (MS-123)	Traffic Volume (%)	IH-10 (MS-152)	Traffic Volume (%)	Arithmetic Mean	Traffic Volume (%)
Passenger Car	38,421	66.13	16,906	65.40	2,679	40.43	58,006	64.04
Truck								
Single Unit								
Panel and Pickup	11,398	19.62	4,866	18.82	670	10.11	16,934	18.70
Other 2-Axle	1,415	2.44	812	3.14	273	4.12	2,500	2.76
3-Axle	795	1.37	123	0.48	49	0.74	967	1.07
4-Axle	2	0.00	0	0.00	0	0.00	2	0.00
Total Single Unit	13,610	23.43	5,801	22.44	992	14.97	20,403	22.53
Combinations								
Semi-trailer								
3-Axle	117	0.20	42	0.16	9	0.14	168	0.19
4-Axle	205	0.35	93	0.36	80	1.21	378	0.42
5-Axle	4,999	8.60	2,658	10.28	2,636	39.78	10,293	11.36
6-Axle or more	91	0.16	28	0.11	9	0.14	128	0.14
Sub-total	5,412	9.32	2,821	10.91	2,734	41.26	10,967	12.11
Semi-trailer-trailer								
5-Axle	131	0.23	171	0.66	128	1.93	430	0.47
6-Axle	12	0.02	44	0.17	56	0.85	112	0.12
7-Axle or more	0	0.00	3	0.01	0	0.00	3	0.00
Sub-total	143	0.25	218	0.84	184	2.78	545	0.60
Total Combination	5,555	9.56	3,039	11.76	2,918	44.04	11,512	12.71
Total Trucks	19,165	32.99	8,840	34.20	3,910	59.01	31,915	35.24
Total Buses	513	0.88	103	0.40	37	0.56	653	0.72
Total Count	58,099	100.00	25,849	100.00	6,626	100.00	90,574	100.00

Source: Policy and Planning Division, TxDOT

CHAPTER 3. LABORATORY TESTING

Core specimens were taken from the eastbound and westbound sections of pavement on IH-10 in El Paso. Two material characteristics—modulus of elasticity and splitting tensile strength—were determined by using test methods ASTM-C-469 and ASTM-C-496, respectively. Details of the procedures used in these two tests are given in this chapter, together with the test results.

3.1 TESTING PROGRAM

Sixteen concrete cores were taken, eight in each direction. The cores were taken approximately 1,000 feet apart in the right wheelpath of the inside travel lane. Four of the sixteen cores were taken over surface cracks. Figure 3.1 is an example of a core taken over a crack in the surface. A crack in the core allows the crack configuration to be observed from the surface down to the base. The core diameters varied slightly with wear of the core barrel. Specific core dimensions and descriptions of the cores are shown in Tables 2.8 and 2.9.

Eleven cores contained a section that had a transverse reinforcement bar running through the middle of the core. Although neither test method permits steel in the specimens, cutting above and below the steel on all cores would have rendered many of the specimens unacceptably short for testing. In order to show the difference between cores containing steel and cores with no steel, a few cores were cut above and below the steel, and tests on these specimens were conducted. Figure 3.2 shows one of the eleven cores which contained transverse steel. Five specimens contained no reinforcing steel, and four of these were trimmed to proper lengths and tested according to ASTM specifications. The fifth core was cracked too severely to test.

Modulus of elasticity for seven specimens was determined in accordance with ASTM-C-469. The splitting tensile strength was performed on the twelve remaining specimens. Specimens from both eastbound and westbound lanes containing no steel were available for modulus testing. Two specimens from each direction, not containing steel, were not available for this test. Those specimens in the best condition, but containing reinforcing, were then chosen as specimens from the westbound lanes for testing.

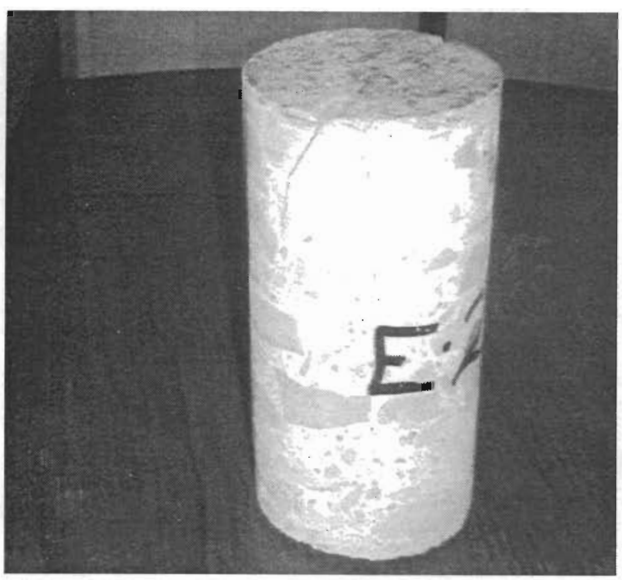


Figure 3.1 Core taken over a surface crack

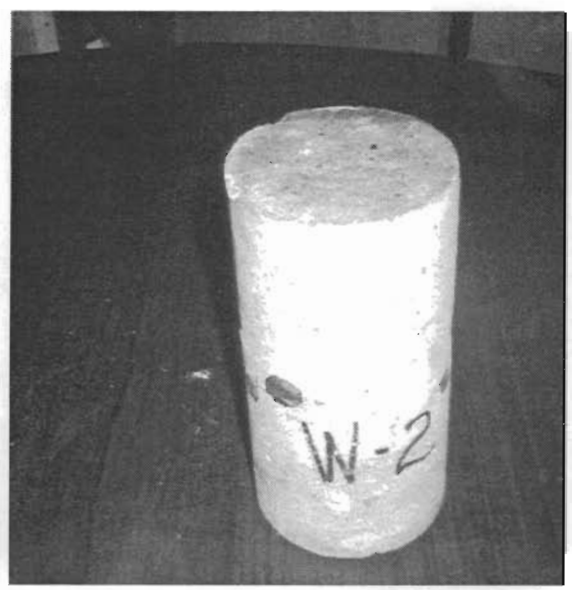


Figure 3.2 Core containing reinforcement bar

3.2 TEST RESULTS

Test results indicated that the moduli ranged from 1.37×10^6 to 5.89×10^6 psi, and their splitting tensile strengths ranged from 430 to 790 psi.

3.2.1 Extension Meter Testing (ASTM-C-469)

Specimen locations were clearly marked eastbound (E) or westbound (W), followed by a number representing the station number. These numbers can be correlated with the condition surveys. Specimens E3, E4, and E6 came from eastbound lanes, while W1, W4, W5, and W6 came from westbound lanes. The specimens ranged in length from 6.81 to 7.66 inches and from 3.95 to 4.00 inches in diameter. Dry unit weights of these specimens ranged from 143 to 154 pounds per cubic foot. Individual sample dimensions and unit weights are provided in Appendix C.

Splitting tension tests were conducted on these specimens and are provided in Table 3.1.

Figure 3.3 shows the stress versus strain curves of three samples taken in the eastbound direction. The stress versus strain curves of the westbound direction samples are shown as Figure 3.4.

3.2.2 Indirect Tensile Strength (ASTM-C-496)

As illustrated in the graphs, specimen E6 had the highest modulus of elasticity, with approximately 6.0×10^6 psi, while E4 had the lowest modulus of elasticity, with 2.5×10^6 psi. In the westbound direction, the chord moduli of the samples ranged between 1.3×10^6 psi to 3.6×10^6 psi. Individual values are shown in Appendix C.

The indirect tensile test is performed by loading the specimen with a compression load which acts parallel to and along the vertical diametrical plane. This loading configuration causes the specimen to fail by splitting or rupturing along the vertical diameter. By using the maximum load and the equation given in ASTM-C-469, the indirect tensile strength can be calculated. For this test, specimens were identified as E1 top, E1 bottom, W8 top, W1, W2, W3, W4, W5, W6, W7, E2, E3, E4, E6, E7, and E8. Top and bottom refer to smaller lengths cut from cores above and below steel reinforcement found in the center of the original specimens. Specimens were examined prior to testing and all significant visible defects were recorded. The splitting tensile strengths are shown in Table 3.1. Maximum loads

Table 3.1 Splitting tensile strengths

Specimen	Length (in.)	Diameter (in.)	Load (in.)	Tensile Strength (psi)
E1 top	2.38	4.00	11,800	790
E1 bottom	4.09	4.00	15,600	605
W8 top	3.78	3.97	13,400	570
E5 bottom	2.98	3.97	10,600	570
E5 top	2.66	3.97	9,100	550
W1	7.66	4.00	25,000	540
W2	*Not tested because specimen was cracked*			
W3	7.56	3.94	22,500	480
W4	*Not tested; the specimen failed during modulus testing*			
W5	7.58	3.95	33,000	700
W6	6.81	3.97	22,200	525
W7	*Not tested because specimen was cracked*			
E2	*Not tested because specimen was cracked*			
E3	7.55	4.00	34,900	735
E4	*Not tested; the specimen failed during modulus testing*			
E6	7	3.95	18,700	430
E7	*Not tested because specimen was cracked*			
E8	7.41	3.95	27,800	605

for the specimens ranged from 9,100 to 34,900 pounds. From these loads, splitting tensile strengths were calculated and ranged from 430 to 790 psi. In all specimens, nearly 100 percent of the coarse aggregates were fractured during the test. Some of the cores could not be tested because of failure from within the cores and because of the testing process.

Comparing the specimens above and below the reinforcing steel, the same tensile strength was obtained in core E5. The tensile strength of the top specimen of core E1 was somewhat higher than that of the bottom specimen. Since the sample of data is small, it is difficult to analyze the variations which suggest different properties.

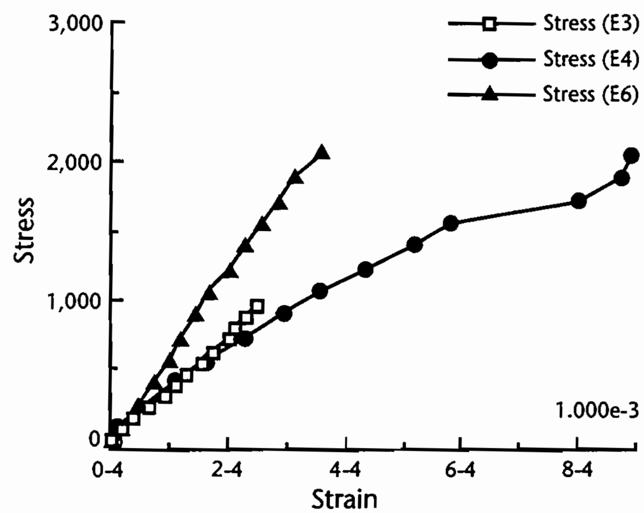


Figure 3.3 Stress and strain curve of test samples in eastbound direction in IH-10 in El Paso

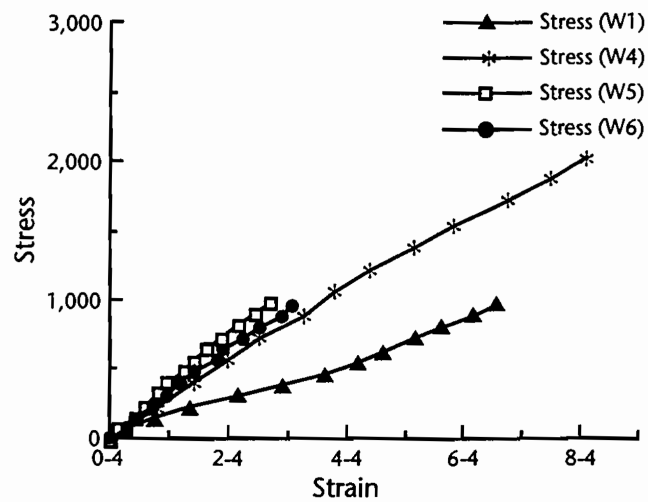


Figure 3.4 Stress and strain curve of test samples in westbound direction in IH-10 in El Paso

CHAPTER 4. DESIGN OF BONDED CONCRETE OVERLAY

4.1 REHABILITATION PROCEDURE

In choosing a rehabilitation alternative for continuously reinforced concrete pavement (CRCP), some factors which must be considered are the state of the existing pavement, the cost associated with rehabilitation, and environmental influences. CRCP can be rehabilitated by applying either a portland cement concrete (PCC) overlay or an asphalt concrete (AC) overlay. Several different overlay design procedures have been developed by different institutions. These include the Corps of Engineers (COE), the Portland Cement Association, and the American Association of State Highways and Transportation Officials (AASHTO).

These methods usually provide a means for obtaining an overlay design thickness by a specific design equation. For example, the Corps of Engineers' design method, which is widely used in overlay design for military projects, uses an accelerated test track to assist in setting up an accurate design model. Models have been developed for bonded, partially bonded, and unbonded PCC overlays. Metzinger pointed out two problems with the COE's methods (Ref 3). The first problem is that the methods are not verified as being applicable to highway pavements. They were developed for taxiway and runway use. Second, because the long-term performance failure criteria are inherent in the COE equation (as well as in the AASHTO rigid design equation), these criteria cannot be used simultaneously. Perhaps the most sophisticated and reasonable overlay design procedure in current use is the Pavement Rigid Overlay Design method (PROD), which was developed by Austin Research Engineers for the Federal Highway Administration (FHWA) (Ref 4). The PROD procedure starts by selecting the design criteria and obtaining condition surveys and deflection measurements. These data are then used to identify design sections for material characterization. The remaining life of each design section and the subsequent overlay thickness are then calculated. This rigid pavement rehabilitation procedure is illustrated in Figure 4.1.

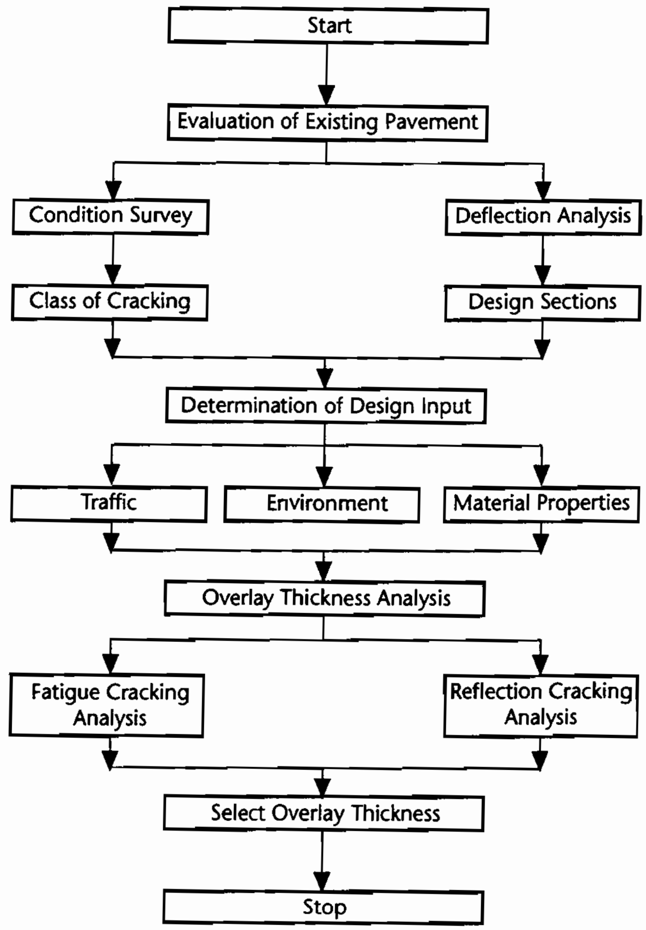


Figure 4.1 Rigid pavement rehabilitation chart

4.2 EXISTING PAVEMENT LAYER CHARACTERISTICS

4.2.1 Typical Section

For the analysis, it is assumed that the thickness and physical condition of the original pavement design and the existing pavement cross section are not exactly the same because of variations in the construction, maintenance work, and various other reasons. Thus, it is necessary to measure thickness, strength, and other material properties of the existing pavement in order to verify the original pavement design. It is difficult to accurately measure the cross-section of the entire existing pavement, but through laboratory testing of cores taken from existing pavement sections, reasonably accurate data can be obtained. It is not possible to use the original pavement design properties as the typical section for the analysis without taking into consideration the existing pavement condition. However, the original design can be modified by applying the results which come from the core testing. The typical cross-section of IH-10 through the downtown portion of El Paso is shown in Figure 4.2.

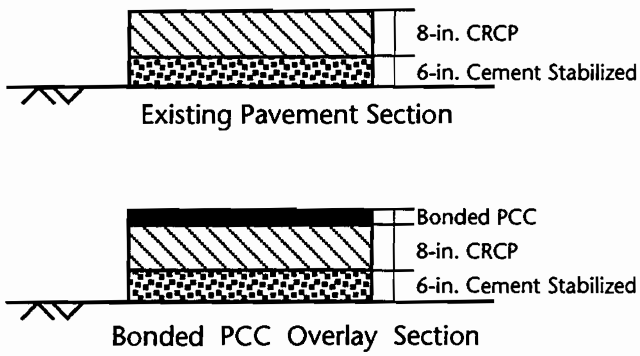


Figure 4.2 Typical pavement section

4.2.2 Analysis of Layer Characteristics

Backcalculation of the layer modulus uses the elastic layer theory, which utilizes midspan deflections by using the Rigid Pavement Evaluation System by Dynamic Deflections (RPEDD1) (Ref 5). The required data for RPEDD1, used for estimating the modulus of elasticity from the existing pavement structure, are listed in Appendix D. Because of the volume of traffic, deflection data were collected in the outside lane only. This was necessary because of the frequent use of the outside lane by large trucks and traffic entering and exiting IH-10.

With the parameters of the homogeneous units defined, the deflection data can be divided by utilizing one of two methods.

(1) *Method 1–Average Deflection Value:* The first method uses the average value of the deflection data of each unit section. This method divides all the deflection data by sensor number and chooses the 85-percent value of each sensor as the representative value for that particular section. With the average value of each unit section identified, the RPEDD1 program can be run. This method was developed specifically for calculating material characteristics using dynamic deflection measurements. The following steps are included:
- Calculate the mean and standard deviation of W1, W2, W3, W7
- Use 85 percent value of W for RPEDD1 input data w = w + z85 * SV

The moduli obtained from these steps are displayed in Tables 4.1 and 4.2. Figures 4.3 to 4.8 show the variation of modulus of elasticity calculated. These graphs give general characteristics of existing pavement by section.

Table 4.1 Backcalculation of modulus of elasticity, psi

Eastbound			
Section	E1	E2	E3
1	3,094,000	563,000	28,930
2	2,000,000	106,300	17,290
3	2,490,000	134,500	23,590
4	2,658,000	357,300	18,850
5	3,337,000	439,200	18,750

Table 4.2 Backcalculation of modulus of elasticity, psi

Westbound			
Section	E1	E2	E3
1	2,436,000	326,800	27,600
2	3,587,000	584,500	19,020
3	4,500,000	645,700	13,900
4	3,175,000	116,800	23,980
5	2,715,000	346,900	30,490

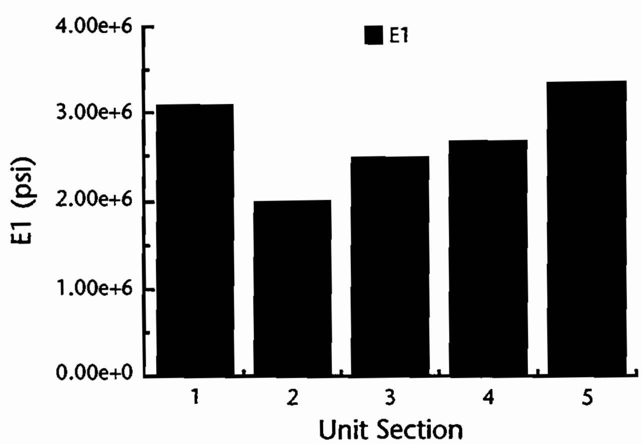


Figure 4.3 Eastbound section 1 RPEDD1 results

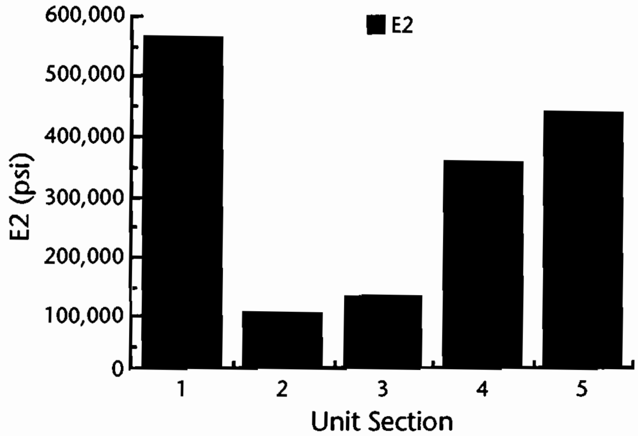


Figure 4.4 Eastbound section 2 RPEDD1 results

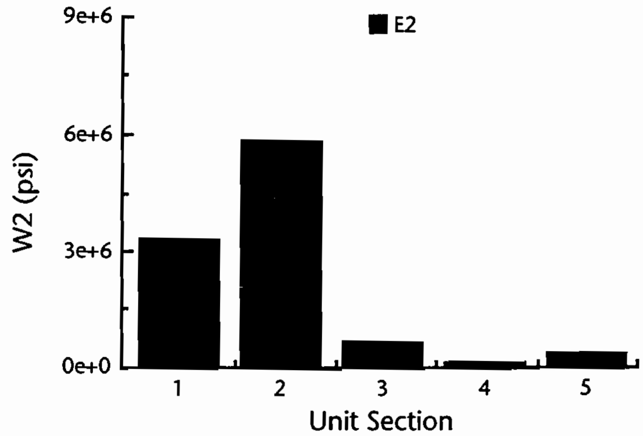


Figure 4.7 Westbound section 2 RPEDD1 results

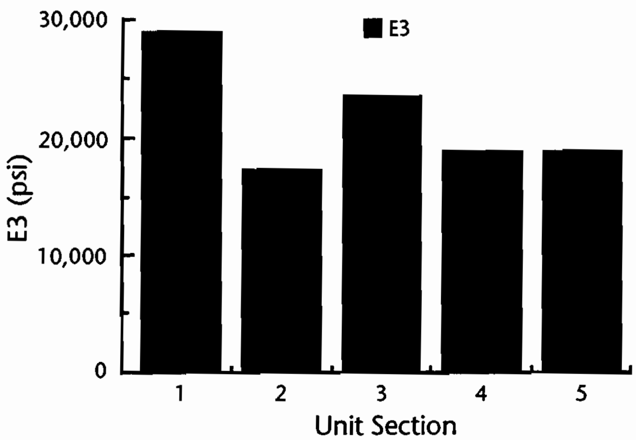


Figure 4.5 Eastbound section 3 RPEDD1 results

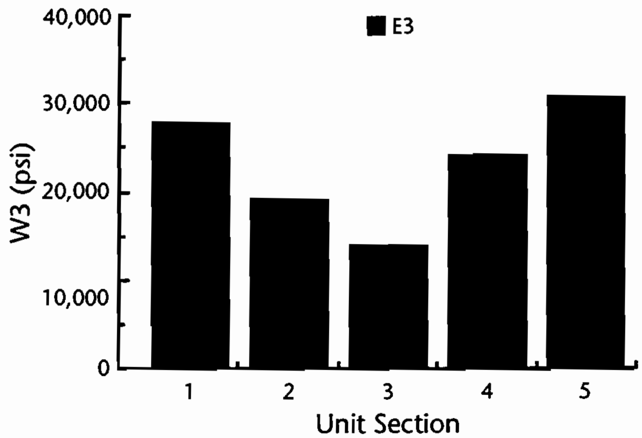


Figure 4.8 Westbound section 3 RPEDD1 results

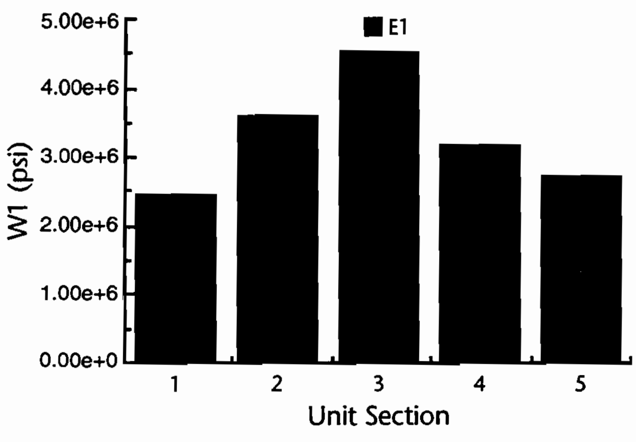


Figure 4.6 Westbound section 1 RPEDD1 results

(2) *Method 2–Using Each Measurement:* Comparing the previous results, we calculated the point measurement system, which shows pavement behavior at the point where the measurement was taken. The deflection data were measured using the FWD at 77 points on the eastbound section and at 78 points on the westbound section. These data were used to calculate the modulus of elasticity using the same program, RPEDD1. The results of the RPEDD1 program run are included in Appendix D. The calculated variation in moduli along the section is shown in Tables 4.3 and 4.4.

Table 4.3 Eastbound backcalculation of modulus of elasticity, psi

	Eastbound		
Section	E1	E2	E3
1	3,437,000	925,000	38,600
2	2,491,000	110,900	22,500
3	2,967,000	474,900	33,500
4	3,370,000	485,000	20,700
5	3,393,000	751,800	24,800

Table 4.4 Westbound backcalculation of modulus of elasticity, psi

	Westbound		
Section	E1	E2	E3
1	3,389,000	968,000	28,900
2	3,749,000	642,500	23,100
3	3,146,000	574,000	28,700
4	3,074,000	474,000	28,200
5	4,277,000	1,321,000	34,100

4.2.3 Comparison of Methods

The stiffness of the existing PCC depends on moisture in the subgrade, loading time, and age of the pavement. Since these values are estimated and vary with time and calculation method, the results may be somewhat ambiguous. The results obtained from the two methods show dissimilarity. The same program and data were used, but utilized different ways of processing the data within the program. Even though deflections were measured by using dynamic impact loading, the layered system is designed to use static loading for the backcalculation. The stiffness from the first method shows relatively lower values than those from the second method. In the future, new methods, such as the Spectral Analysis of Surface Waves (SASW), may be utilized to improve the accuracy of backcalculating the modulus of elasticity.

4.3 REMAINING LIFE

It is difficult to precisely estimate remaining life of existing pavements. In the AASHTO guide, five methods are recommended for estimating the remaining life of pavements. Two of the five recommended methods were selected for use in this study. The first method is based on the mechanistic fatigue model, using the material properties obtained in the previous section. The second method is the condition survey method. This method is based on the present distress condition as shown in the condition surveys, age, and past equivalent 18-kip ESAL. Major discrepancies between the two estimates of the remaining life of the existing pavement should be investigated and adjusted if necessary. Figure 4.9 shows the steps involved in this process.

4.3.1 Mechanistic Fatigue Method

The first method selected to estimate the remaining life of the existing pavement uses the E-value from Section 4.2. This value, combined with the mechanistic fatigue model shown below, is used to determine the remaining design life of the pavement.

$$RL = \left(1 - \frac{n18}{N18}\right) \bullet 100$$

where: RL = percent remaining life;
n18 = accumulated past traffic in 18-kip ESAL; and
N18 = original (or design) fatigue life of existing pavement in 18-kip ESAL.

The mechanistic fatigue model and the structural performance history of pavement are combined in the equation. The most important information required is the present condition of the pavement. The following steps assess the present condition of the pavement:

(1) calculate the cumulative past equivalent traffic data (N18) in design lane;
(2) estimate the material properties and layer thicknesses of the existing pavement;
(3) calculate the tensile stress in the PCC slab;
(4) survey existing PCC flexural strength;
(5) adjust tensile stress into critical stress; and
(6) estimate original structural design life (N18) in 18-kip ESAL.

The above procedure is a general approach used to assess the remaining life of existing pavements. After step 2, it is necessary to compare the estimated slab modulus (ESM) with values for similar materials from the region. If the ESM is lower than the values for similar materials, the existing slab is fatigued and the estimated remaining life is equal to zero. If the ESM is relatively high in comparison, the remaining life of the existing pavement structure must be calculated.

The flexural strength of PCC can be obtained from either laboratory test data on samples which were taken from the existing slab, or flexural strength values of similar materials in the region. The samples for the three-point loading test,

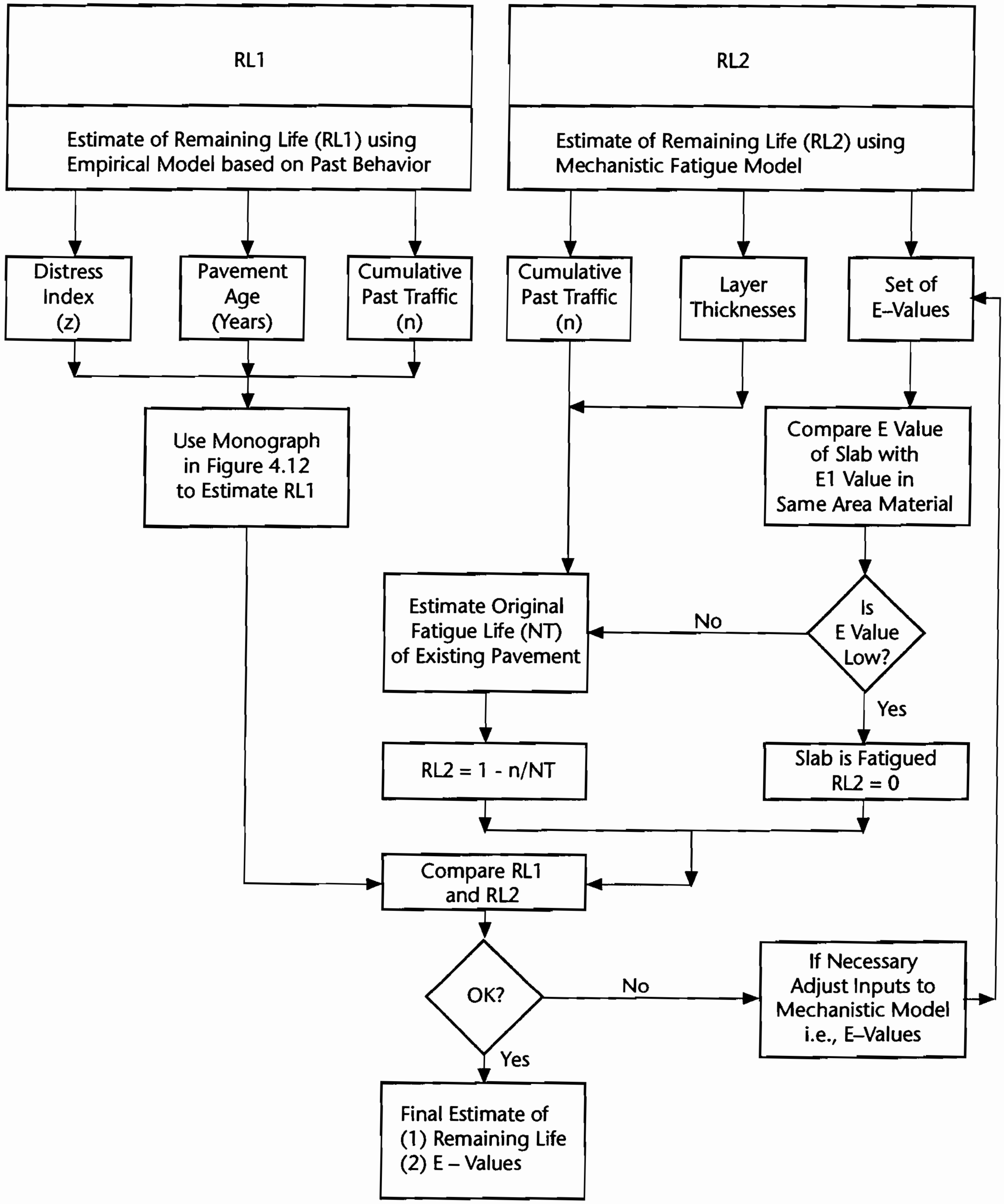


Figure 4.9 Process of estimating remaining life

which gives flexural strength used in the design procedure, cannot be easily obtained. The results are taken from 4-inch cores and converted from tensile strength into flexural strength as shown in Figure 4.10. An 85-percent value of flexural strength was used for estimating remaining life.

The stress factor, which is used to adjust tensile stress into critical stress, was recommended by CTR (Ref 6) to range from 1.05 to 1.10. A stress factor of 1.10 is used in this study. The tensile stress was calculated using the elastic layer program ELSYM5.

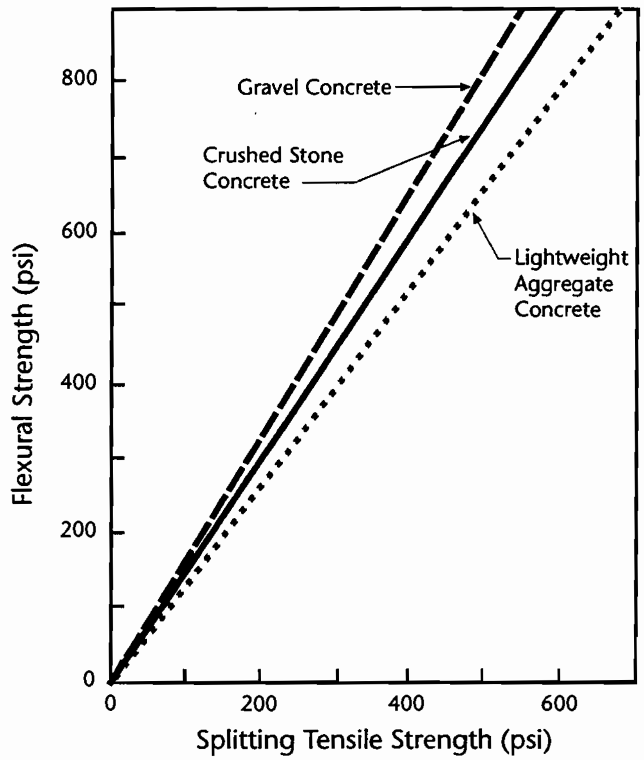


Figure 4.10 Relationship of tensile and flexural strengths

The original design fatigue life (N18) is then calculated using the following equation:

$$(N18) = 46000\left(\frac{f}{Sc}\right) \bullet 30$$

where:

N18 = original design fatigue life in 18-kip ESAL;
Sc = critical stress factor; and
f = concrete flexural strength.

From the previous chapter, the properties of the pavement structure are obtained from every section by using the RPEDD1. The program can also estimate the remaining life of every section. The results obtained from the program are shown in Table 4.5.

Table 4.5 Remaining life using mechanistic fatigue model

Eastbound Section Number	Percent of Remaining Life	Westbound Section Number	Percent of Remaining Life
1	80.0	1	71.6
2	40.8	2	68.9
3	53.7	3	51.9
4	63.6	4	60.5
5	58.6	5	69.6

4.3.2 Remaining Life Based on the Condition Survey Results

The condition survey and deflection measurements are used to determine the maintenance strategy at the project level of pavement management. It is reasonable to use distress as a barometer to represent remaining life. Using information from the surface condition of the existing pavement, distress can be identified and recorded on condition survey forms. From the condition survey results, the remaining life of the pavement structure can be obtained.

The distress index is assigned a number according to the pavement deterioration by using the following equation for the CRCP (Ref 7):

$$Zc = 1.0 - 0.065\,FF - 0.015\,MS - 0.009\,SS$$

where:

Zc = distress index;
FF = number of failures per mile, i.e., sum of punchouts and patches;
MS = percent minor spalling; and
SS = percent severe spalling.

From the condition survey, detailed information about the severity of cracks is limited because of lack of resources and time constraints at the time of recording. The pavement was in good enough shape to assume that (1) the minor spalling is less than 5 percent, and (2) the severe spalling will be less than 2 percent. Figure 4.11 shows the plot of "Zc versus distance" for both eastbound and westbound lanes. The index can be categorized into three levels (Ref 8). If the distress index ranges from 1 to 0, it means that no distresses appear on the pavement section. A moderate distress state is supposed to exist if the distress index ranges from –2 to 0. Severe distress is present when the distress index is less than –2. Under these criteria, the eastbound and westbound sections are in relatively good condition. A few of the sections would fall into the "no distress" category.

From past records, the age of the existing pavement was shown generally to be 27 years. The past traffic of the design lane was calculated in 18-kip ESAL (N18). It is assumed that the past traffic increase rate was the same as the current increase rate. The remaining life was estimated by entering on the nomograph information on the distress index (Figure 4.11), age, and past traffic. Remaining life could be calculated for only two of the westbound sections because the nomograph does not cover the range beyond –1 of the distress index. The first and fourth westbound sections have remaining lives of 50 percent and 20 percent, respectively.

4.3.3 Comparison of Models

It is difficult to apply the condition survey method for calculating remaining life of the existing pavement structure. In addition to the lack of detailed distress information (such as spalling), the nomograph which was developed for this method is about 10 years old and needs updating. This makes it difficult to compare the remaining life calculation from both methods. The comparison is still useful as a general guide in estimating remaining life expectancy of the pavement. From the condition survey method, the estimated remaining life of each section is lower than that obtained from the mechanistic approach. The condition survey method was used to check the mechanistic approach.

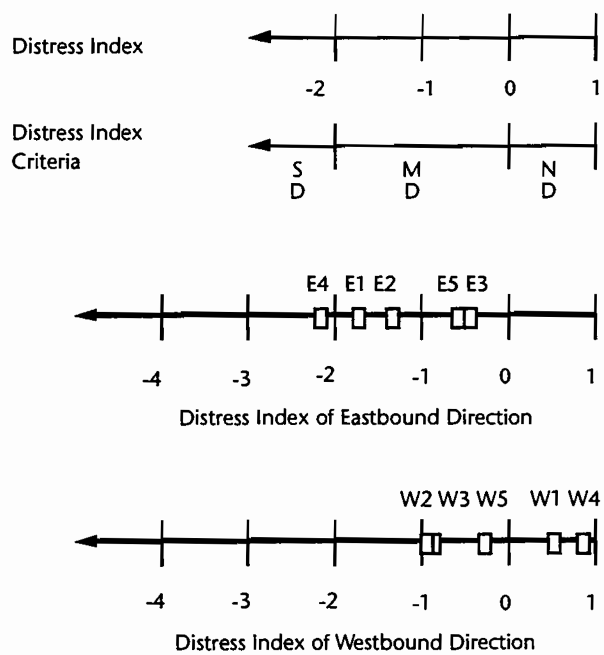


Figure 4.11 Distress index

4.4 OVERLAY THICKNESS DESIGN

The overlay thickness design depends on the remaining life of the existing pavement, which was calculated in the previous section. Using the remaining life expectancy and the pavement rehabilitation design system, the design thickness can be calculated. The basic concept of overlay thickness design is to find the optimal or long-term economical design strategy that also allows for safety and comfort for the highway user. Estimating stress decrease associated with a selected overlay thickness is the first step of the design process. Next, some type of long-term performance model has to be applied to evaluate the pavement. Finally, a design strategy can be recommended that will meet the needs of the increasing traffic in the years to come.

4.4.1 Program PRDS-1

A pavement rehabilitation design system (PRDS) was developed at the Center for Transportation Research for obtaining the required overlay thickness (Ref 6). This program allows the highway engineer to consider several factors associated with overlay design and construction. In the search for the optimal strategy, the PRDS program is a key tool for identifying design thickness. A summary of the various inputs to the PRDS program is presented in Appendix E. The inputs have been divided into the eleven broad categories shown in the following list:

(1) project description
(2) original pavement
(3) traffic variables
(4) time constants
(5) remaining life variables
(6) overlay characteristics
(7) overlay construction cost variables
(8) traffic delay cost variables
(9) distress/maintenance cost variables
(10) cost return
(11) combined interest and inflation rate

Large amounts of detailed accurate data are needed to run the program for estimating the overlay design. The detailed information can be found in a CTR report (Ref 6). It is useful to point out some of the significant aspects about the data needed:

(1) Layer moduli was determined using the backcalculation procedure (i.e., the FWD deflection basin fitting procedure).

(2) The critical stress factor, which represents the ratio of critical stress to the interior stress in the existing pavement, uses a value suggested by the manual.
(3) Even though original pavement has carried a lot of traffic over the years, its present remaining life is estimated to be medium with a few exceptions.
(4) Since remaining life of existing pavement is at a medium level, three overlay types were considered: ACP, unbonded CRCP, and bonded CRCP. If a section has less than 10 percent of remaining life, bonded concrete overlays are not considered because of reflective cracking.
(5) One level of PCC flexural strength for all the CRCP overlay strategies was considered.
(6) All cost information is based on information which comes from the average allowable low bid unit prices in District 24.
(7) The congestion cost information comes from the Highway Economic Evaluation Model (HEEM-II).
(8) The CRCP steel reinforcement percentages were based on the experience and expertise of the highway engineers.
(9) Finally, salvage value and the value of each year of extended life were considered as well.

The program output provides an overlay design strategy. The final design strategy of each section is made up of two components, fatigue life after the first overlay and overlay thickness. Tables 4.6 and 4.7 show a possible alternative strategy for each section of both eastbound and westbound directions.

As shown in these tables, the bonded concrete overlay method is a good design strategy for these project sections. For the eastbound direction, a thin asphalt concrete overlay cannot be applied because of low remaining life expectancy of the existing pavement structure. An unbonded concrete overlay may be applied to the westbound sections, but it may not be an economical strategy because its greater thickness may raise construction costs and reduce its life considerably. Bonded concrete overlay (BCO) is the best alternative for the eastbound sections. BCO has a longer life and lower construction costs, compared with other methods.

Table 4.6 Overlay thickness calculation of eastbound using PRDS

	ACP		Bonded PCC		Unbonded PCC	
	Thickness (in.)	Expected Life (Year)	Thickness (in.)	Expected Life (Year)	Thickness (in.)	Expected Life (Year)
East 1	2.0	25+	3.0	25+	7.0	20.8
East 2	–	–	3.5	25+	–	–
East 3	–	–	3.5	20.1	7.0	16.5
East 4	2.0	23.4	3.0	25+	7.0	18.4
East 5	3.0	21.3	3.0	25+	7.0	20.2

Table 4.7 Overlay thickness calculation of westbound using PRDS

	ACP		Bonded PCC		Unbonded PCC	
	Thickness (in.)	Expected Life (Year)	Thickness (in.)	Expected Life (Year)	Thickness (in.)	Expected Life (Year)
West 1	2.0	25+	3.0	25+	7.0	18.2
West 2	2.0	25+	3.5	25+	7.0	21.4
West 3	5.0	20.7	3.5	22.7	7.0	22.8
West 4	5.0	16.3	3.0	21.3	7.0	17.8
West 5	2.0	29.2	3.0	25+	7.0	19.0

Three types of overlays could be adapted to the westbound sections because they show better pavement surface conditions, but bonded concrete overlay has also been selected as the optimal overlay strategy for the westbound sections. An asphalt concrete overlay may cause construction problems, owing to the variations in needed thicknesses. The third and fourth sections of the westbound lanes need 5 inches of thickness, while only 2 inches are needed in the other sections. The fourth section has about 16 years of expected pavement service life; it will need a second overlay within 20 years. An unbonded concrete overlay can be considered as a reasonable method for westbound sections; however, some sections will need a second overlay within a specified period. A bonded concrete overlay may overcome these problems. It has been demonstrated through research that the bonded concrete overlay provides improved serviceability as well as stronger structural capacity. The main problem that seems to affect bonded concrete overlays is delamination. Lundy (Ref 9) concluded that the debonding of overlays is an early-age phenomenon and can be attributed to an excess of moisture and the associated volume change. Delamination is not caused by long-term traffic loading. Delamination can be reduced by taking the necessary precautions recommended by Lundy.

The design of a bonded concrete overlay has now been completed. It is necessary, however, to check the design thickness against another method. The AASHTO method was used as the second design method.

4.4.2 Design Overlay Thickness Using AASHTO Methods

In order to verify the thickness recommended by the previous design method, the AASHTO overlay design method was considered as an alternative design strategy. The method follows the Corps of Engineers' method with a few variations. Serviceability of traffic concepts are used in the overlay design method. It also uses life-cycle cost concepts to obtain a cost-effective overlay recommendation. Generally, the overlay design thickness of bonded concrete is determined by the following equation:

$$DO = DY - Deff \bullet FRL$$

where:

DO = overlay thickness by AASHTO;
DY = design thickness by AASHTO;
Deff = effective thickness of pavement; and
FRL = remaining life factor.

The AASHTO method, based on empirical testing, suggests that a terminal PSI value of 2.0 be used at the end of the overlay life. The following assumptions were made in developing the design:

Desired level of reliability	95 percent
Serviceability Index	
After initial construction	4.5
At the end of performance period	2.5
Load transfer coefficient	3.0
Drainage coefficient	1.0
Overall standard deviation	0.39
Design life	30 years

Using this method, the thickness of a bonded concrete overlay with 95 percent reliability can be calculated as shown in Tables 4.8 and 4.9. The AASHTO guide suggests various methods to determine an effective thickness for the existing pavement. By using the remaining life or applying the modulus of elasticity of the surface layer, different values are obtained. Since condition survey results show good serviceability on the existing pavement, the following criteria were suggested to determine an effective thickness. If the remaining life of the existing pavement is greater than 70 percent, all thicknesses of the surface layer are considered an effective thickness. When the range is from 70 to 50 percent, 95 percent of the thickness is considered an effective thickness. When the range is below 50 percent of remaining life, 90 percent of the total thickness is considered an effective thickness. The remaining life factor (FRL) was calculated using the remaining life of the existing pavement (R_X) and the overlaid pavement (R_Y). The results for the remaining life factor (FRL) are presented on a 0-to-1 scale.

The overall overlay thickness of the eastbound sections is greater than that of the westbound. A similar pattern is shown when using the PRDS design method. The maximum overlay thickness is required at the second unit section of eastbound direction. This would require a 5.9-inch thickness for the overlay design. Typical output from the AASHTO program is presented in Appendix F.

4.4.3 Comparison

The main difference between the two methods is their reliability. The AASHTO method utilizes a probability which allows for variation of many design factors, such as pavement structure, roadbed soil, environmental condition, and pavement condition factors. The 99.9 percent reliability factor using the AASHTO guide method significantly increases the thickness. Compared with the PRDS design method, it is obvious that the AASHTO guide recommends thicker overlays. The PRDS method does not utilize the same factors within its model. However, it does provide for a reasonable safety factor. Since the target project section is located in the downtown area of El Paso, it acts as a bridge to connect freight movement between Mexico and the United States. Because of this factor, we recommend the AASHTO guide method rather than the PRDS method. The final design of the recommended overlay thickness is presented in the next chapter.

Table 4.8 Eastbound design thickness using AASHTO guide

	Design Thickness DY	Remaining Life RX	Effective Thickness DO	Remaining Life Factor FL (0 to 1)	Overlay Thickness
East 1	11.65	80.0	8.00	0.920	4.29
East 2	11.88	40.8	7.20	0.825	5.94
East 3	11.82	53.7	7.60	0.860	5.28
East 4	11.92	63.6	7.60	0.895	5.12
East 5	12.09	58.6	7.60	0.895	5.29

Table 4.9 Westbound design thickness using AASHTO guide

	Design Thickness DY	Remaining Life RX	Effective Thickness DO	Remaining Life Factor FL (0 to 1)	Overlay Thickness
West 1	11.51	71.6	8.00	0.915	4.19
West 2	12.11	68.9	7.60	0.935	5.00
West 3	12.46	51.9	7.60	0.900	5.62
West 4	12.07	60.5	7.60	0.910	5.15
West 5	11.54	69.6	7.60	0.918	4.56

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

Through study of the proposed research sections in El Paso, a rehabilitation design recommendation has been formulated. The conclusions and recommendations that follow are results of the research conducted in the field, the laboratory, and through the various computer programs developed for rehabilitation design.

5.1 CONCLUSIONS

The conclusions from the field measurements, laboratory measurements, and theoretical analysis are:

(1) The eastbound pavement is in better condition than the westbound.
(2) The condition survey results correspond to the average value of deflection measurements in both directions.
(3) The remaining life estimate derived from the condition surveys is lower than the remaining life estimate derived from the mechanistic approach.
(4) The AASHTO overlay design method recommends a thicker concrete pavement overlay than the PRDS design method. This may be attributed to the differences in reliability.
(5) The effective thickness calculation method suggested by the AASHTO guide gives different values for remaining life when using the modulus of elasticity of the surface layer.
(6) Accurate traffic data are essential in recommending a rehabilitation design thickness.

5.2 RECOMMENDATIONS

5.2.1 Recommendation of Design Thickness

Using the program PRDS, the overlay design thickness was calculated for each overlay type. Because the existing pavement has not yet become completely fatigued, it is recommended that a bonded concrete overlay design be applied in El Paso on IH-10 as the rehabilitation strategy. The recommended design overlay thicknesses were modified using the AASHTO overlay design approach. Tables 5.1 and 5.2 show the recommended design overlay thickness for each direction.

Table 5.1 Recommended eastbound overlay design thickness

Unit Section	Station (ft)	Thickness (in.)
East 1	Start - 1,800	4.5
East 2	1,800 - 2,850	5.5
East 3	2,850 - 4,200	5.0
East 4	4,200 - 7,200	5.0
East 5	7,200 - End	5.0

Table 5.2 Recommended westbound overlay design thickness

Unit Section	Station (ft)	Thickness (in.)
West 1	Start - 850	4.5
West 2	850 - 3,000	5.0
West 3	3,000 - 4,500	5.5
West 4	4,500 - 6,200	5.0
West 5	6,200 - End	4.5

5.2.2 Recommendation for Further Research

Several items which require further research were identified during the design procedure. Some of these requirements include the models which were developed and which have not been updated. Another future research item which would be beneficial is the development of a program to bridge the gap between the research models and the field data.

(1) *Traffic Effect Measurement:* Generally the ESAL is adapted in order to estimate the various vehicle types using the road. It can ideally cover gear configuration, tire spacing, tire

pressure, and axle load. The AASHTO guide suggests that loadmeter forms be used to represent wheel load effects on the pavement structure, using an 18-kip wheel load. However, this is not practical because it is difficult to get detailed axle data and nearly impossible to get accurate current traffic counts. Taking into account that the performance curve is usually drawn by comparing the ESAL to the type of distress index, a reliable traffic effect measurement method should be developed. Feasible methods include the vehicle classification method, the standard vehicle method, and a possible future weigh-in-motion site. The weigh-in-motion (WIM) instrumentation can efficiently calculate vehicle size, weight, speed, and classification, such as dual-wheel trucks or tandem-axle trailers. Although the WIM testing method is relatively new to Texas, it has been successfully used by CTR to obtain accurate traffic data in District 11. These accurate data have assisted in isolating the most cost-effective long-term rehabilitation plan. Accurate traffic data are essential when searching for the safest and most viable rehabilitation design.

(2) *Backcalculation:* The material characteristics of existing pavements can be determined using nondestructive testing methods (dynamic loading devices like the Dynaflect or FWD). The basic concept of backcalculation is to compare the measured deflection data with the estimated deflections using a basic pavement model. Layered theory models, such as BISAR or ELSYM5, have generally been used in the past. However, these models usually use a static loading boundary condition instead of measured deflections coming from a dynamic loading condition. Another problem is finding a unique set of material stiffnesses in each layer by using the backcalculation process. Many programs give different stiffness sets even though they utilize the same deflection measurements. It is necessary to develop a standard method for conducting backcalculations, taking into consideration all available methods.

(3) *Remaining Life:* Remaining life calculations from the condition survey method should be modified to reflect state-of-the-art research results and stocked data. Since conditions of surface layers may be a barometer to represent real conditions of pavement structures, condition surveys should be updated to reflect the surface condition.

(4) *Performance Measurement:* Since the main cause of failure on bonded concrete overlays is delamination (Ref 9), observations should be conducted before and after construction in order to measure the performance of the structure. This method of rehabilitation is relatively new, so research should be conducted continually.

(5) *Environmental Monitoring:* The use of environmental monitoring should be included in future construction, paying particular attention to the dry, hot climate present in El Paso. The evaporation rate is strongly influenced by humidity, air speed, air temperature, and concrete temperature. Evaporation rates of 0.2 pounds of water per square foot will quite likely cause plastic shrinkage cracking, which has been found to increase the amount of delamination.

(6) *Quality Control:* Several new methods have been designed to monitor properties of concrete at early ages. This can help to improve the quality of concrete and to reduce the associated costs to the Department. The maturity method is a simple instrument used to measure the temperature of the concrete over time. The accumulated areas beneath the time-temperature curve can be correlated with the concrete strength. The Spectral Analysis of Surface Waves (SASW) method measures the velocity of waves from a source (such as a drop hammer) to provide data which can be used to calculate the modulus of elasticity of the concrete beginning at the very early ages of the concrete. The compression strength can then be correlated with the modulus of elasticity. The SASW method also permits thicknesses of different materials to be measured. Other simple tests need further development in field conditions before a recommendation can be given.

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APPENDIX A. STATISTICAL TEST RESULTS

DEFLECTION VARIATION OF MIDSPAN AND ON-CRACK CONDITION

1) Test results of eastbound direction

a) The third drop impact load of eastbound direction

Data File	Difference Mean	S.V.	Statistics	Test Results
E31.DAT	0.2183	0.3727	5.1405	REJECT
E32.DAT	0.1582	0.3231	5.0296	REJECT
E33.DAT	0.1388	0.2435	5.0025	REJECT
E34.DAT	0.0896	0.1867	4.2125	REJECT
E35.DAT	0.0381	0.1580	2.1127	REJECT
E36.DAT	0.0184	0.1209	1.3388	ACCEPT
E37.DAT	-0.0010	0.1275	-0.0715	ACCEPT

e.g., E31.DAT: Eastbound, third drop, first sensor

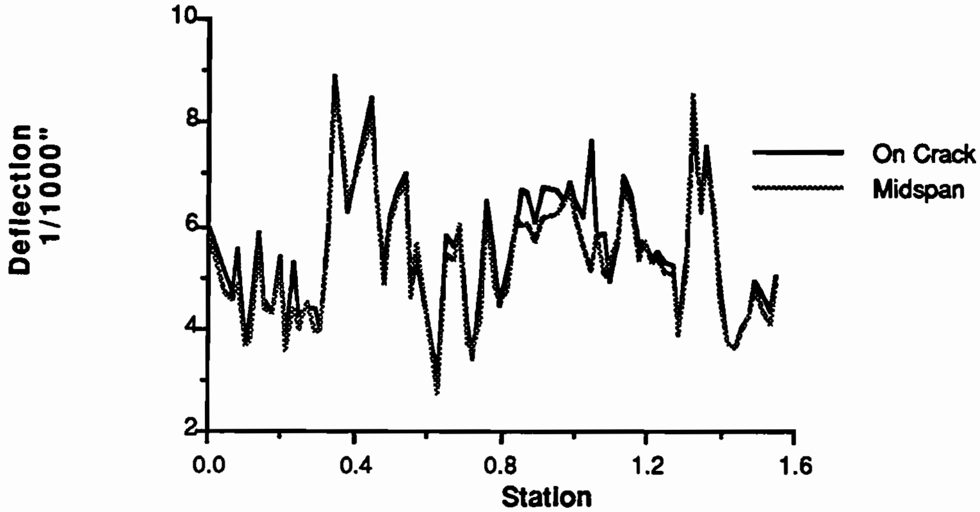
b) The fourth drop impact load in eastbound direction

Data File	Difference Mean	S.V.	Statistics	Test Results
E41.DAT*	0.3394	0.5091	5.8491	REJECT
E42.DAT	0.2834	0.4281	5.8087	REJECT
E43.DAT	0.1971	0.3287	5.2635	REJECT
E44.DAT	0.1143	0.2485	4.0357	REJECT
E45.DAT	0.0506	0.2014	2.2071	REJECT
E46.DAT	0.0179	0.1645	0.9562	ACCEPT
E47.DAT	-0.0119	0.1501	-0.6984	ACCEPT

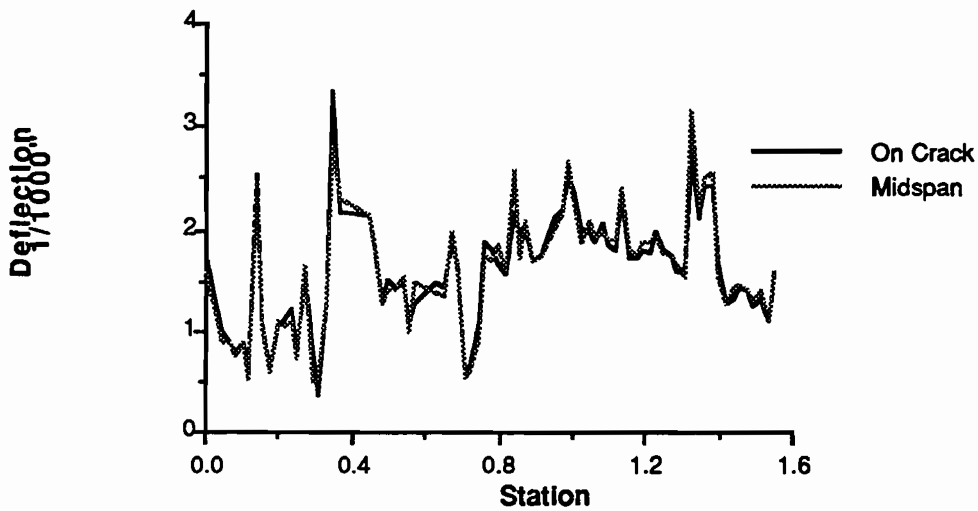
e.g., E41.DAT: Eastbound, third drop, first sensor

2) Deflection profile in eastbound direction

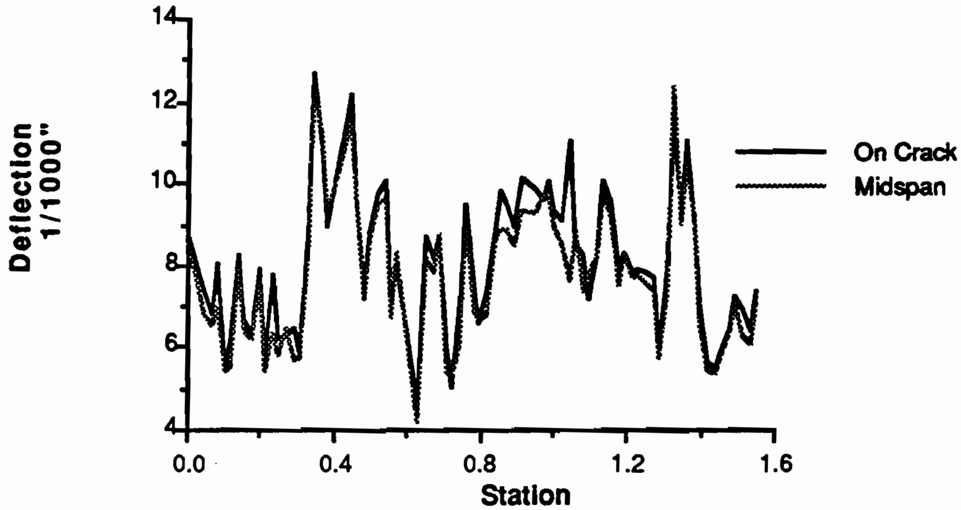
a) Third drop – first sensor



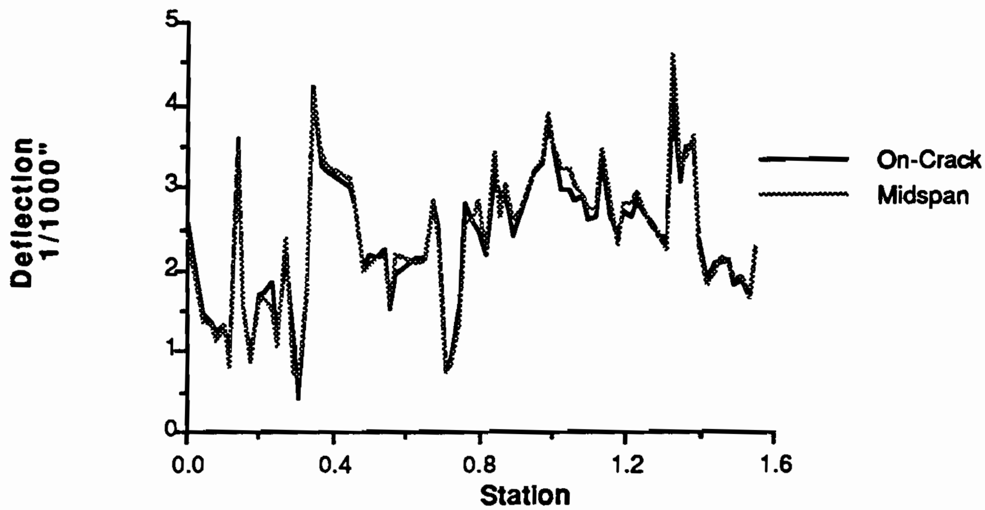
b) Third drop – seventh sensor



c) Fourth drop – first sensor



d) Fourth drop – seventh sensor



3) Test results of westbound direction

a) The third drop impact load of eastbound direction

Data File	Difference Mean	S.V.	Statistics	Test Results
W31.DAT	0.0803	0.4952	1.4312	ACCEPT
W32.DAT	0.0837	0.4792	1.5429	ACCEPT
W33.DAT	0.0481	0.4098	1.0361	ACCEPT
W34.DAT	0.0095	0.3372	0.2485	ACCEPT
W35.DAT	-0.0047	0.2572	-0.1629	ACCEPT
W36.DAT	-0.0131	0.1931	-0.5982	ACCEPT
W37.DAT	-0.0138	0.1380	-0.8859	ACCEPT

e.g., W31.DAT: Westbound, third drop, first sensor

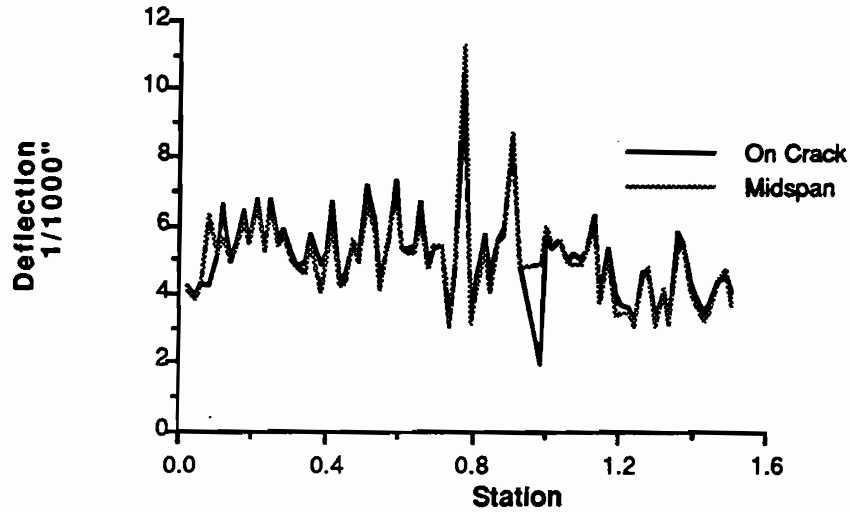
b) The fourth drop impact load in westbound direction

Data File	Difference Mean	S.V.	Statistics	Test
W41.DAT	0.1581	0.7045	1.9818	REJECT
W42.DAT	0.1431	0.6984	1.8094	ACCEPT
W43.DAT	0.0876	0.5814	1.3302	ACCEPT
W44.DAT	0.0387	0.4759	0.7185	ACCEPT
W45.DAT	0.0147	0.3554	0.3664	ACCEPT
W46.DAT	-0.0036	0.2622	-0.1209	ACCEPT
W47.DAT	-0.0053	0.1868	-0.2485	ACCEPT

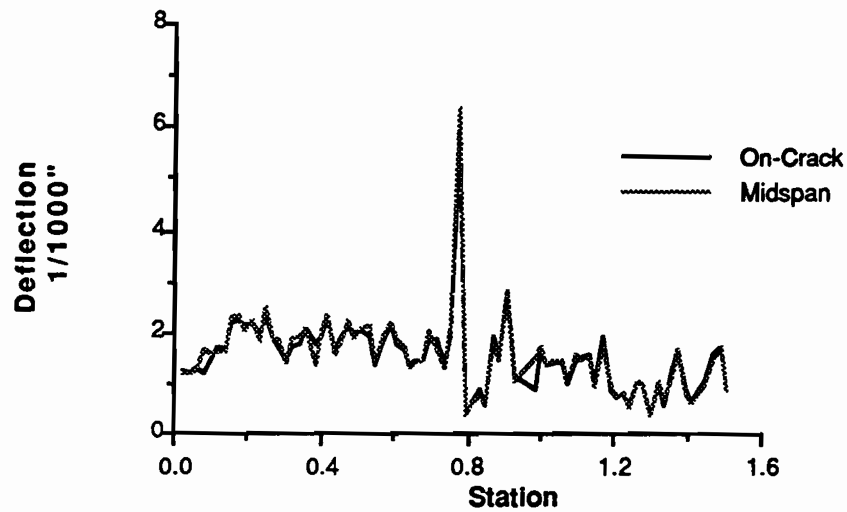
e.g., W41.DAT: Westbound, fourth drop, first sensor

4) *Deflection profile of westbound direction*

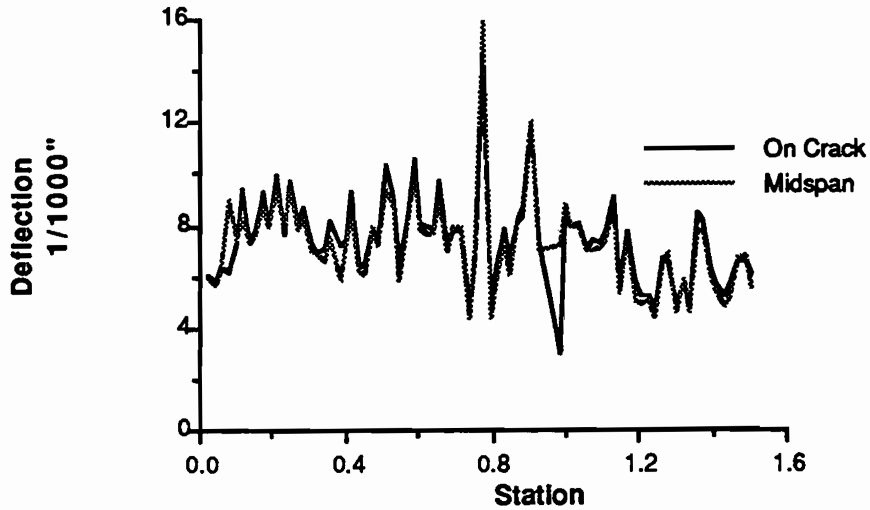
a) Third drop – first sensor



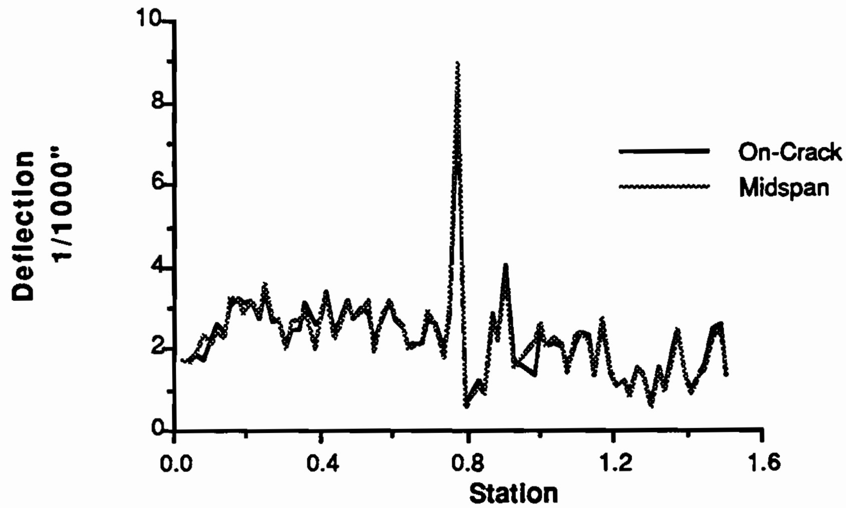
b) Third drop – seventh sensor



c) Fourth drop – first sensor



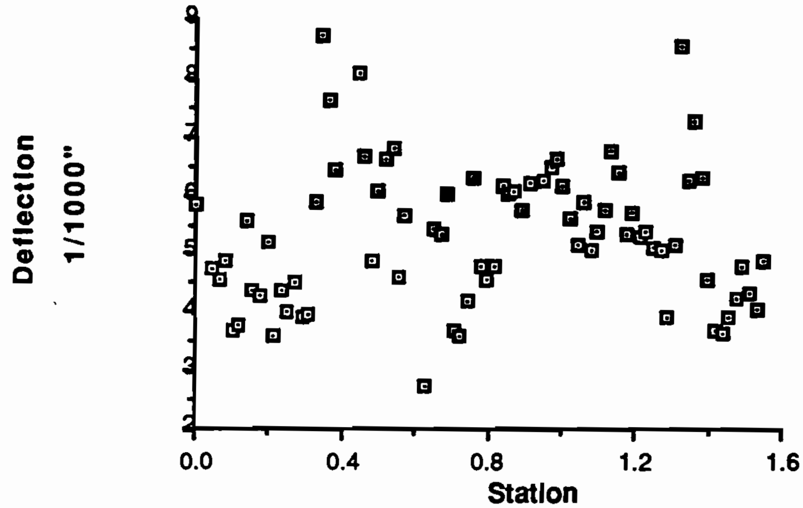
d) Fourth drop – seventh sensor



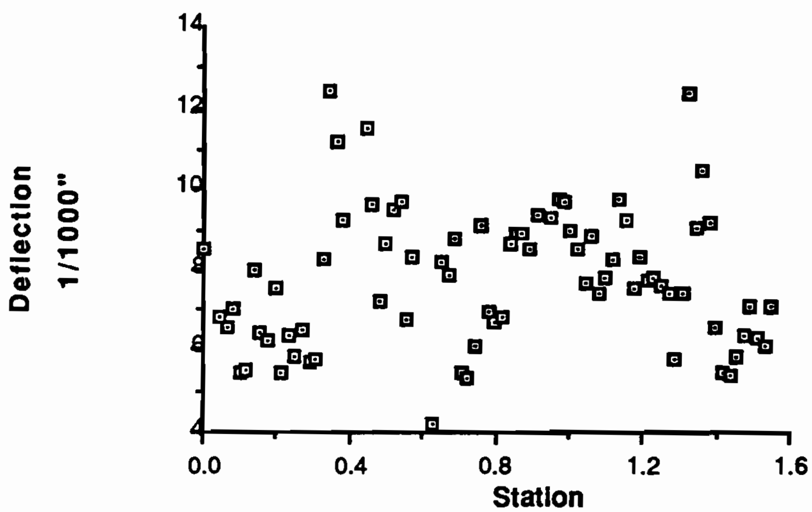
APPENDIX B. STANDARD JUDGMENT METHOD

1) When using sensor 1 of east direction

a) Third drop

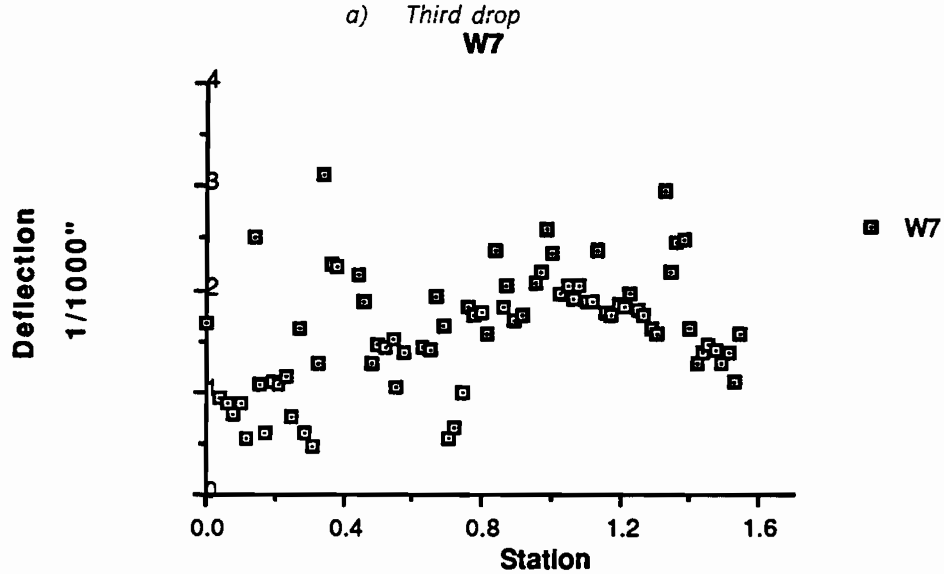


b) Fourth drop

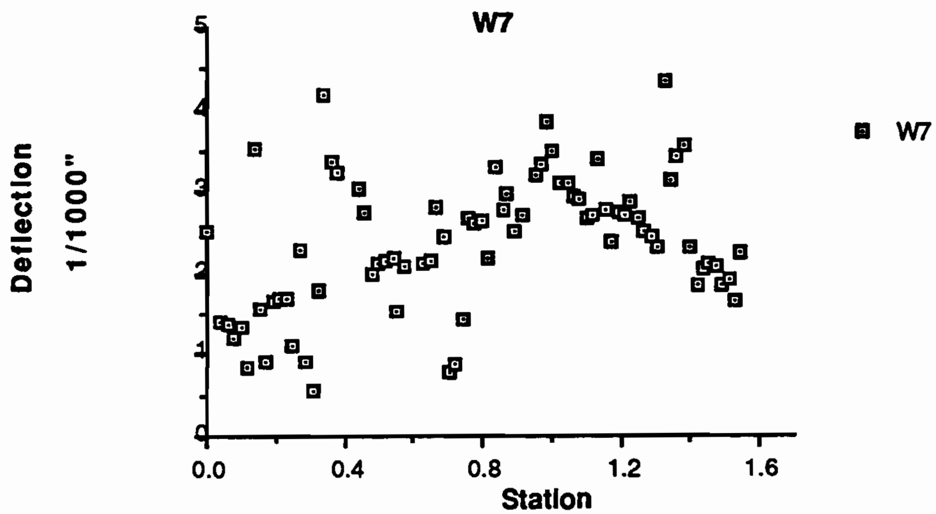


2) *When using sensor 7 of east direction*

a) *Third drop*

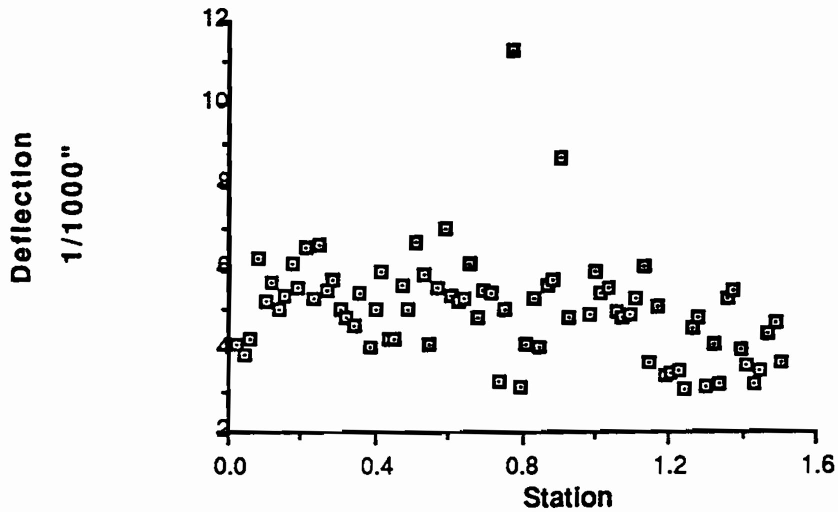


b) *Fourth drop*

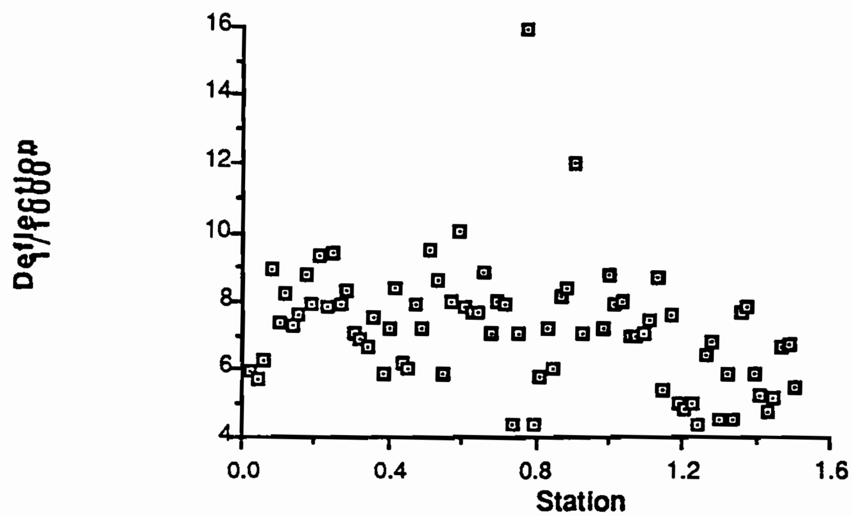


3) When using sensor 1 of west direction

a) Third drop

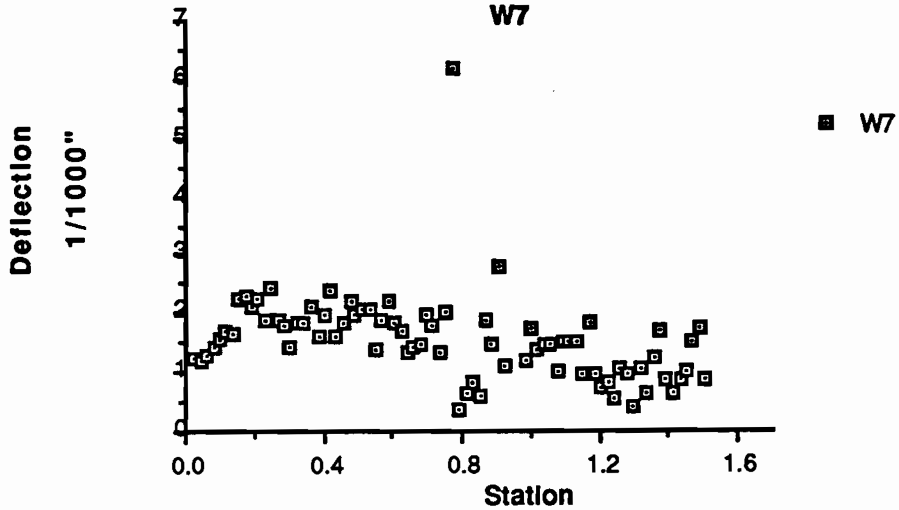


b) Fourth drop

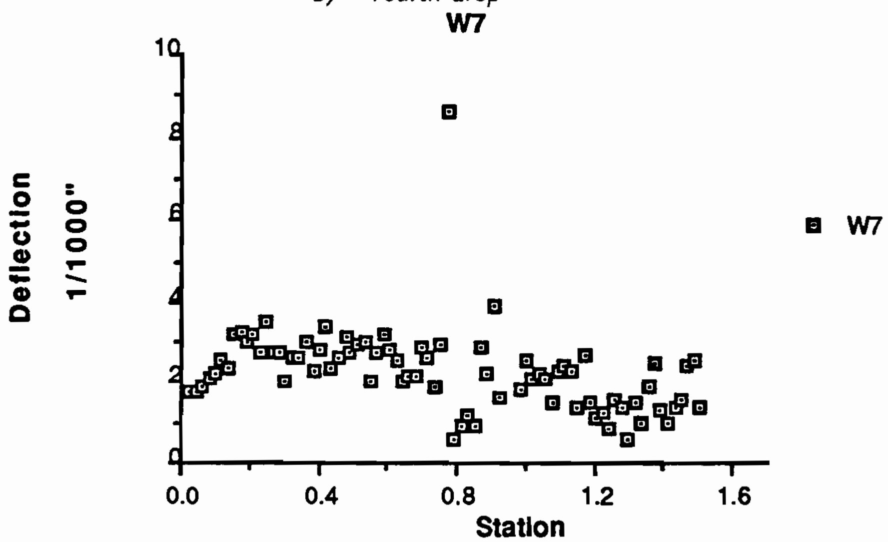


4) *When using sensor 7 of west direction*

a) Third drop



b) Fourth drop



APPENDIX C. MODULUS OF ELASTICITY TESTING

1) Modulus of elasticity testing data for El Paso IH-10 Cores-E3

Inventory	Displaced	Load	Strain	Stress
E3	0	0	0	0
	0.002	1000	0.0000182	80
Length = 7.55 in.	0.004	2000	0.0000364	159
Width = 4.00	0.007	3000	0.0000636	239
	0.001	4000	0.0000909	318
MOR = 3.83E+06	0.0012	5000	0.000109	398
	0.0014	6000	0.000127	478
	0.0017	7000	0.000155	557
	0.0019	8000	0.000173	637
	0.0022	9000	0.000200	717
	0.0023	10000	0.000209	796
	0.0025	11000	0.000227	876
	0.0027	12000	0.000245	955

2) Modulus of elasticity testing data for El Paso IH-10 Cores-E4

Inventory	Displaced	Load	Strain	Stress
E4	0	0	0	0
	0.0001	1000	0.00000909	82
Length = 7.59 in.	0.0006	3000	0.0000545	245
Width = 3.95 in.	0.0012	5000	0.000109	408
	0.0018	7000	0.000164	572
MOR = 2.60E+06	0.0025	9000	0.000227	735
(psi)	0.0032	11000	0.000291	898
	0.0039	13000	0.000355	1061
	0.0048	15000	0.000436	1225
	0.0057	17000	0.000518	1388
	0.0064	19000	0.000582	1551
	0.0088	21000	0.000800	1715
	0.0096	23000	0.000873	1878
	0.0098	25000	0.000891	2041

3) Modulus of elasticity testing data for El Paso IH-10 Cores-E6

Inventory	Displaced	Load	Strain	Stress
E6	0	0	0	0
	0.002	1000	0.0000182	82
Length = 7.00 in.	0.0005	3000	0.0000455	245
Width = 3.95 in.	0.0008	5000	0.0000727	408
	0.0011	7000	0.000100	572
MOR = 5.89E+06	0.0013	9000	0.000118	735
(psi)	0.0016	11000	0.000145	898
	0.0018	13000	0.000164	1061
	0.0022	15000	0.000200	1225
	0.0025	17000	0.000227	1388
	0.0028	19000	0.000255	1551
	0.0031	21000	0.000282	1715
	0.0034	23000	0.000309	1878
	0.0039	25000	0.000355	2041

4) Modulus of elasticity testing data for El Paso IH-10 Cores-W1

Inventory	Displaced	Load	Strain	Stress
W1	0	0	0	0
	0.0003	1000	0.0000273	80
Length = 7.66 in.	0.0008	2000	0.0000727	159
Width = 4.00 in.	0.0015	3000	0.000136	239
	0.0024	4000	0.000218	318
MOR = 1.37E+06	0.0032	5000	0.000291	398
(psi)	0.0040	6000	0.000364	478
	0.0046	7000	0.000418	557
	0.0051	8000	0.000464	637
	0.0057	9000	0.000518	717
	0.0062	10000	0.000564	796
	0.0068	11000	0.000618	876
	0.0072	12000	0.000655	955

5) Modulus of elasticity testing data for El Paso IH-10 Cores-W4

Inventory	Displaced	Load	Strain	Stress
W4	0	0	0	0
	0.0003	1000	0.0000273	81
Length = 7.41 in.	0.0009	3000	0.0000818	242
Width = 3.97 in.	0.0016	5000	0.000145	404
	0.0022	7000	0.000200	566
MOR = 2.65E+06	0.0028	9000	0.000255	727
(psi)	0.0036	11000	0.000327	889
	0.0042	13000	0.000382	1051
	0.0049	15000	0.000445	1212
	0.0057	17000	0.000518	1374
	0.0064	19000	0.000582	1536
	0.0074	21000	0.000673	1697
	0.0082	23000	0.000748	1859
	0.0089	25000	0.000809	2021

6) Modulus of elasticity testing data for El Paso IH-10 Cores-W5

Inventory	Displaced	Load	Strain	Stress
W5	0	0	0	0
	0.0002	1000	0.0000182	82
Length = 7.58 in.	0.0005	2000	0.0000455	163
Width = 3.95 in.	0.0007	3000	0.0000636	245
	0.0009	4000	0.0000818	327
MOR = 3.60E+06	0.0011	5000	0.000100	408
(psi)	0.0014	6000	0.000127	490
	0.0016	7000	0.000145	572
	0.0018	8000	0.000164	653
	0.0021	9000	0.000191	735
	0.0024	10000	0.000218	816
	0.0027	11000	0.000245	898
	0.0030	12000	0.000273	980

7) Modulus of elasticity testing data for El Paso IH-10 Cores-W6

Inventory	Displaced	Load	Strain	Stress
W6	0	0	0	0
	0.0003	1000	0.0000273	81
Length = 6.81 in.	0.0005	2000	0.00004551	162
Width = 3.97 in.	0.0008	3000	0.0000726	242
	0.0011	4000	0.0001	323
MOR = 2.55E+06	0.0013	5000	0.000118	404
(psi)	0.0016	6000	0.000145	485
	0.002	7000	0.000182	566
	0.0021	8000	0.000193	647
	0.0025	9000	0.000227	727
	0.0028	10000	0.000255	808
	0.0032	11000	0.000291	889
	0.0034	12000	0.000309	970

APPENDIX D. THE RPEDD1

1) Example data format of the RPEDD1

Input Data	Default	Adapted
Card1 : Total number of deflection basins (max : 50)		
Card2 : Title information data	999	
Card3 : Station and type of NDT devices		
Card4 : Characteristic of NDT device (in particular, FWD)		
* Code for NDT device	(FWD = 2)	2
* Number of sensors	(at least 6)	7
* Peak force of FWD signal	(15800)	variable
* Peak stress of FWD at surface	(144.40)	variable
* Radius of FWD loading	(150mm)	5.9 inch
* Duration of FWD force signal	(25 msec)	

Card5 : Control (Optional) Card

* Output of back-calculated Young's modulus (0)
  - 0 : for summary only
  - 1 : for detailed output

* Remaining life analysis (0)
  - 0 : skip remaining life analysis
  - 1 : make remaining life analysis

* Finite thickness of subgrade (0)
  - 0 : ignoring the default procedure to create a rigid layer
  - 1 : activating

* Type of rigid pavement (1)
  - 0 : JCP/JRCP
  - 1 : CRCP

* Shoulder type (1)
  - 0 : JCP/JRCP
  - 1 : CRCP

* Type of layer above subgrade (2)
  - 1 : granular
  - 2 : stabilized

* Unit weight of subgrade soil (115.0 ib/cft)

* Condition of concrete pavement (0)
  - 0 : normal, not severely damaged
  - 1 : severely cracked

* Equivalent linear analysis (0)
  - 0 : making a complete analysis
  - 1 : skip

Card6: Measured deflection data : Not exceeding 7 sensors

Card7 : Number of idealized pavement structures

* Number of layers 3
* Radial distance from the first sensor (default value)

Card8 : Pavement layer characteristics from the surface layer

* Layer number (1,2,...) (3)
* Thickness in inches
* Poisson's ratio
* Seed modulus (Initial assumed values)
* Maximum allowable value of Young's modulus
* Minimum allowable value of Young's modulus

*** example ****

4

1	8.00	0.15	4000000	6500000	2000000
2	6.00	0.30	1000000	2000000	50000
3		0.40	12000	70000	5000

2) *The results of the RPEDD1*

Eastbound direction

East 1

Station	W1	W2	W3	W4	W5	W6	W7	E1	E2	E3
0.000	8.54	7.70	6.48	5.27	4.13	3.19	2.43	2550000	154700	28170
0.042	6.80	5.63	4.60	3.65	2.61	1.91	1.37	2462000	53700	46930
0.063	6.57	5.69	4.57	3.41	2.52	1.84	1.34	4666000	2000000	31200
0.080	7.02	5.79	4.46	3.24	2.28	1.63	1.16	2000000	320600	47620
0.099	5.43	4.71	3.98	3.20	2.41	1.80	1.35	5382000	2000000	31200
0.117	5.49	4.41	3.41	2.51	1.74	1.21	0.81	3388000	2000000	42890
0.138	8.00	7.40	6.59	5.67	4.87	4.11	3.46	5225000	604600	18290
0.155	6.41	5.69	4.64	3.62	2.80	2.11	1.56	2605000	146500	39310
0.174	6.24	5.06	3.87	2.80	1.92	1.37	0.89	2000000	50000	65200
0.194	7.56	6.73	5.44	4.12	3.12	2.27	1.65	2333000	50000	36390
0.212	5.43	4.98	4.31	3.52	2.76	2.17	1.67	5128000	2000000	28790
0.233	6.34	5.56	4.37	3.41	2.73	2.06	1.55	2425000	406000	39600
0.250	5.80	4.88	3.84	2.82	2.06	1.50	1.07	5072000	2000000	31200
0.269	6.50	6.04	5.33	4.55	3.70	2.94	2.37	4942000	1652800	22940
0.289	5.05	3.89	3.11	2.32	1.61	1.13	0.77	4250000	2000000	42890
0.308	5.79	4.62	3.58	2.69	1.82	1.25	0.68	2000000	241400	69870
0.328	8.27	7.29	5.96	4.61	3.48	2.53	1.81	2000000	50000	33330
								3436941	925312	38578

East 2

Station	W1	W2	W3	W4	W5	W6	W7	E1	E2	E3
0.345	12.42	11.14	9.92	8.44	6.74	5.23	4.15	2211000	90200	15120
0.364	11.17	10.48	9.15	7.46	5.96	4.57	3.43	2635000	50000	18050
0.383	9.25	8.67	7.58	6.33	5.14	4.10	3.27	3087000	182000	19430
0.444	11.52	10.11	8.81	7.06	5.49	4.17	3.09	2000000	50000	20050
0.461	9.62	8.63	7.47	6.09	4.73	3.64	2.74	2601000	68000	22550
0.480	7.20	6.34	5.54	4.50	3.48	2.61	1.98	2989000	133800	31110
0.499	8.66	7.86	6.63	5.23	4.01	2.93	2.07	2406000	50000	29230
0.518	9.46	8.46	6.98	5.45	4.10	2.96	2.15	2000000	263800	24280
								2491125	110975	22478

East 3

Station	W1	W2	W3	W4	W5	W6	W7	E1	E2	E3
0.541	9.66	8.79	7.29	5.53	4.15	3.01	2.16	2417000	953300	24460
0.555	6.75	6.15	5.05	3.92	2.99	2.15	1.56	2755000	50000	39070
0.573	8.32	7.54	6.25	4.71	3.47	2.59	2.2	2310000	55000	27880
0.630	4.17	4.01	3.86	3.52	3.21	2.64	2.1	6500000	2000000	21310
0.649	8.17	7.72	6.22	4.82	3.78	2.86	2.13	2499000	167500	28920
0.669	7.83	7.26	6.15	5.06	4.16	3.44	2.84	3920000	660000	22340
0.690	8.74	7.93	6.59	5.26	4.20	3.20	2.37	2618000	230400	25980
0.706	5.44	4.67	3.55	2.55	1.90	1.20	0.76	2000000	104000	65610
0.722	5.28	4.69	3.70	2.73	1.96	1.27	0.86	2296000	355000	54240
0.744	6.08	5.32	4.28	3.30	2.48	1.84	1.33	2119000	190300	44950
0.761	9.07	8.11	6.93	5.67	4.45	3.44	2.57	2024000	134800	23640
0.780	6.91	6.16	5.28	4.38	3.66	3.12	2.63	4150000	799200	24040
								2967333	474958	33537

East 4

Station	W1	W2	W3	W4	W5	W6	W7	E1	E2	E3
0.798	6.67	5.98	5.40	4.79	4.05	3.40	2.83	4895000	1572200	21430
0.818	6.81	5.94	5.00	4.26	3.41	2.78	2.22	2875000	627100	27720
0.837	8.61	7.88	6.98	6.15	5.05	4.20	3.44	4810000	258000	18340
0.858	8.89	7.98	6.86	5.61	4.57	3.49	2.64	2336000	159600	22960
0.873	8.90	8.09	6.95	5.76	4.69	3.76	3.04	2935000	522100	20750
0.889	8.52	7.58	6.42	5.29	4.20	3.45	2.6	2271000	316300	23260
0.913	9.33	8.39	7.24	5.93	4.67	3.59	2.73	2616000	70500	22680
0.952	9.31	8.59	7.44	6.20	5.05	4.06	3.2	2908000	191400	19800
0.969	9.74	9.06	7.83	6.52	5.31	4.20	3.33	3300000	390500	18460
0.988	9.69	8.74	7.87	6.98	5.71	4.80	3.88	3734000	300600	16230
1.004	8.94	8.16	7.18	6.15	5.11	4.22	3.5	5071000	787400	17000
1.024	8.50	7.59	6.78	5.81	4.78	3.91	3.22	3595000	438800	19790
1.046	7.64	6.85	6.04	5.33	4.41	3.76	3.22	4072000	901700	19520
1.062	8.83	7.94	6.87	5.74	4.67	3.77	3.03	2699000	246900	20970
1.081	7.37	6.85	6.09	5.12	4.26	3.53	2.92	3866000	551200	21720
1.099	7.77	6.86	5.96	5.08	4.05	3.41	2.74	3021000	500900	23090
1.117	8.24	7.22	6.16	5.25	4.14	3.43	2.75	2444000	377100	23050
1.134	9.78	8.78	7.66	6.42	5.19	4.20	3.46	3213000	512100	17150
								3370056	484689	20773

East 5

Station	W1	W2	W3	W4	W5	W6	W7	E1	E2	E3
1.155	9.26	8.13	6.73	5.48	4.31	3.44	2.87	2000000	374300	21250
1.173	7.52	6.39	5.39	4.71	3.68	2.91	2.33	2308000	255600	26890
1.192	8.31	7.40	6.41	5.34	4.31	3.52	2.81	2778000	261600	22330
1.211	7.74	7.11	6.24	5.30	4.29	3.59	2.8	3218000	353300	22510
1.229	7.79	7.21	6.16	5.01	4.30	3.54	2.93	4367000	687900	21490
1.248	7.57	6.67	5.71	4.82	3.90	3.23	2.67	3552000	965600	22580
1.268	7.37	6.55	5.63	4.62	3.77	3.09	2.51	2568000	554100	25450
1.286	5.76	5.10	4.53	4.01	3.45	2.93	2.45	6500000	2000000	24430
1.306	7.40	6.26	5.15	4.21	3.52	2.78	2.25	2222000	662600	27580
1.324	12.36	11.43	9.88	8.19	6.82	5.60	4.61	2662000	229400	13790
1.343	9.04	7.94	6.65	5.61	4.62	3.85	3.22	2582000	666100	19000
1.359	10.45	9.36	8.03	6.59	5.35	4.25	3.35	2328000	213700	18430
1.379	9.16	8.54	7.58	6.51	5.45	4.48	3.62	3866000	338300	17370
1.398	6.57	6.01	5.05	4.21	3.47	2.84	2.3	4089000	402000	26650
1.418	5.46	5.09	4.22	3.37	2.80	2.27	1.83	4988000	2000000	27230
1.436	5.37	4.87	4.24	3.56	2.98	2.45	2	4364000	855800	31520
1.455	5.82	5.20	4.48	3.77	3.17	2.61	2.15	4250000	1437400	28440
1.474	6.38	5.72	4.87	4.03	3.39	2.60	2.09	3846000	744000	29230
1.492	7.04	6.17	5.07	3.98	3.05	2.36	1.89	2132000	283600	32360
1.513	6.32	5.43	4.54	3.71	2.91	2.33	1.93	2784000	724300	31630
1.532	6.07	5.31	4.38	3.46	2.67	2.07	1.66	4566000	2000000	28700
1.547	7.09	6.26	5.32	4.43	3.61	2.91	2.28	2670000	529600	26990
								3392727	751782	24811

Westbound direction

West 1

Station	W1	W2	W3	W4	W5	W6	W7	E1	E2	E3
0.024	5.94	5.01	4.25	3.43	2.74	2.15	1.76	4878000	2000000	27960
0.043	5.69	4.82	4.02	3.31	2.65	2.16	1.72	4836000	2000000	28350
0.062	6.26	5.58	4.66	3.73	2.99	2.37	1.9	2981000	388000	33590
0.084	8.97	8.06	6.69	5.27	4.05	3.08	2.34	2058000	85400	26270
0.1	7.39	6.32	5.33	4.43	3.46	2.78	2.15	2193000	368900	28670
								3389200	968460	28968

West 2

Station	W1	W2	W3	W4	W5	W6	W7	E1	E2	E3
0.118	8.23	7.08	6	4.9	3.82	3.15	2.4	2261000	244200	26000
0.138	7.3	6.42	5.66	4.85	3.78	2.97	2.29	3043000	260400	27380
0.155	7.59	6.92	6.22	5.44	4.61	3.91	3.28	5424000	888900	17980
0.175	8.78	7.94	6.94	5.89	4.8	3.96	3.24	3507000	631200	19500
0.193	7.95	7.31	6.47	5.4	4.62	3.68	2.9	3285000	302100	21720
0.212	9.31	8.16	6.98	6	4.82	3.95	3.17	2390000	447500	19190
0.234	7.85	6.83	6.05	5.1	4.18	3.53	2.78	2511000	615200	22700
0.25	9.42	8.08	7.22	6.29	5.04	4.2	3.57	2944000	935200	17670
0.268	7.89	7.04	5.95	4.89	4.14	3.31	2.76	3480000	768400	22050
0.286	8.32	7.41	6.43	5.3	4.27	3.42	2.75	2657000	287600	23160
0.305	7.04	6.16	5.08	4.03	3.21	2.55	2.04	2365000	427100	30190
0.325	6.94	6.28	5.32	4.48	3.84	3.23	2.69	4122000	694800	23720
0.343	6.63	6	5.15	4.35	3.79	3.24	2.74	5785000	740100	23030
0.361	7.52	6.82	5.94	5.07	4.24	3.54	2.91	5134000	429900	21810
0.386	5.85	4.82	3.8	3.17	2.79	2.36	2.02	4065000	2000000	30480
0.4	7.2	6.54	5.69	4.84	4.13	3.45	2.9	4038000	748800	21720
0.419	8.36	7.42	6.46	5.52	4.71	4	3.35	4277000	776000	18640
0.437	6.21	5.69	4.96	4.16	3.48	2.81	2.26	4602000	356600	28370
0.456	6.07	5.48	4.84	4.21	3.59	3.02	2.54	6500000	1020000	24880
0.478	7.93	7.17	6.4	5.59	4.65	3.86	3.15	4995000	296800	20110
0.492	7.19	6.56	5.67	4.81	4.07	3.37	2.79	3741000	660700	22780
0.511	9.46	8.33	6.9	5.57	4.49	3.6	2.89	2030000	338600	21160
0.532	8.63	7.74	6.77	5.8	4.87	4	3.2	3451000	310600	20020
0.549	5.89	5.15	4.3	3.49	2.84	2.34	1.95	3380000	1241100	31600
								3749458	642575	23160.8

West 3

Station	W1	W2	W3	W4	W5	W6	W7	E1	E2	E3
0.569	7.97	7.24	6.19	5.13	4.22	3.43	2.78	3757000	345600	22910
0.590	0.06	9.1	7.85	6.48	5.26	4.17	3.22	2731000	111500	19130
0.607	7.83	7.12	6.16	5.15	4.28	3.48	2.8	3746000	915200	21800
0.629	7.67	6.79	5.8	4.86	3.97	3.22	2.57	2854000	460400	24720
0.644	7.69	6.59	5.43	4.36	3.43	2.66	2.04	2095000	230200	29910
0.661	8.88	7.64	6.18	4.8	3.7	2.8	2.11	2000000	80800	29100
0.683	7.02	6.24	5.37	4.45	3.57	2.81	2.15	2520000	286300	28620
0.696	7.98	7.24	6.38	5.46	4.54	3.71	2.95	3782000	288700	21520
0.717	7.94	7.21	6.29	5.27	4.2	3.3	2.57	3031000	196800	24830
0.737	4.42	3.87	3.48	3.19	2.63	2.23	1.83	6175000	2000000	27400
0.756	7.09	6.79	6.08	5.29	4.49	3.72	3.04	6500000	268900	21200
0.777	5.89	5.45	4.49	3.2	1.75	0.28	8.95	3520000	413800	7610
0.794	4.41	3.5	2.61	1.92	1.29	0.85	0.57	4966000	2000000	42890
0.813	5.84	4.94	3.85	2.85	1.98	1.3	0.87	2000000	318200	53640
0.832	7.23	6.16	4.87	3.65	2.55	1.71	1.1	2000000	870900	47620
0.851	6.06	5.13	3.98	2.97	2.09	1.39	0.91	2000000	1219300	53210
0.870	8.14	7.25	6.39	5.41	4.45	3.58	2.82	2799000	309800	22320
0.887	8.36	7.26	6.19	5.1	3.9	2.99	2.22	2000000	136300	27390
0.906	2.01	1.09	9.61	8.02	6.44	5.05	3.83	2157000	75600	15870
0.925	7.04	6.02	5.07	4.11	3.04	2.21	1.57	2300000	411900	33360
								3146650	547010	28753

West 4

Station	W1	W2	W3	W4	W5	W6	W7	E1	E2	E3
0.985	7.18	6.81	6.19	5.3	4.17	3.14	2.22	4250000	50000	27620
1.002	8.81	7.54	6.59	5.61	4.38	3.41	2.6	2534000	100000	23710
1.018	7.9	7.05	5.94	4.8	3.73	2.9	2.12	2505000	95500	28850
1.039	7.98	7.58	6.2	4.76	3.76	2.87	2.26	2867000	205700	27450
1.057	6.98	6.36	5.45	4.5	3.6	2.81	2.15	2967000	214000	28630
1.077	6.96	5.69	4.51	3.46	2.64	2	1.47	2000000	297800	40370
1.094	7.06	5.89	5.15	4.38	3.37	2.73	2.37	2883000	1196300	25830
1.113	7.46	6.52	5.6	4.59	3.7	2.99	2.41	2902000	617100	26040
1.134	8.71	7.78	6.41	4.98	3.84	2.91	2.24	2153000	122000	27120
1.150	5.38	4.54	3.83	3.21	2.35	1.82	1.41	5084000	2000000	31200
1.170	7.57	7.15	6.06	4.98	4.13	3.32	2.74	3668000	317900	23300
								3073909	474209	28193

West 5

Station	W1	W2	W3	W4	W5	W6	W7	E1	E2	E3
1.189	5.03	4.27	3.71	3.09	2.46	1.97	1.53	5544000	2000000	29950
1.206	4.87	4.02	3.18	2.46	1.94	1.51	1.12	5710000	2000000	31200
1.224	5.05	4.15	3.4	2.7	2.11	1.64	1.26	5481000	2000000	31200
1.245	4.37	3.78	3.02	2.41	1.8	1.24	0.85	4959000	2000000	42890
1.261	6.46	5.46	4.53	3.59	2.76	2.11	1.59	2092000	229800	37910
1.282	6.85	6.07	5.02	3.85	2.87	2.03	1.38	2475000	267800	36570
1.299	4.56	3.45	2.67	1.96	1.35	0.91	0.61	5121000	2000000	42890
1.319	5.85	5.12	4.28	3.52	2.71	2.05	1.51	2591000	189200	40360
1.337	4.56	3.91	3.03	2.29	1.75	1.3	0.96	5190000	2000000	42890
1.356	7.69	6.55	5.29	4.18	3.13	2.37	1.79	2000000	144500	34320
1.373	7.87	7.14	6.01	4.89	3.91	3.09	2.5	3372000	153300	25110
1.393	5.91	5.05	3.98	3.06	2.33	1.74	1.28	4790000	2000000	31200
1.411	5.29	4.35	3.33	2.5	1.76	1.29	0.92	3589000	2000000	42890
1.434	4.81	4.07	3.41	2.81	2.21	1.74	1.35	5777000	2000000	31200
1.450	5.17	4.54	3.96	3.26	2.57	1.97	1.49	5339000	2000000	30300
1.469	6.7	6.14	5.44	4.61	3.8	3.03	2.32	4018000	244400	27340
1.488	6.75	6.15	5.4	4.58	3.72	3.04	2.51	3982000	552800	25170
1.506	5.51	4.62	3.87	3.11	2.41	1.84	1.41	4955000	2000000	31200
								4276944	1321211	34144

APPENDIX E. THE PRDS1

1) Summary of PRDS1

PRDS1 (Pavement Rehabilitation Design System version 1)

• This program can be used to obtain the required overlay thickness using various data. These input data have been divided into eleven categories as follows:

1) Project description

2) Original pavement

- Original pavement information - geometric data
- Pavement structure - structural information

3) Traffic variables

- Traffic volume and 18kip ESAL

4) Time constants

- Analysis period

5) Remaining life variables

- Original pavement remaining life
- First overlay remaining value

6) Overlay characteristics

- Types of first overlay
- Types of second overlay
- No. of different overlay thicknesses
- ACP first overlay thickness
- ACP second overlay thickness
- PCC overlay thickness
- Allowable total overlay thickness
- Pavement stress factor of various overlay materials
- Other overlay material characteristics

7) Overlay construction cost variables

- Site establishment cost
- Pavement surface preparation costs
- Fixed cost of overlay construction
- Variable costs of overlay construction

8) Traffic delay cost variables

- No. of open and closed lanes
- Hours per day during overlay construction
- Speed of overlay and non-overlay direction
- Distance traffic is slowed
- Average vehicle delay

9) Distress / maintenance cost variables

- Distress repair costs
- Variation of distress rate of various pavement structures

10) Cost return

- Salvage value
- Value of each year of extended life

11) Combined interest and inflation rate

2) Example of input of the PRDS1

```
PRDS1 - PAVEMENT REHABILITATION DESIGN SYSTEM - VERSION 1, APRIL 1982
CENTER FOR TRANSPORTATION RESEARCH
UNIVERSITY OF TEXAS AT AUSTIN
LATEST REVISION - ARE INC., CONSULTING ENGINEERS


**********************************
P R D S   I N P U T   S U M M A R Y
**********************************


  PROJECT DESCRIPTION
  *******************

     1.1  TITLE
  BONDED CONCRETE OVERLAY IN ELPASO - PROJECT 1957 - East-1___


  ORIGINAL PAVEMENT
  *****************

     2.1  SURFACE TYPE                                      CRCP
     2.2  CONCRETE SHOULDER                                  YES
     2.3  NO. OF LANES (ONE DIRECTION)                         3
     2.4  NO. OF PAVEMENT LAYERS                               3

     3.1  PROJECT LENGTH. MILES                              .34
     3.2  LANE WIDTH, FEET                                  12.0
     3.3  TOTAL SHOULDER WIDTH, FEET                          8.
```

PAVEMENT STRUCTURE

	4.0	5.0	6.0
LAYER	THICKNESS	ELASTIC MODULUS	POISSONS
NO.	(IN)	(PSI)	RATIO
1	8.0	3094000.	.15
2	6.0	563000.	.30
3	SEMI-INFINITE	28930.	.40

7.1	CONCRETE FLEXURAL STRENGTH, PSI	720.
7.2	CRITICAL STRESS FACTOR	1.05
7.3	CONCRETE STIFFNESS AFTER CRACKING, PSI	800000.

8.1	NO. OF EXISTING DEFECTS PER MILE	5.
8.2	COST OF REPAIRING A DEFECT, DOL	2000.
8.3	RATE OF DEFECT DEVELOPMENT, NO./YR/MILE	2.

TRAFFIC VARIABLES

****

9.1	AVERAGE DAILY TRAFFIC (ADT)	145000.
9.2	ADT GROWTH RATE, PERCENT	4.00
9.3	INITIAL YEARLY 18-KIP ESAL, MILLIONS	4.760
9.4	18-KIP ESAL GROWTH RATE, PERCENT	4.00
9.5	DIRECTIONAL DISTRIBUTION FACTOR, PERCENT	50.0
9.6	LANE DISTRIBUTION FACTOR, PERCENT	50.0

TIME CONSTRAINTS

****

10.1	ANALYSIS PERIOD, YEARS	20.0
10.2	MINIMUM TIME BETWEEN OVERLAYS, YEARS	15.0
10.3	MAXIMUM ALLOWABLE YEARS OF HEAVY MAINTENANCE AFTER LOSS OF STRUCTURAL LOAD-CARRYING CAPACITY	4.0

REMAINING LIFE VARIABLES

****

11.1 NO. OF ORIGINAL PAVEMENT REMAINING LIFE VALUES TO CONSIDER 9

11.2 MINIMUM EXISTING PAVEMENT REMAINING LIFE BELOW WHICH A BONDED PCC OVERLAY MAY NOT BE PLACED 10.

11.3 VALUES OF ORIGINAL PAVEMENT REMAINING LIFE AT WHICH FIRST OVERLAY MAY BE PLACED

NO.	REMAINING LIFE (PERCENT)
1	80.
2	70.
3	60.
4	50.
5	40.
6	30.
7	20.
8	10.
9	2.

12.1 NO. OF FIRST OVERLAY REMAINING LIFE VALUES TO CONSIDER 0

12.2 VALUES OF FIRST OVERLAY REMAINING LIFE AT WHICH SECOND OVERLAY MAY BE PLACED

OVERLAY CHARACTERISTICS

****

13.0 TYPES OF FIRST OVERLAY TO CONSIDER

.1 ACP - YES

.2 BONDED CRCP - YES

.3 UNBONDED CRCP - YES

.4 BONDED JCP - NO

.5 UNBONDED JCP - NO

14.0 TYPES OF SECOND OVERLAY TO CONSIDER

.1 ACP - NO

.2 CRCP - NO

.3 JCP - NO

15.0 NO. OF DIFFERENT OVERLAY THICKNESS TO CONSIDER

.1 ACP FIRST OVERLAY - 5

.2 ACP SECOND OVERLAY - 0

.3 PCC OVERLAY - 7

16.0 ACP FIRST OVERLAY THICKNESSES, INCHES

.1 2.0

.2 2.5

.3 3.0

.4 4.0

.5 5.0

17.0 ACP SECOND OVERLAY THICKNESSES. INCHES

(NONE)

18.0 PCC OVERLAY THICKNESSES. INCHES

.1	3.0
.2	3.5
.3	4.0
.4	4.5
.5	5.0
.6	6.0
.7	7.0

19.1	ALLOWABLE TOTAL OVERLAY THICKNESS, INCHES	25.0
19.2	AVERAGE LEVEL-UP THICKNESS. INCHES	.5
19.3	BOND BREAKER THICKNESS, INCHES	1.0
20.1	ACP OVERLAY DESIGN STIFFNESS, PSI	300000.
20.2	POISSONS RATIO, ACP OVERLAY	.30
20.3	PCC OVERLAY DESIGN STIFFNESS, PSI	4500000.
20.4	POISSONS RATIO, PCC OVERLAY	.15
20.5	BOND BREAKER STIFFNESS. PSI	50000.
20.6	POISSONS RATIO. BOND BREAKER	.30
21.1	NO. OF OVERLAY FLEXURAL STRENGTHS TO CONSIDER	1
21.2	NO. WHICH IDENTIFIES WHICH FLEXURAL STRENGTH IN THE LIST TO USE FOR A BONDED PCC OVERLAY	1
22.0	PCC OVERLAY FLEXURAL STRENGTH(S), PSI	
	.1 720.	

*** PAVEMENT STRESS FACTORS AFTER OVERLAY ***

	FIRST OVERLAY TYPE	SECOND OVERLAY TYPE	CRITICAL STRESS LOCATION	OVERLAY SHOULDER TYPE	CRIT./INTER. STRESS FACTOR
23.1	ACP	(NONE)	EX PAVT	ACP	1.25
24.1	ACP	ACP	EX PAVT	ACP	.00
25.1	ACP	CRCP	EX PAVT	ACP	.00
25.2	ACP	CRCP	EX PAVT	CRCP	.00
26.1	ACP	CRCP	CRCP O/L	ACP	.00
26.2	ACP	CRCP	CRCP O/L	CRCP	.00
27.1	ACP	JCP	EX PAVT	ACP	.00
27.2	ACP	JCP	EX PAVT	JCP	.00
28.1	ACP	JCP	JCP O/L	ACP	.00
28.2	ACP	JCP	JCP O/L	JCP	.00
29.1	BOND CRC	(NONE)	EX PAVT	ACP	1.25
29.2	BOND CRC	(NONE)	EX PAVT	CRCP	1.25
30.1	BOND CRC	ACP	EX PAVT	ACP	.00
30.2	BOND CRC	ACP	EX PAVT	CRCP	.00
31.1	BOND JCP	(NONE)	EX PAVT	ACP	.00
31.2	BOND JCP	(NONE)	EX PAVT	JCP	.00
32.1	BOND JCP	ACP	EX PAVT	ACP	.00

32.2	BOND JCP	ACP	EX PAVT	JCP	.00
33.1	UNBD CRC	(NONE)	EX PAVT	ACP	1.25
33.2	UNBD CRC	(NONE)	EX PAVT	CRCP	1.25
34.1	UNBD CRC	(NONE)	CRCP O/L	ACP	1.25
34.2	UNBD CRC	(NONE)	CRCP O/L	CRCP	1.25
35.1	UNBD CRC	ACP	EX PAVT	ACP	.00
35.2	UNBD CRC	ACP	EX PAVT	CRCP	.00
36.1	UNBD CRC	ACP	CRCP O/L	ACP	.00
36.2	UNBD CRC	ACP	CRCP O/L	CRCP	.00
37.1	UNBD JCP	(NONE)	EX PAVT	ACP	.00
37.2	UNBD JCP	(NONE)	EX PAVT	JCP	.00
38.1	UNBD JCP	(NONE)	JCP O/L	ACP	.00
38.2	UNBD JCP	(NONE)	JCP O/L	JCP	.00
39.1	UNBD JCP	ACP	EX PAVT	ACP	.00
39.2	UNBD JCP	ACP	EX PAVT	JCP	.00
40.1	UNBD JCP	ACP	JCP O/L	ACP	.00
40.2	UNBD JCP	ACP	JCP O/L	JCP	.00

NOTE - STRATEGIES WITH A ZERO VALUE FOR THE CRITICAL TO INTERIOR STRESS FACTOR WILL NOT BE CONSIDERED.

41.1 1 - LAYER PACKAGE USED TO PREDICT RESPONSE.

OVERLAY CONSTRUCTION COST VARIABLES

****

42.0 SITE ESTABLISHMENT COST, DOL

.1	ACP EQUIPMENT	500000.
.2	CRCP EQUIPMENT	500000.
.3	JCP EQUIPMENT	0.
.4	ACP AND CRCP EQUIPMENT	1000000.
.5	ACP AND JCP EQUIPMENT	0.

43.0 PAVEMENT SURFACE PREPARATION COSTS, DOL/SY

.1	EXISTING PAVEMENT	.20
.2	ACP OVERLAY	.20
.3	CRCP OVERLAY	.20
.4	JCP OVERLAY	.00

44.1	FIXED COST OF ACP OVERLAY CONSTRUCTION, DOL/SY	3.00
44.2	VARIABLE COST OF ACP OVERLAY CONSTR., DOL/SY/IN	1.00
44.3	FIXED COST OF FLEXIBLE SHOULDER CONSTR., DOL/SY	3.00
44.4	VARIABLE COST OF FLEX. SHOULDER CONSTR., DOL/SY/IN	1.00
44.5	COST OF BOND BREAKER CONSTRUCTION, DOL/SY	3.00

45.0 CRCP FIXED COST FOR EACH FLEXURAL STRENGTH

	FLEXURAL STRENGTH (PSI)	FIXED COST (DOL/SY)
.1	720.	12.00

46.0 CRCP VARIABLE COST FOR EACH FLEXURAL STRENGTH

	FLEXURAL STRENGTH (PSI)	VARIABLE COST (DOL/SY/IN)
.1	720.	2.00

47.0 JCP FIXED COST FOR EACH FLEXURAL STRENGTH

	FLEXURAL STRENGTH (PSI)	FIXED COST (DOL/SY)
.1	720.	.00

48.0 JCP VARIABLE COST FOR EACH FLEXURAL STRENGTH

	FLEXURAL STRENGTH (PSI)	VARIABLE COST (DOL/SY/IN)
.1	720.	.00

49.1	TOTAL STEEL PERCENTAGE REQUIRED IN CRCP OVERLAYS	.60
49.2	TOTAL STEEL PERCENTAGE REQUIRED IN JCP OVERLAYS	.00
49.3	COST OF STEEL REINFORCEMENT, DOL/LB	1.75

TRAFFIC DELAY COST VARIABLES

****

50.1	LOCATION OF PROJECT (1=RURAL.2=URBAN)	2
50.2	MODEL NO. FOR HANDLING TRAFFIC	3
50.3	NO. OF OPEN LANES. OVERLAY DIRECTION	2
50.4	NO. OF OPEN LANES, NON-OVERLAY DIRECTION	3
51.1	MILITARY TIME OVERLAY CONSTRUCTION BEGINS	600.
51.2	MILITARY TIME OVERLAY CONSTRUCTION ENDS	1800.
51.3	HOURS PER DAY OVERLAY CONSTRUCTION OCCURS	6.0
51.4	NO. OF DAYS CONCRETE IS ALLOWED TO CURE	14.
51.5	DETOUR DISTANCE TO USE IN MODEL 5, MILES	2.5
52.1	AVERAGE APPROACH SPEED, MPH	55.
52.2	AVERAGE SPEED, OVERLAY DIRECTION, MPH	35.
52.3	AVERAGE SPEED, NON-OVERLAY DIRECTION, MPH	55.
53.1	DISTANCE TRAFFIC IS SLOWED, OVERLAY DIRECTION, MILES	2.0
53.2	DISTANCE TRAFFIC IS SLOWED, NON-OVERLAY DIR., MILES	.0
53.3	PERCENT OF VEHICLES STOPPED, OVERLAY DIRECTION	10.0
53.4	PERCENT OF VEHICLES STOPPED, NON-OVERLAY DIRECTION	.0
53.5	AVERAGE VEHICLE DELAY, OVERLAY DIRECTION, HRS	.00200
53.6	AVERAGE VEHICLE DELAY, NON-OVERLAY DIRECTION, HRS	.00000
54.1	ACP PRODUCTION RATE, CY/HR	42.
54.2	CRCP PRODUCTION RATE, CY/HR	60.
54.3	JCP PRODUCTION RATE, CY/HR	0.
54.4	BOND BREAKER PRODUCTION RATE, CY/HR	40.

DISTRESS/MAINTENANCE COST VARIABLES

****

55.1	DISTRESS REPAIR COST, CRCP OVERLAY, DOL	2000.00
55.2	INITIAL CRCP OVERLAY DISTRESS RATE, NO./MI/YR	1.0
55.3	SECONDARY CRCP OVERLAY DISTRESS RATE, NO./MI/YR	.0
55.4	CRCP OVERLAY DISTRESS RATE FOR EACH YEAR AFTER LOSS OF PAVEMENT LOAD-CARRYING CAPACITY	

YEAR AFTER FAILURE	DISTRESS RATE (NO./MILE)
1	3.0
2	5.0
3	8.0
4	16.0

56.1	DISTRESS REPAIR COST, JCP OVERLAY, DOL	.00
56.2	INITIAL JCP OVERLAY DISTRESS RATE, NO./MI/YR	.0
56.3	SECONDARY JCP OVERLAY DISTRESS RATE, NO./MI/YR	.0
56.4	JCP OVERLAY DISTRESS RATE FOR EACH YEAR AFTER LOSS OF PAVEMENT LOAD CARRYING CAPACITY	

YEAR AFTER FAILURE	DISTRESS RATE (NO./MILE)
1	.0
2	.0
3	.0
4	.0

57.1 DISTRESS REPAIR COST, ACP OVERLAY ON CRCP, DOL 500.00

57.2 INITIAL ACP/CRCP DISTRESS RATE. NO./MI/YR 1.0

57.3 SECONDARY ACP/CRCP DISTRESS RATE, NO./MI/YR 2.0

57.4 ACP/CRCP DISTRESS RATE FOR EACH YEAR AFTER LOSS OF PAVEMENT LOAD-CARRYING CAPACITY

YEAR AFTER FAILURE	DISTRESS RATE (NO./MILE)
1	3.0
2	5.0
3	8.0
4	16.0

58.1 DISTRESS REPAIR COST, ACP OVERLAY ON JCP, DOL 100.00

58.2 INITIAL ACP/JCP DISTRESS RATE, NO./MI/YR 5.0

58.3 SECONDARY ACP/JCP DISTRESS RATE, NO./MI/YR 10.0

58.4 ACP/JCP DISTRESS RATE FOR EACH YEAR AFTER LOSS OF PAVEMENT LOAD CARRYING CAPACITY

YEAR AFTER FAILURE	DISTRESS RATE (NO./MILE)
1	20.0
2	40.0
3	80.0
4	160.0

COST RETURNS

****

59.1	SALVAGE VALUE, PERCENT OF OVERLAY CONSTRUCTION COST	10.0
59.2	VALUE OF EACH YEAR OF EXTENDED LIFE, DOL/SY/YR	.25

COMBINED INTEREST AND INFLATION RATE

****

60.1	INTEREST RATE MINUS INFLATION RATE, PERCENT	5.0

APPENDIX F. EXAMPLE OF OUTPUT OF AASHTO PROGRAM

```
DNPS86 (1) - AASHTO DESIGN OF NEW PAVEMENT STRUCTURES PROGRAM
             VERSION 1 - SEPTEMBER 1986

PROBLEM NO. EAST-1                                          Page 1
  BONDED CONCRETE OVERLAY DESIGN ON IH 10 IN EL PASO
  NOV. 92    .


GENERAL DESIGN INPUT REQUIREMENTS

  Analysis Period (years)                                     30.0

  Discount Rate (percent per year)                            5.00

  Number of Traffic Lanes (one direction)                        3

  Lane Width (feet)                                           12.0

  Combined Width of Shoulders (feet. one direction)             8.


ROADBED SOIL RESILIENT MODULI

  Season:               1       2       3       4       5       6
  Modulus (psi):  28930.       0.      0.      0.      0.      0.


DESIGN INPUTS FOR FLEXIBLE AND RIGID PAVEMENTS

  Desired Level of Reliability (percent)                     95.00

  Design Terminal Serviceability                              2.50

  Roadbed Soil Swelling                            (Not Considered)

  Frost Heave                                      (Not Considered)
```

PROBLEM NO. EAST-1

BONDED CONCRETE OVERLAY DESIGN ON IH 10 IN EL PASO
NOV. 92

RIGID PAVEMENT DESIGN INPUTS

Performance Period for Initial Pavement (years)	30.0
Serviceability Index After Initial Construction	4.50
Traffic	
Growth Rate (percent)	4.00
Type of Growth	COMPOUND
Initial Yearly 18-kip ESAL (both directions)	4764028.
Directional Distribution Factor (percent)	50.
Lane Distribution Factor (percent)	50.
Overall Standard Deviation (log repetitions)	.390
Subbase	
Subbase Type	C S SLAB
Thickness (inches)	6.00
Elastic Modulus (psi)	563000.
Unit Cost ($/CY)	.00
Salvage Value (percent)	0.
Portland Cement Concrete Slab	
Type of Construction	CPCP
PCC Elastic Modulus (psi)	3094000.
Average PCC Modulus of Rupture (psi)	720.
Unit Cost of PCC ($/CY)	.00
Salvage Value (percent)	0.
Structural Characteristics	
Load Transfer Coefficient	3.00
Drainage Coefficient	1.00
Loss of Support Factor	.50
Other Construction Related Costs	
Shoulders, If Not Full Strength ($/linear foot)	.00
Drainage ($/linear foot)	.00
Mobilization and Other Fixed Costs ($/linear foot)	.00
Maintenance Cost	
Initial Year Costs Begin to Accrue	.0
Yearly Increase ($/lane mile/year)	.00

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RIGID PAVEMENT STRUCTURAL DESIGN

Effective Modulus of Subgrade Reaction (pci)	992.
Subbase Type	C S SLAB
Subbase Thickness (inches)	6.00
Pavement Type	CPCP
Required Slab Thickness (inches)	11.65
Performance Life (years)	30.0
Allowable 18-kip ESAL Repetitions	66797450.

LIFE-CYCLE COSTS ($/SY)

Initial Construction	.00
Maintenance	.00
Salvage Value	.00
First Overlay Construction	.00
First Overlay Maintenance	.00
First Overlay Salvage Value	.00
Second Overlay Construction	.00
Second Overlay Maintenance	.00
Second Overlay Salvage Value	.00
Total Net Present Value	.00

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GENERAL DESIGN INPUT REQUIREMENTS

Analysis Period (years)	30.0
Discount Rate (percent per year)	5.00
Number of Traffic Lanes (one direction)	3
Lane Width (feet)	12.0
Combined Width of Shoulders (feet, one direction)	8.

ROADBED SOIL RESILIENT MODULI

Season:	1	2	3	4	5	6
Modulus (psi):	27600.	0.	0.	0.	0.	0.

DESIGN INPUTS FOR FLEXIBLE AND RIGID PAVEMENTS

Desired Level of Reliability (percent)	95.00
Design Terminal Serviceability	2.50
Roadbed Soil Swelling	(Not Considered)
Frost Heave	(Not Considered)

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RIGID PAVEMENT DESIGN INPUTS

Performance Period for Initial Pavement (years)	30.0
Serviceability Index After Initial Construction	4.50
Traffic	
Growth Rate (percent)	4.00
Type of Growth	COMPOUND
Initial Yearly 18-kip ESAL (both directions)	4764028.
Directional Distribution Factor (percent)	50.
Lane Distribution Factor (percent)	50.
Overall Standard Deviation (log repetitions)	.390
Subbase	
Subbase Type	C S SLAB
Thickness (inches)	6.00
Elastic Modulus (psi)	326800.
Unit Cost ($/CY)	.00
Salvage Value (percent)	0.
Portland Cement Concrete Slab	
Type of Construction	CPCP
PCC Elastic Modulus (psi)	2436000.
Average PCC Modulus of Rupture (psi)	720.
Unit Cost of PCC ($/CY)	.00
Salvage Value (percent)	0.
Structural Characteristics	
Load Transfer Coefficient	3.00
Drainage Coefficient	1.00
Loss of Support Factor	.50
Other Construction Related Costs	
Shoulders. If Not Full Strength ($/linear foot)	.00
Drainage ($/linear foot)	.00
Mobilization and Other Fixed Costs ($/linear foot)	.00
Maintenance Cost	
Initial Year Costs Begin to Accrue	.0
Yearly Increase ($/lane mile/year)	.00

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RIGID PAVEMENT STRUCTURAL DESIGN

Effective Modulus of Subgrade Reaction (pci)	878.
Subbase Type	C S SLAB
Subbase Thickness (inches)	6.00
Pavement Type	CPCP
Required Slab Thickness (inches)	11.51
Performance Life (years)	30.0
Allowable 18-kip ESAL Repetitions	66797450.

LIFE-CYCLE COSTS ($/SY)

Initial Construction	.00
Maintenance	.00
Salvage Value	.00
First Overlay Construction	.00
First Overlay Maintenance	.00
First Overlay Salvage Value	.00
Second Overlay Construction	.00
Second Overlay Maintenance	.00
Second Overlay Salvage Value	.00
Total Net Present Value	.00