DEPARTMENTAL RESEARCH

Report Number : 101- 1F

AN ASPHALTIC CONCRETE OVERLAY DESIGN SUBSYSTEM

RESEARCH PROJECT 1-8-66-101

TEXAS HIGHWAY DEPARTMENT

AN ASPHALTIC CONCRETE OVERLAY DESIGN SUBSYSTEM

by

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Research Report 101-1F

Utilizing Deflection Measurements
To Upgrade Pavement Structures

Research Project 1-8-66-101

conducted

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

by the

Highway Design Division, Research Section
Texas Highway Department

December 1970

"WELL, THIS SECTION IS TAKEN CARE OF.... UNLESS THERES A LOUD THUNDERCLAP, OR SOME JET BREAKS THE SOUND BARRIER!"

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

PREFACE

This is the only report resulting from Research Study 1-8-66-101, "Utilizing Deflection Measurements to Upgrade Pavement Structures." As such, its purpose is two-fold. The primary purpose is to present an overlay design method to pavement designers, specifically to Texas Highway Department designers that are trained in the use of the Texas Highway Department Flexible Pavement Design System. The second objective, that of research documentation, has been done by placing most research discussion in Appendices A, B, and C. For those readers primarily interested in the research method it is recommended that they read this report in the following order: Chapter 1, Appendix A, Appendix B, and Appendix C followed by the remainder in the order of presentation.

The authors wish to acknowledge the work done on Texas Research Project 32 by Frank Scrivner and his associates; upon which this report is only a small amplification.

ABSTRACT

An asphaltic concrete overlay design subsystem for the Texas Highway Department Flexible Pavement Design System is presented. This subsystem provides for generation of several asphaltic concrete overlay strategies for existing flexible pavements. These strategies are listed in order of ascending cost. Dynaflect deflections are used to characterize the existing pavement structure and the asphaltic concrete overlay material. Uncertainty in the predicted pavement life, as a result of the variability in the two materials characterized, is treated so that the designer may select either a 95% or 99% confidence level.

RECOMMENDED IMPLEMENTATION

The following steps are recommended for implementing the results of this research project:

1. The results of this work should be reviewed by the Principal Investigators of The Texas Highway Department Research Project 123, "A Systems Analysis of Pavement Design and Research Implementation". After this review the overlay subsystem should be incorporated into the overall Flexible Pavement Design System and the "Supplement to the User's Manual" (Appendix D) should be issued to all those that have been trained to use the Flexible Pavement Design System.

2. The staff of Research Project 123 should examine the possibility of revising the overlaying routine in the Flexible Pavement Design System to incorporate some measure of uncertainty similar to that adopted for the overlaying subsystem. It is recommended that, until a more sophisticated stochastic approach can be developed, the approach developed in Appendix C be applied in the overall Flexible Pavement System.

3. The Texas Highway Department designers that are utilizing the Flexible Pavement System on a trial basis should be encouraged to also use the overlaying subsystem on the same basis. They should also use the average stiffness coefficient of 0.96 found for asphaltic concrete in FPS.

Stated more simply the overlaying subsystem should merely become an integral part of the Flexible Pavement Design System and implementation should then continue as it is currently being done with the overall system.

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LIST OF SYMBOLS

W_j = The deflection measured by the jth geophone in mils.

r_j = Distance in inches from the point of application of either Dynaflect load to the jth geophone. $r_1^2 = 100$ $r_2^2 = 244$

SCI = Surface Curvature Index is equal to the difference in W_1 and W_2. Recognition of symmetry shows that SCI is proportional to curvature in the commonly used three point finite difference equation.

D_i = Thickness of the i^{th}. pavement layer. The thickness of the bottom layer (subgrade) is assumed to be infinite. The subscript, i, indicates which layer of pavement with i - 1 being the surfacing.

a_i = Dynaflect Stiffness Coefficient

A = Fitting constant assumed to be a function of the overlay material properties and the thickness of the overlay.

C = .891

C_1 = 4.5

C_2 = 6.25

Throughout the report a subscript, B, indicates that the symbol applies to data representing the before overlaying condition. The subscript, A, represents after overlaying data. The subscript, O, indicates overlay.

$s.e._p$ = Standard error in fitting an equation to individual project data (root-mean-squared error)

$s.e._t$ = Standard error in fitting an equation to all data combined

s = Standard deviation in SCI for a design section

S.E. = Overall standard error in designing an overlay for a design section.

CHAPTER 1
A SUMMARY OF TEXAS RESEARCH PROJECT 101, "UTILIZING DEFLECTION MEASUREMENTS TO UPGRADE PAVEMENT STRUCTURES"

The advancement of the state of the art in measuring and utilizing deflection measurements in pavement design prompted B. F. McCullough* to propose the subject research project to the Texas Highway Department Research and Development Committee in early 1966. Notable among the developments which led to this project were the publication of the California State Highway Department's overlay design procedure utilizing deflections (Ref. 1). Dehlen's work in considering deflections and curvature measurements in South Africa (Ref. 2), and Scrivner's attempt to translate the AASHO Road Test results to Texas conditions (Ref. 3).

Of equal importance to the Texas Research and Development Committee and others sponsoring the project was a recognition of the growing need to upgrade many existing pavement structures. This was discussed informally by the author at the 1966 meeting of the Texas Section of the American Society of Civil Engineers (Ref. 4).

The research project objectives from the proposal (Ref. 5) are quoted below:

1. To further develop and modify a design procedure that utilizes deflection measurements to determine the improvements required to up-grade an existing pavement structure to handle future traffic.

2. To establish the effect of various overlay combinations in reducing deflection to a satisfactory level.

3. To supply data and information accumulated to Texas Research Project 123, "A System Analysis of Pavement Design and Research Implementation", so that the principal investigators can utilize it in designing long term performance studies.

Implied in the original work plan, though not stated explicitly, was the need to obtain a pavement performance equation from other research. That is, there were no plans made to measure performance in this research study -- only plans to utilize deflections to characterize the pavement structures and/or materials before and after overlaying.

The research method consisted essentially of the following four steps:

(a) Measure deflections on pavements both before and after overlaying (see Appendix A for a detailed description of data collection).

(b) Select various models to predict the change due to the overlays.

(c) Select the most efficient models for predicting the after conditions (see Appendix B for data analysis).

(d) Combine the selected model with other elements to form a design system (Chapters 2, 3, and 4 describe and discuss this design system. Appendices C, D, and E, further describe it).

Figure 1-1 shows the location of the eleven asphaltic concrete overlay construction projects for which deflections were measured before and after overlay construction. Figures 1-2 thru 1-6 summarizes the pavement data on each of the eleven projects.

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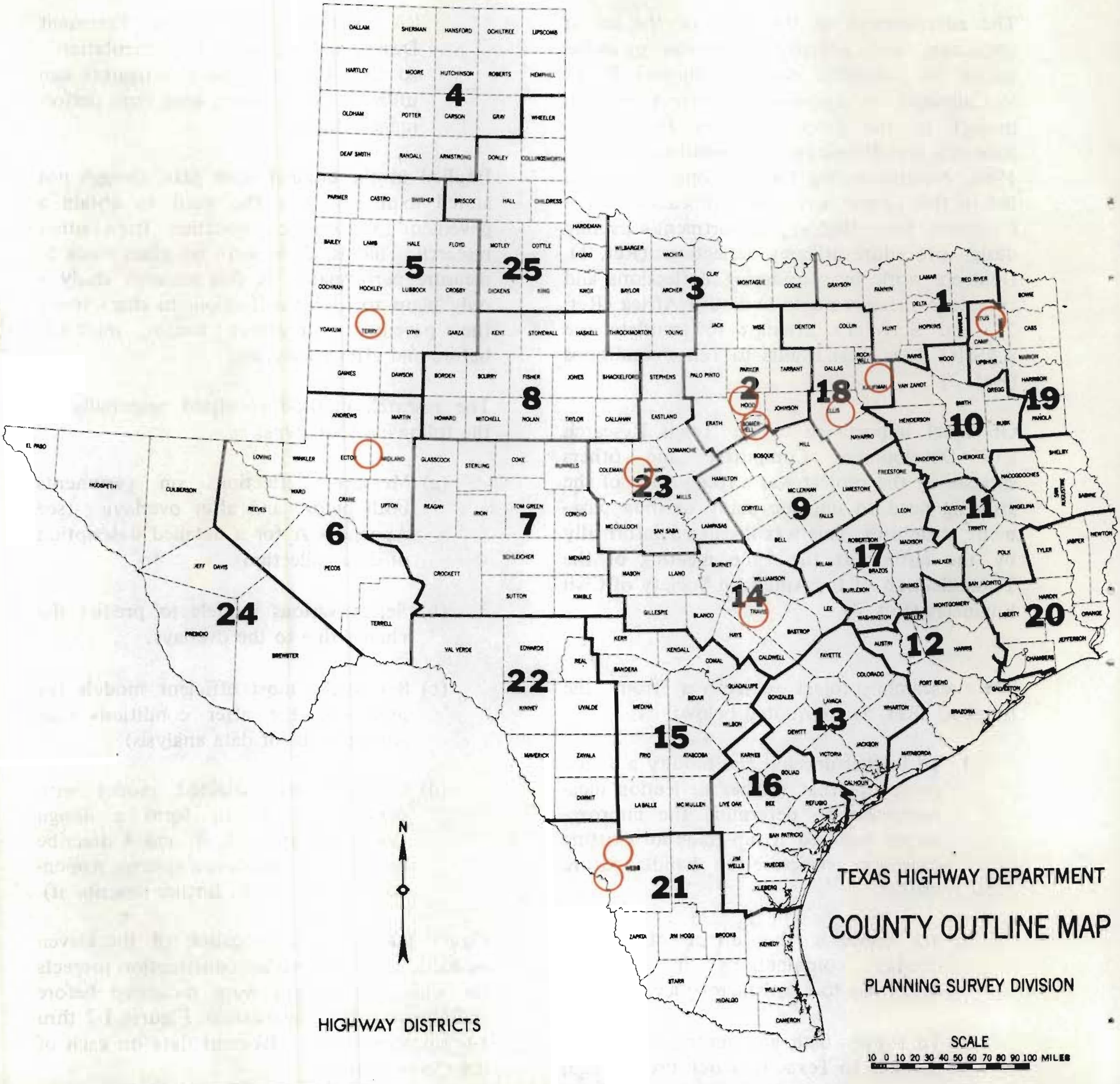
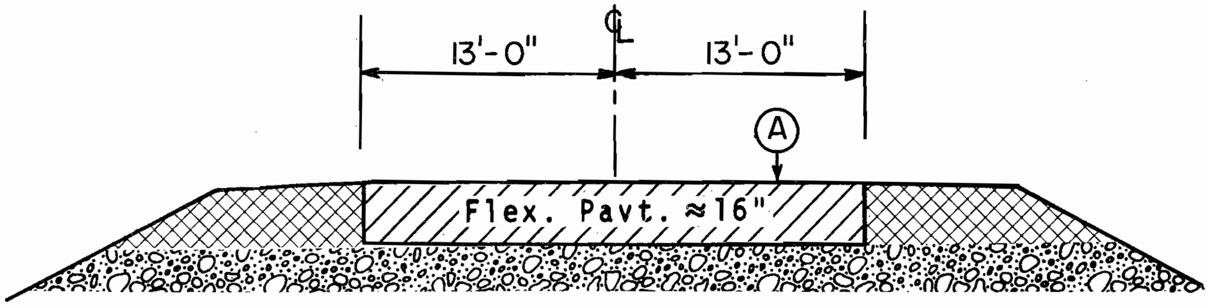


Figure I-1 LOCATION OF OVERLAY PROJECTS

DISTRICT 2. US 67 EBL

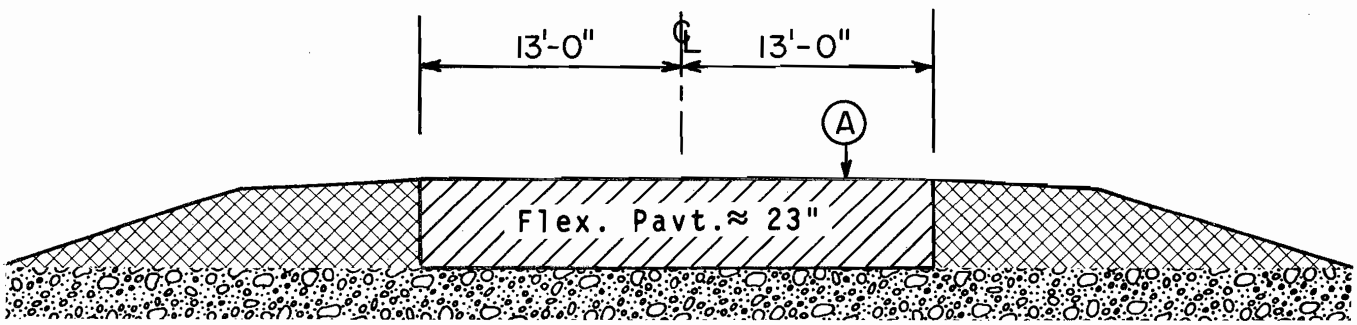


27 Before (07/02/67) and After (08/07/68) deflection measurements taken approximately each 0.1 mi. on the EBL only.

Overlay = 165#/sy Ty "D" Item 340-071

Note : (A) = point of measurement.

DISTRICT 2. US 377 NBL

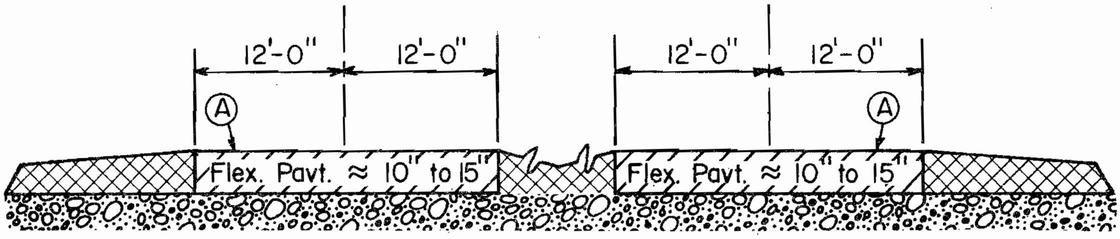


21 Before (07/02/67) and After (08/07/68) deflection measurements taken approximately each 0.1 mi. on the NBL only.

Overlay = 125#/sy Ty "FFF" Item 350-041

Figure 1-2 SUMMARY OF PAVEMENT DATA-BEFORE AND AFTER SECTIONS

DISTRICT 5 US 62 WBL and EBL

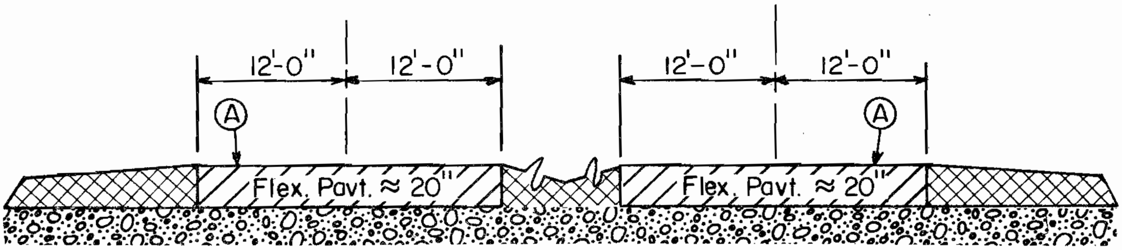


268 Before (06/20/67) and After (08/20/68) deflection measurements taken approximately each 0.1 mi. on both roadbeds.

Overlay = 125#/sy Ty "D" Item 340 and 250#/sy Ty "A" Item 340

Note : (A) = point of measurement.

DISTRICT 6 US 80 WBL and EBL

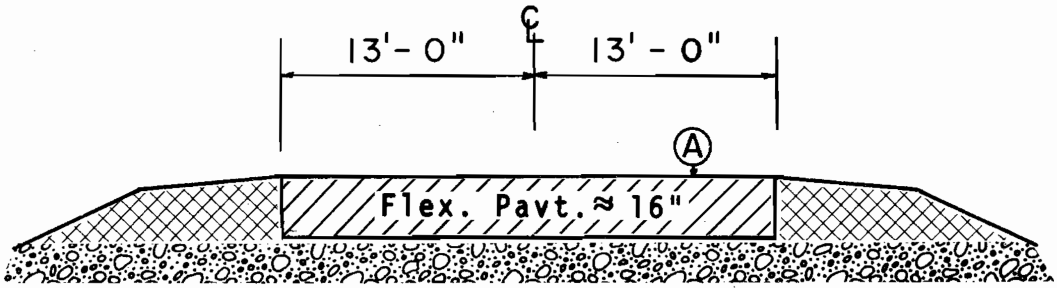


144 Before (05/30/67) and After (08/21/68) deflection measurements taken approximately each 0.1 mi. on both roadbeds.

Overlay = 125#/sy Ty "D" Item 340-073
and 475#/sy Ty "A" Item 340-073

Figure 1-3 SUMMARY OF PAVEMENT DATA - BEFORE AND AFTER SECTIONS

DISTRICT 18 — US 287 NBL

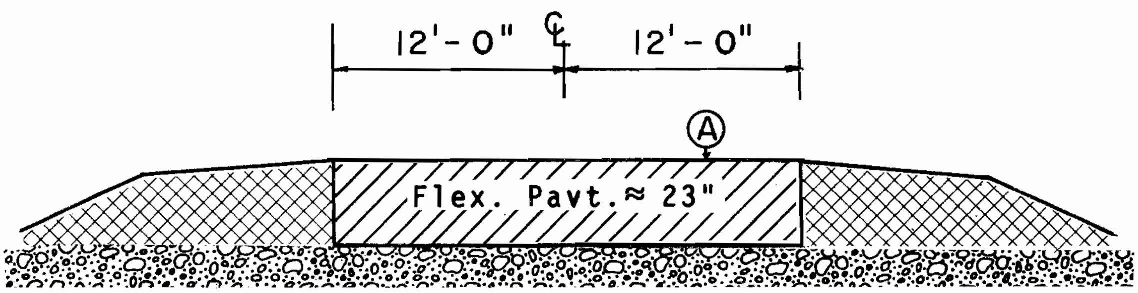


44 Before (07/24/67) and After (08/28/68) deflection measurements taken approximately each 0.1 mi. on NBL only

Overlay = 160#/sy Ty "D" Item 340

Note : (A) = point of measurement.

DISTRICT 18 — US 80 WBL

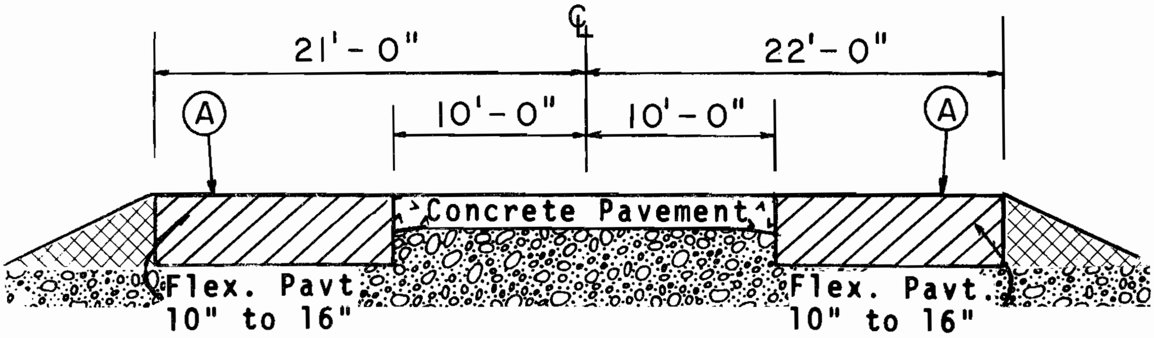


11 Before (07/24/67) and After (08/28/68) deflection measurements taken approximately each 0.1 mi. on WBL only

Overlay = 130# Ty "D" Item 340.072

Figure 1-4 SUMMARY OF PAVEMENT DATA-BEFORE AND AFTER SECTIONS

DISTRICT 19 - US 67 EBL and WBL

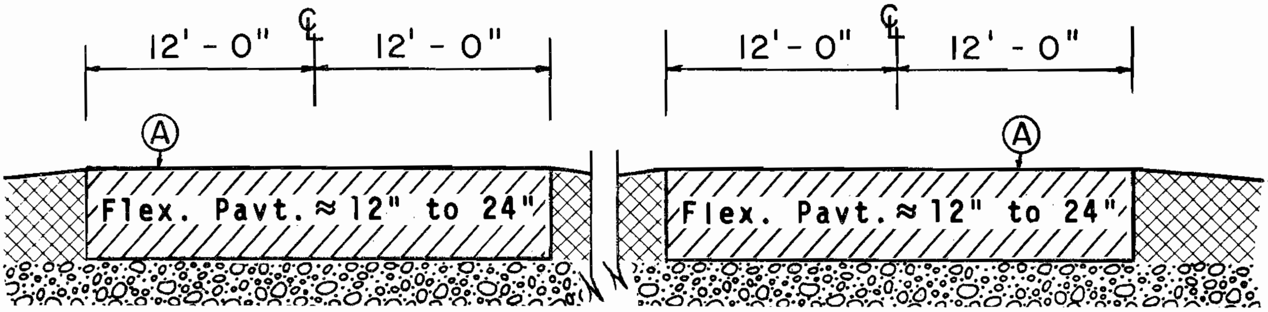


359 Before (08/30/66) and After (07/17/68) deflection measurements taken approximately each 500 feet on both roadbeds.

Overlay = 330#/sy Ty "C" Item 340-035

Note : (A) = point of measurement

DISTRICT 21 - I.H. 35 NBL and SBL



164 Before (08/23/66) and After (07/09/68) deflection measurements taken approximately every 500 feet on the SBL only from Sta. 2005+00 to 1455+00, Sta. 1390+00 to 1445+00 and Sta. 1110+00 to 1075+00

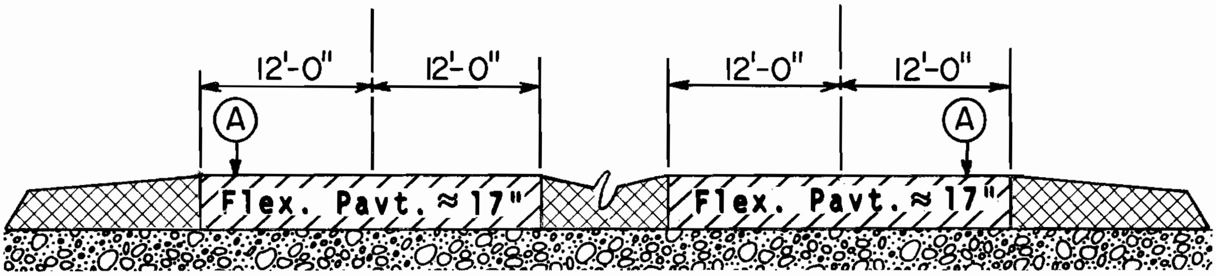
Overlay = 150#/sy Ty "D" Item 340

381 Before (08/23/66) and After (07/09/68) deflection measurements taken approximately every 500 feet on both roadbeds from Sta. 145+00 to Sta. 680+00 and NBL only from Sta. 1075+00 to Sta. 1995+00

Overlay = 100#/sy Ty "D" Item 340 and 500#/sy Ty "A" Item 340

Figure I-5 SUMMARY OF PAVEMENT DATA - BEFORE AND AFTER SECTIONS

DISTRICT 14 IH 35 NBL and SBL

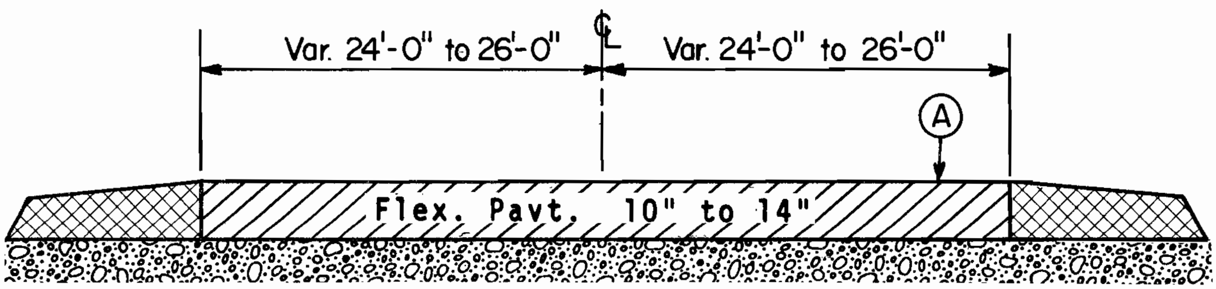


62 Before (12/22/66) and After (08/15/68) deflection measurements taken approximately each 0.1 mi. on both roadbeds

Overlay = 1 1/4" Ty "D" Item 340 and 3" Ty "B" Item 340

Note : (A) = point of measurement.

DISTRICT 23 US 67 & 84 EBL and WBL



64 Before (09/06/66) and After (08/06/68) deflection taken approximately 0.1 mi. on both roadbeds.

Overlay = 125# Ty "D" Item 340 and 375# Ty "B" Item 340

Figure I-6 SUMMARY OF PAVEMENT DATA—BEFORE AND AFTER SECTIONS

CHAPTER 2
THE PAVEMENT OVERLAY DESIGN SUBSYSTEM

The design subsystem for overlays resulting from the Research Project summarized in the preceding chapter is essentially an addition to the Texas Highway Department Flexible Pavement Design System (FPS) currently being implemented on a trial basis by the Department. This chapter briefly summarizes the system and the modifications made to it for overlay design. It is not anticipated that designers will use the Overlay Design Subsystem unless they are also using the entire Flexible Pavement Design System.

The Flexible Pavement Design System (FPS) has been thoroughly described in References 6 through 10. Additionally, a User's Manual has been written for it (Ref. 11). Appendix D of this report is a recommended addition to this User's Manual. Its purpose is to add the overlay procedures to the overall design system.

Briefly, the objective of FPS is to generate the design strategy that will provide an acceptable serviceability level for the road at a minimum net present cost. Serviceability index or performance within a performance period is considered to be a function of a deflection parameter, a temperature statistic, a traffic parameter, and non-traffic-associated deterioration parameters. A performance period is defined as the time period from initial construction to an overlay or from an overlay to the next overlay. An overlay is assumed to restore serviceability index to a high level.

The models listed below are combined with calculations for the cost of various actions in a manner such that the net present cost of each design strategy is calculated.

(a) the traffic equation
(b) the non-traffic deterioration equation
(c) the deflection equation
(d) the overlaying routine
(e) the performance equation

An optimizing routine generates all possible design strategies and their costs and then arrays them in ascending order of cost. A set of the more economical strategies is printed out for the designer to make a final selection.

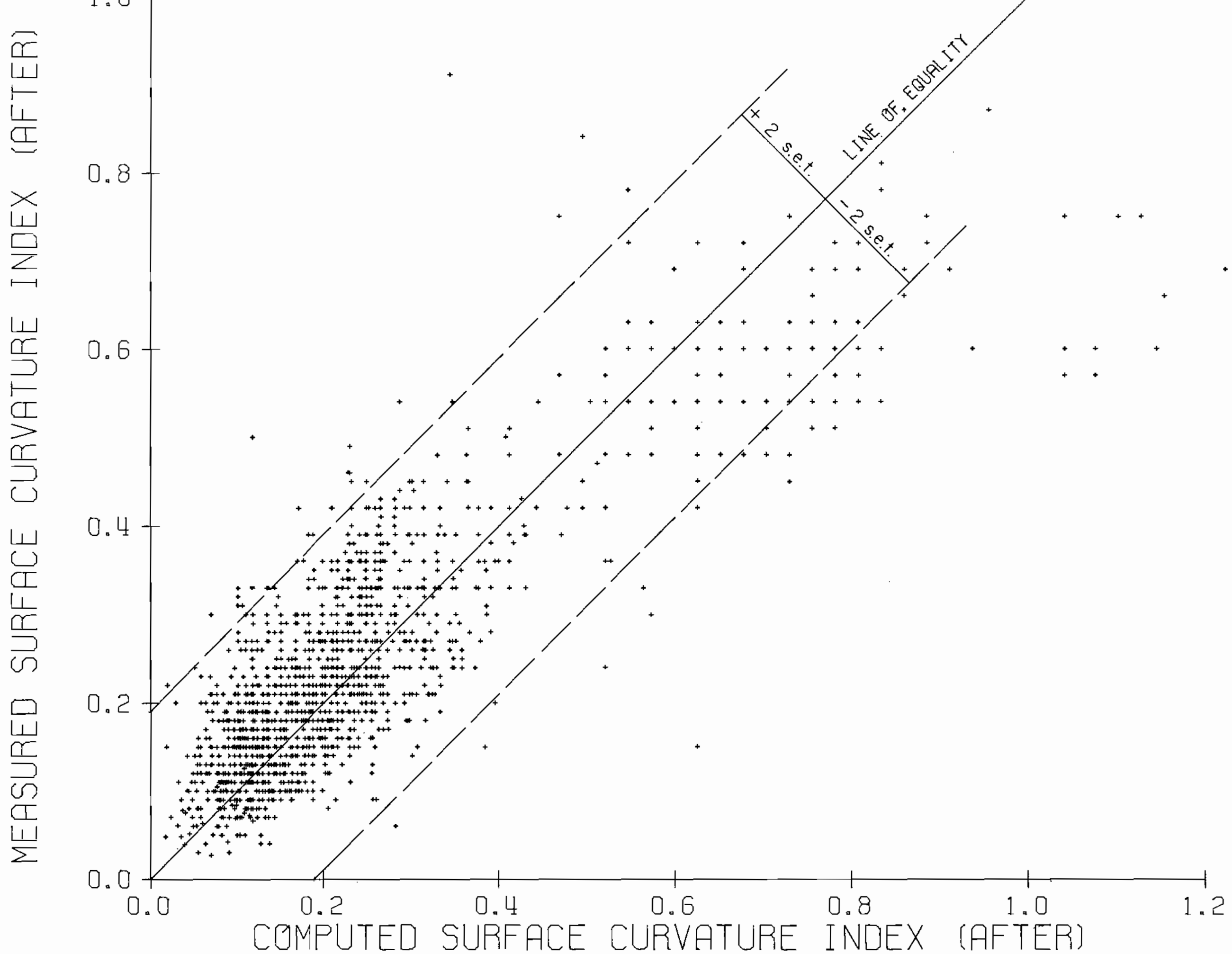
The overall design system is considered to include the personnel, equipment, and organization required to collect the data and reduce it to inputs for design computations, as well as the computing program. In addition, the selection of a design, the construction of it, and the follow-up with maintenance and reconstruction are also considered part of the system. Also, verification of predictions made during design must be done through follow-up research.

The overlay design subsystem described herein makes three relatively small changes in this process. In data collection and reduction, there is no longer a need to use information about proposed pavement layers except the proposed asphaltic concrete. There is a need to collect information about the existing pavement. In computation, it is not necessary to compute the life of the initial construction proposed as is done in FPS. Thirdly, it is now possible to specify a confidence level on alternate design strategies as a result of the follow-up research done in Project 101. The deflection parameter, surface curvature index or SCI, is used to characterize the existing pavement. In addition to an average SCI, the program uses the standard deviation of the SCI for a particular section of roadway. The recommended procedure for measuring the SCI and reducing these measurements to a design input is described in Appendix D.

An average stiffness coefficient of 0.956 was found for the overlay materials studied in Project 101. This coefficient has been built into the overlay design program, OVERLAY-1. Figure 2-1 shows the prediction accuracy when using this average stiffness coefficient. The standard error, $s.e._t$, in SCI was $\pm$ 0.095.

The program combines the two measures of uncertainty, i.e. (a) the standard error due to variation in the overlay material and (b) the standard deviation for the existing pavement, to obtain an overall measure of uncertainty in SCI. Examination of the simulated design results described in Chapter 3 led to the selection of a high confidence level being recommended to accomodate this uncertainty. Appendix C discusses the development of the stochastic concepts more fully.

Figure 2-1 COMPUTED VS MEASURED SURFACE CURVATURE INDICES SCRIVNER'S MODEL



CHAPTER 3
SIMULATED OVERLAY DESIGN

Overlays were designed for seven projects using the Overlay Design Subsystem-both to illustrate the results a designer would receive and to examine them for "reasonableness". The seven projects were selected from the before and after projects listed in Chapter 1. Continuous Dynaflect profiles were available for the before overlay condition. This permitted a comparison of actual construction with that recommended by the overlay subsystem.

Table 3-1 is a list of the inputs that were held fixed for all the simulated designs. Some of these inputs have little or no effect on the optimum overlay strategies. Three important variables were held constant merely to make comparisons easy. In reality, these variables were not constant for the real design projects. They are the swelling clay parameter (b_1), fixed at .01; the minimum time between overlays, set at six years; and the minimum overlay thickness, set at one-half inch.

The seven projects, identified in Table 3-2, varied in swelling clay conditions from the moderately swelling condition in Districts 21 and 23, through an intermediate swelling condition in District 19, to the essentially non-swelling conditions in District 5 and 6. As will be discussed later, the minimum time between overlays and the minimum overlay thickness are judgement inputs that should be carefully considered by the designer for each individual project. The effect of fixing these three variables must be considered when comparing the recommended designs from the computations with the overlays that were actually constructed in 1967.

Figure 3-1 shows the profile of SCI's measured in District 19. The computer program PROFILE ANALYSIS was applied to this data as instructed in Appendix D in order to verify the various design sections. Six significantly different design sections were found. These had average SCI's varying from 0.287 to 0.464 with standard deviations varying from 0.064 to 0.112. Design sections were also isolated for the other six projects listed in Table 3-2. Design computations were not made for every design section. They were made for those values indicated in Table 3-2. These covered the entire range of average SCI's on each project and were enough sections so that interpolation for the other sections could be done easily. All computations were made for 50, 95, and 99% confidence levels as defined in Appendix C.

The cost and traffic data were obtained from project files and Planning Survey Division projections, respectively. Detour inputs used are shown in Table 3-3. Their effect was practically negligible for the rural highways being examined. The following sections discuss the simulated designs for 99% confidence level for the individual projects in more detail.

District 5, U. S. Highway 62 & 82

In Terry County of District 5, U. S. 62 and 82 was overlaid from the Hockley County Line to Brownfield City Limits. Figure 1-3 summarizes the pavement data before and after overlaying. Application of the PROFILE ANALYSIS program resulted in five design sections; the shortest being 0.6 of a mile and the longest 9.7 miles. The total project length was over 14 miles. The design program OVERLAY-1 was first run fixing the initial overlay at 3.4 inches - the thickness actually placed in 1967. Computer runs were also made permitting the initial overlay to be as thin as one inch. These runs were made with the SCI's indicated in Table 3.2.

TABLE 3-1 COMMON INPUTS TO THE DESIGN PROJECTS

THE COMPOSITE THICKNESS OF THE CURRENT PAVEMENT (INCHES)	0.0
THE IN-PLACE PRESENT VALUE OF THE EXISTING PAVEMENT (DOLLARS/CY)	0.0
SALVAGE VALUE OF PRESENT STRUCTURE AT END OF ANALYSIS PERIOD (PERCENT)	0.0
SALVAGE VALUE OF PROPOSED ACP AT END OF ANALYSIS PERIOD (PERCENT)	20.0
NUMBER OF OUTPUT PAGES DESIRED (8 DESIGNS/PAGE)	3
LENGTH OF THE ANALYSIS PERIOD (YEARS)	20.0
WIDTH OF EACH LANE (FEET)	12.0
SERVICEABILITY INDEX P1 AFTER AN OVERLAY	4.2
MINIMUM SERVICEABILITY INDEX P2	3.0
SWELLING CLAY PARAMETERS – P2 PRIME	1.50
B1	0.0100
MINIMUM TIME BETWEEN OVERLAYS (YEARS)	6.0
TIME TO FIRST SEAL COAT AFTER INITIAL OR OVERLAY CONST. (YEARS)	21.0
TIME BETWEEN SEAL COATS (YEARS)	21.0
THE LEVEL-UP REQUIRED FOR THE FIRST OVERLAY (INCHES)	0.5
MINIMUM OVERLAY THICKNESS (INCHES)	0.5
ACCUMULATED MAXIMUM DEPTH OF ALL OVERLAYS (INCHES) (EXCLUDING LEVEL-UP)	9.0
ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)	80.0
ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)	1.80
DETOUR DISTANCE AROUND THE OVERLAY ZONE (MILES)	0.0
OVERLAY CONSTRUCTION TIME (HOURS/DAY)	10.0
NUMBER OF OPEN LANES IN RESTRICTED ZONE IN O.D.	1
NUMBER OF OPEN LANES IN RESTRICTED ZONE IN N.O.D.	1
PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN O.D. (PERCENT)	0.0
PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN N.O.D. (PERCENT)	0.0
AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN O.D. (HOURS)	0.0
AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN N.O.D. (HOURS)	0.0
AVERAGE APPROACH SPEED TO THE OVERLAY ZONE (MPH)	60.0
TRAFFIC MODEL USED IN THE ANALYSIS	4
FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE MILE)	50.00
INCREMENTAL INCREASE IN MAINT. COST PER YEAR (DOLLARS/LANE MILE)	20.00
COST OF A SEAL COAT (DOLLARS/LANE MILE)	0.0
INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)	5.0

TABLE 3-2 VARIABLE INPUTS TO THE DESIGN PROJECTS

Project	Average SCI	Std. Dev., 's'	Cost ACP	Alpha*	Begin ADT	End ADT	18 KSA
Dist 5	0.610	0.086	11.45	16.0	1950	3400	964,000
US 62-82	0.452	0.063					
	0.436	0.086					
Dist 6	0.647	0.109	10.85	23.0	5450	9350	1,806,000
US 80	0.540	0.115					
	0.485	0.089					
	0.471	0.052					
Dist 19	0.462	0.112	14.29	25.0	2825	2250	1,012,000
US 67	0.378	0.083					
	0.287	0.064					
Dist 21	1.216	.205	9.79	38.0	905	2950	837,000
IH 35 SBL	1.182	.138					
Encinal	.881	.058					
to US 83	.791	.223					
	.566	.132					
	.451	.101					
Dist 21	1.277	.199					
IH 35 NBL	1.111	.172					
US 83 to	.971	.113					
Encinal	.650	.099					
	.403	.156					
Dist 21	.982	.211			1480	4500	1,182,000
IH 35 NBL	.901	.172					
and SBL	.672	.058					
Laredo	.452	.141					
to US 83							
Dist 23	.420	.179	13.82	25.0	2050	3300	867,000
US 67-84	.322	.126					
	.195	.126					
	.195	.096					
	.130	.031					

*A temperature statistic related to performance. See Ref. 8 for a complete explanation.

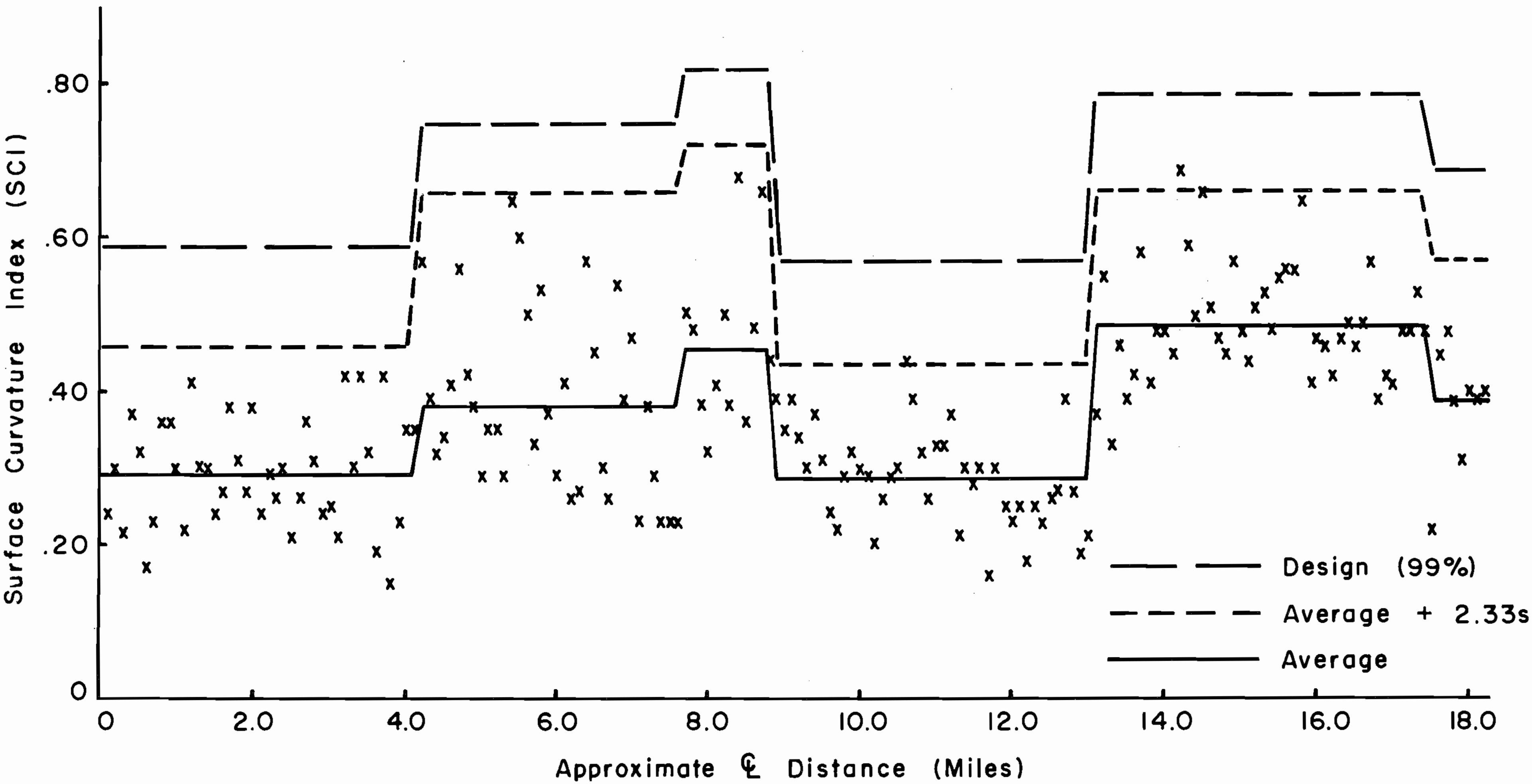


Figure 3-1 SCI PROFILE AND DESIGN SECTIONS
U.S. 67, DISTRICT 19

TABLE 3-3 MORE VARIABLE INPUTS TO THE DESIGN PROJECTS

Project	Percent ADT/HR	Rural or Urban	Funds Avail./ Sy.	Distance Slowed (miles) O.D.	Distance Slowed (miles) N.O.D.	Speed Thru Zone O.D.	Speed Thru Zone N.O.D.
Dist 5, US 62-82	6.5	R	*	2.0	2.0	30.0	30.0
Dist 6, US 80	6.5	U	*	2.0	2.0	30.0	30.0
Dist 19 US 67	6.0	R	*	1.0	1.0	30.0	30.0
Dist. 21 IH 35 SBL Encinal to US 83	6.5	R	.45	5.0	5.0	40.0	40.0
IH 35 NBL US 83 to Encinal	—	—	*	—	—	—	—
IH 35 NBL and SBL Laredo to US 83	6.0	—	—	—	—	—	—
Dist 23, US 67-84	6.5	R	*	3.5	3.5	30.0	30.0

*FUNDS AVAILABLE FOR THESE PROJECTS WERE NON RESTRICTED

Optimal solutions were now available for each design section. However, they were sub-optimal for the project as a whole. The author believes that the following criteria should be applied when selecting the overall project strategy from the available section strategies:

> While thickness of overlay may vary along a project length, some minimum thickness must be placed throughout the entire project. Additionally, for any future overlays a minimum thickness must be placed throughout the entire length.

In other words, if the optimum solution for one section calls for an overlay after six years and in another section after eight years, the overlay must be placed at six years; not some at six and some at eight.

Figure 3.2 shows the overall project design strategy using a 3.4 inch overlay initially and the strategy using a variable initial overlay both for a 99% confidence level. The band width on the present serviceability index curve results from the variable SCI design sections. Costs were weighted according to the length of the various design sections and are also shown on Figure 3.2. An approximate 30% saving in net present cost is indicated if the "Design" strategy had been selected instead of the 3.4 inch overlay throughout. Most of this savings comes from placing a thinner initial overlay over much of the project. Note that three inches of overlay was required to satisfy the arbitrarily selected six year minimum time between overlays and that the 3.4 inch overlay resulted in a minimum time between overlays exceeding eight years.

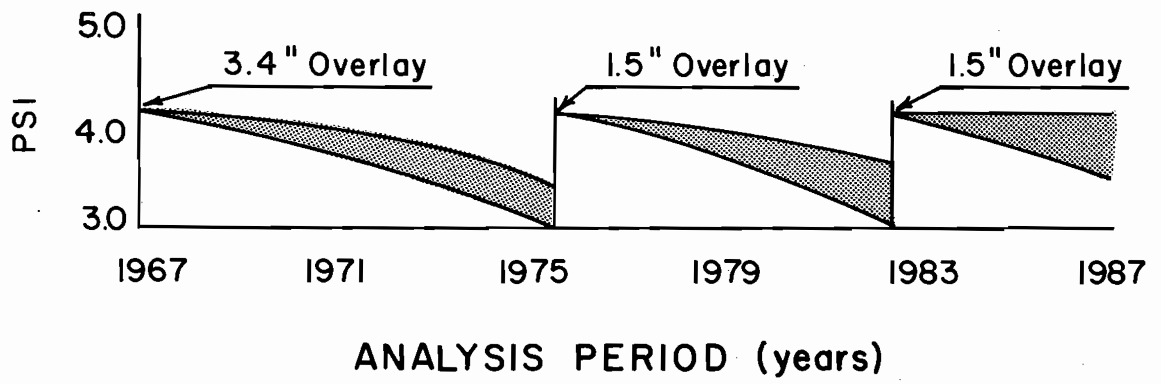
District 6, U. S. Highway 80

Between Midland and Odessa in District 6, U. S. Highway 80 was overlaid with approximately 5.5 inches of Types A and D. The deflection measurement and pavement data is summarized in Figure 1-3. Application of the PROFILE ANALYSIS program resulted in five design sections varying from 0.6 of a mile to 3.4 miles in length. The design sections totaled over 9 miles. As was true with all of the simulated project designs, OVERLAY-1 was run with the initial overlay fixed at the actual construction thickness and then the program was rerun permitting the initial overlay to be as thin as one inch. Again the runs were made with the SCI's indicated in Table 3.2. Figure 3-3 shows three overall project design strategies; the first, using the actually constructed thickness of 5.5 inches as initial overlay, and two more nearly optimal design strategies using lesser amounts of initial overlay. The more economical three-overlay strategy indicated a 13% savings in net present cost and the other design strategy a 6% savings over that actually constructed. The most economical strategy had a six year minimum time between overlays. For the actual construction 12 years between overlays was indicated. The savings for the most economical design resulted primarily from discounting future construction costs since the material required during the twenty years was about the same. The savings for the intermediate strategy resulted from saving one inch of asphaltic concrete for some sections of the road.

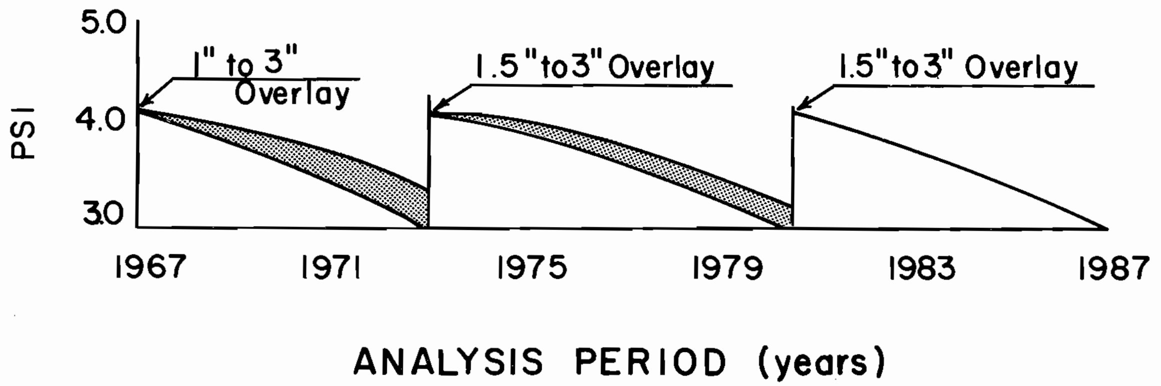
District 19, U. S. Highway 67

In District 19, U. S. Highway 67 was overlaid with 3 inches of asphaltic concrete between Mount Pleasant and Naples. Figure 1-5 summarizes the existing pavement, overlay, and measurement data. Using PROFILE ANALYSIS on the data, six design sections were isolated. They ranged in length from 0.6 of a mile to 4 miles. The measurements represented a total length of over 18 miles. Figure 3-4 shows three overall project design strategies. The indicated most ecomical strategy resulted

ACTUAL CONSTRUCTION



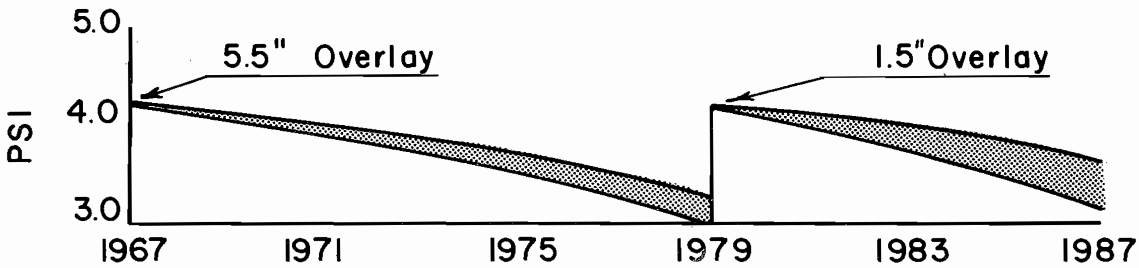
DESIGN



	ACTUAL	RECOMMENDED
INITIAL CONSTRUCTION COST	1.08	0.40
INITIAL USER COST	.09	0.04
FUTURE CONSTRUCTION COST	.54	0.66
FUTURE USER COST	.06	0.08
ROUTINE MAINTENANCE COST	.20	0.20
SALVAGE VALUE	-.09	-.05
NET PRESENT COST	1.89	1.33

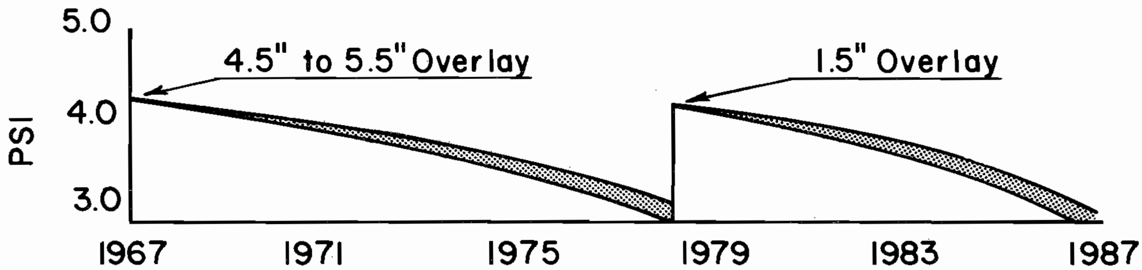
Figure 3–2 U.S. 62–82 DISTRICT 5 DESIGN STRATEGIES

ACTUAL CONSTRUCTION



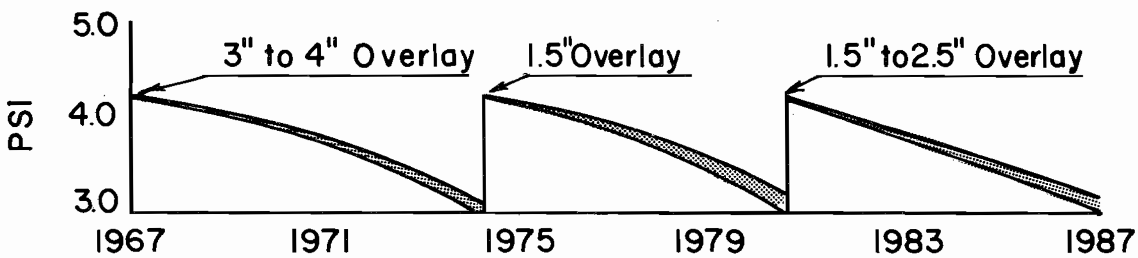
ANALYSIS PERIOD (years)

DESIGN



ANALYSIS PERIOD (years)

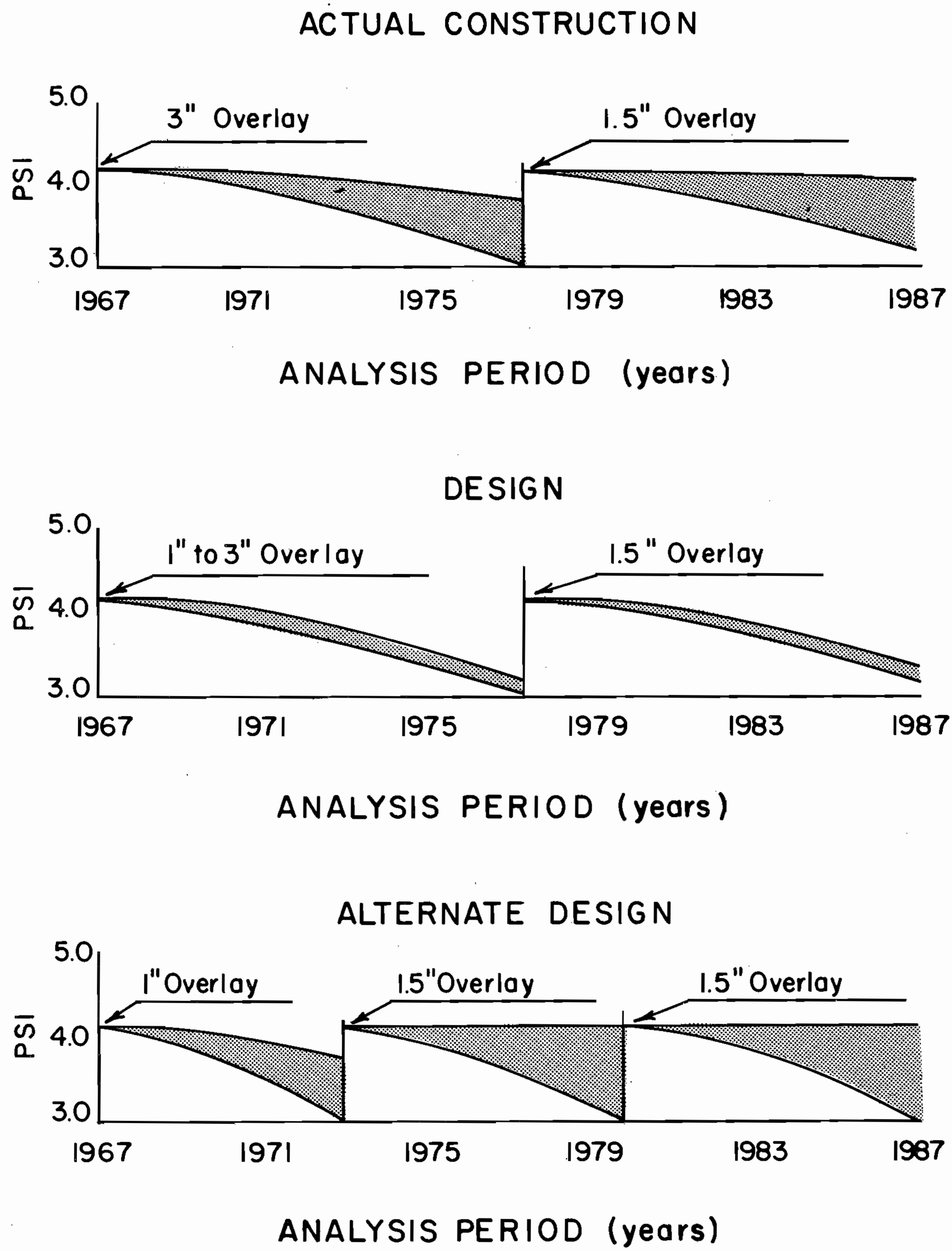
ALTERNATE DESIGN



ANALYSIS PERIOD (years)

	ACTUAL	DESIGN	ALTERNATE
INITIAL CONSTRUCTION COST	1.66	1.46	1.00
INITIAL USER COST	.32	.28	.19
FUTURE CONSTRUCTION COST	.25	.26	.66
FUTURE USER COST	.07	.14	.18
ROUTINE MAINTENANCE COST	.26	.25	.19
SALVAGE VALUE	-.12	-.11	-.10
NET PRESENT COST	2.43	2.28	2.12

Figure 3-3 U.S. 80 DISTRICT 6 DESIGN STRATEGIES



	ACTUAL	DESIGN	ALTERNATE
INITIAL CONSTRUCTION COST	1.19	.96	.40
INITIAL USER COST	.08	.06	.03
FUTURE CONSTRUCTION COST	.37	.36	.76
ROUTINE MAINTENANCE COST	.25	.25	.19
SALVAGE VALUE	-.09	-.06	-.04
FUTURE USER COST	.02	.01	.05
NET PRESENT COST	1.81	1.58	1.37

Figure 3-4 U.S 67 DISTRICT 19 DESIGN STRATEGIES

from 3 minimum thickness overlays. A 24% savings in net present cost would result from using this instead of that actually constructed. An alternate two-overlay scheme would result in a 13% indicated savings. The savings in the two-overlay scheme are a result of reducing the thickness in portions of the job from the 3 inches in the first overlay. The savings from the three-overlay scheme are the result of discounting future construction costs. The three-overlay design strategy had a minimum time between overlays of six years while both of the two-overlay schemes had a minimum time between overlays exceeding ten years.

It should be noted that on this project, the discussion and design strategies are based on the assumption that the flexible pavement on the outer lanes controlled the design. In reality this was not true; a minimum thickness asphaltic concrete was required for the old concrete pavement in the center portion of the road.

District 21, Interstate Highway 35

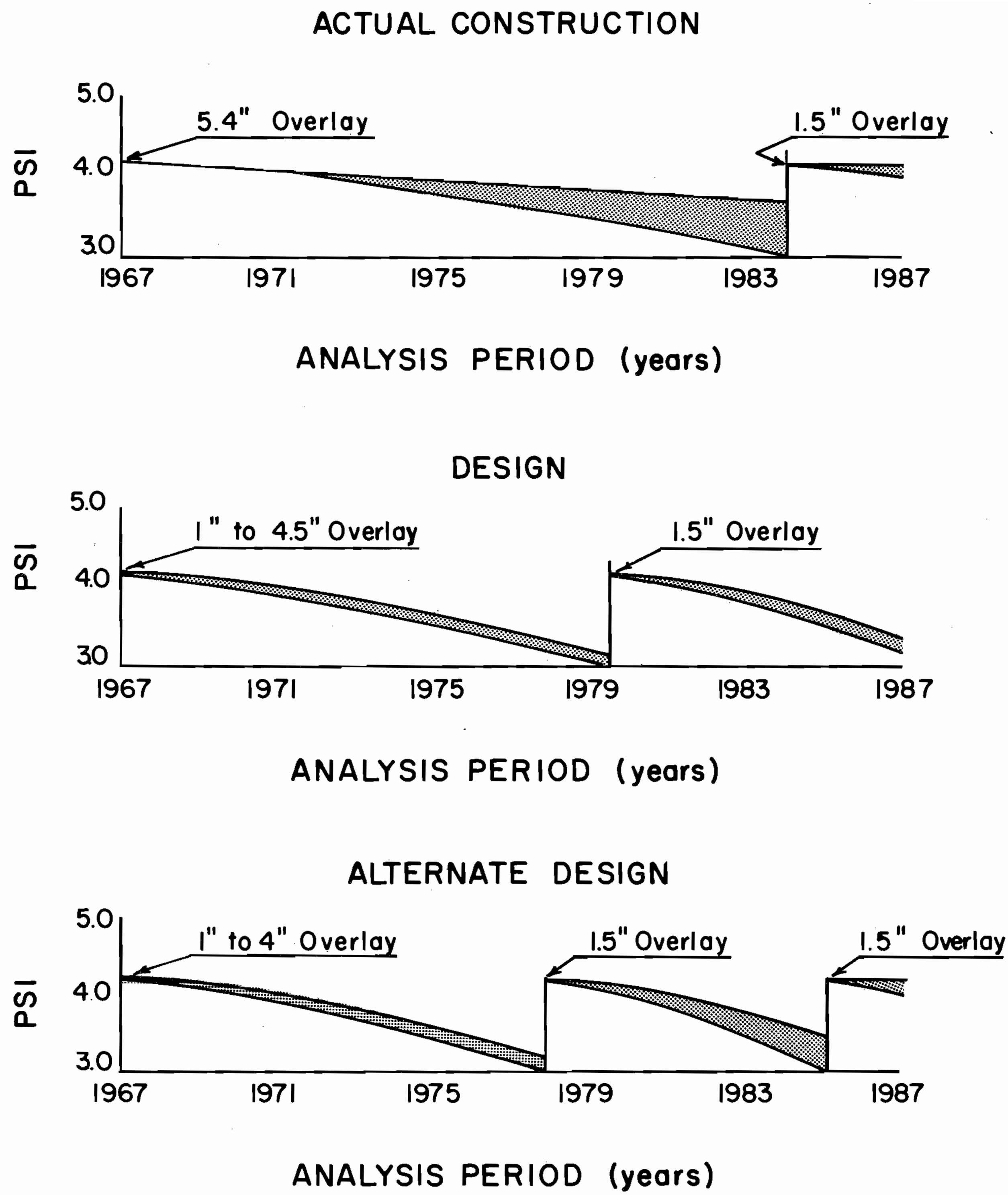
From Encinal south to the junction of U. S. Highway 83, Interstate Highway 35 was overlaid with 1.5 inches ACP in the south-bound-lane and approximately 5.5 inches in the north-bound-lane. From the junction of U. S. Highway 83 south to near Laredo, both lanes were overlaid with 5.5 inches of asphaltic concrete. Further discussion of these simulated designs will be limited to that portion from U. S. Highway 83 south; except to point out that the 1.5 inch overlay was not predicted to last the specified minimum 6 years with a 99% confidence. The section from Laredo to U. S. 83 illustrates all the other salient points for this discussion. Five design sections varying in length from 0.8 of a mile to 4.6 miles for the total project length of slightly over 10 miles were isolated with PROFILE ANALYSIS.

Figure 1-5 summarizes the pavement and measurement data for these sections. Figure 3-5 shows three overall project design strategies including the one actually constructed. Both of the other design strategies would have resulted in approximately 25% savings in net present cost. Most of the savings come from placing a lesser initial overlay for some sections of the road. The minimum time between overlays for the three-overlay strategy was about 7 years and exceeded 12 years for the two-overlay design strategy. The program indicated nearly 18 years should elapse before another overlay would be required.

District 23, U. S. Highway 67-84

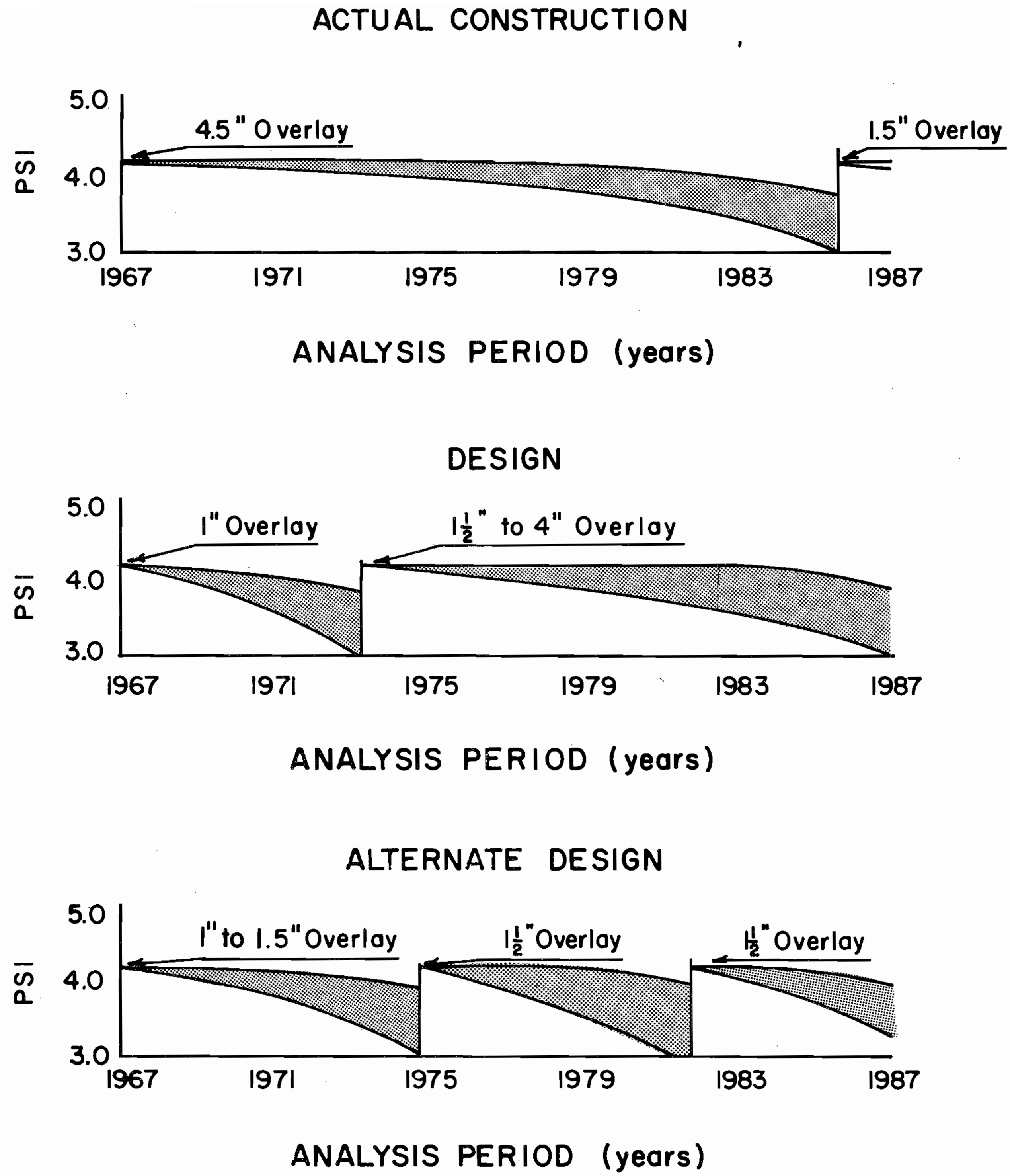
Roughly three miles of a 4.5 inch ACP Overlay on U. S. Highway 67-84 in District 23 was examined. For this project only, the SCI profile for each side of the roadway was treated as a separate profile. On other projects, the SCI's for opposite side of the roadway were averaged.

The rough terrain and obvious difference in SCI's for some sections dictated that opposite sides of the roadway be designed separately. Seven design sections ranging from 0.4 of a mile to 2.1 miles in length were isolated using PROFILE ANALYSIS. Figure 3-6 shows three overall design strategies--the first using the actual construction thickness of 4.5 inches as an initial overlay with the other two design strategies using lesser amounts of initial overlay. An approximate 40% savings was indicated from either of the strategies using thinner overlays initially. Eighteen years between overlays was predicted for the actual construction strategy as opposed to about six years between overlays for the other two strategies.



	ACTUAL	DESIGN	ALTERNATE
INITIAL CONSTRUCTION COST	1.47	.98	0.85
INITIAL USER COST	.06	.03	.03
FUTURE CONSTRUCTION COST	.18	.23	.41
FUTURE USER COST	.02	.02	.04
ROUTINE MAINTENANCE COST	.33	.26	.23
SALVAGE VALUE	-.11	-.06	-.08
NET PRESENT COST	1.94	1.46	1.48

Figure 3-5 I.H. 35 DISTRICT 21 DESIGN STRATEGIES
(Laredo to U.S. 83)



	ACTUAL	DESIGN	ALTERNATE
INITIAL CONSTRUCTION COST	1.73	.38	.46
INITIAL USER COST	.18	.04	.05
FUTURE CONSTRUCTION COST	.23	.69	.67
FUTURE USER COST	.04	.09	.09
ROUTINE MAINTENANCE COST	.37	.25	.20
SALVAGE VALUE	-.13	-.07	-.06
NET PRESENT COST	2.40	1.38	1.41

Figure 3-6 U.S. 67-84 DISTRICT 23 DESIGN STRATEGIES

Summary

In summary, two major differences between the actual construction selected by Highway Department overlay designers and that suggested by the design system are apparent. First, the designers selected a constant thickness from end to end for all of the overlay projects studied. The design procedure suggests that the road can be broken into sections using variable overlay thicknesses at a considerable savings in cost. Secondly, the designers placed thicker initial overlays than the design procedure selects for optimum cost even when using a 99% confidence level. Another way to think of this difference is to say that the designers desired longer than six years life for the initial overlay.

Although none of the results are shown, the same series of simulated designs where run at 50% and 95% confidence levels. In general these merely required thinner and fewer overlays. There was an even larger disparity between what the designers actually placed as initial overlays and that which was recommended by the program.

The remaining discussion in this chapter is placed here because it is felt that it might be helpful to others trying to use the program. If the following conditions exist, the optimum design strategy computed from OVERLAY-1 will be a series of minimum thickness overlays:

1. Average daily traffic must not approach capacity any time during the design period. If it does approach capacity, the program will avoid overlaying during that time by placing thicker overlays earlier. In a rare case where traffic might be declining from a capacity situation, it would try to postpone overlaying until that time when traffic had declined.

2. Higher interest rates favor postponing overlay construction to later times by the placement of a series of thin overlays.

3. The higher the swelling clay parameter, b_1 the more the program prefers to delay overlay placement.

Several opposite influences tend to make the program place a thicker overlay initially followed with a series of thinner overlays. They are as follows:

1. The fact that material placed initially is used throughout the analysis period with no reduction in strength causes the program to generally place the thickest overlay first.

2. The safety factor introduced through the confidence level as explained in Appendix C has a component that is placed with each overlay. That is, three overlays require some amount of asphaltic concrete to be used for safety that is basically three times as large as that required by a one-overlay scheme. This tends to cause the program to place fewer, thicker overlays.

3. The program will tend to place more of the needed material when ADT is light. In rural traffic situations this generally is negligible; however, the effect can be quite large as capacity is approached.

4. Finally, the two arbitrary restraints, minimum thickness for each overlay and minimum time between overlays; can cause fewer and thicker overlays to be used.

CHAPTER 4
STRENGTHS AND WEAKNESSES OF THE OVERLAY DESIGN SUBSYSTEM

This chapter basically represents the senior author's opinions as to the strengths and weaknesses of the overlay subsystem. It is not intended to be an exhaustive discussion. The enumerated strengths and weaknesses are the more obvious ones that have occurred to him while using the subsystem.

The ability of the Dynaflect to detect variations in pavement structures, both along a roadway of the same pavement design and when comparing roadways of different design, is one of the most important strengths of this design procedure. A corollary to this characterization of in-place pavements is the fact that enough measurements can be made economically, to not only characterize the average in-place materials, but also to measure the dispersion about this average.

The fact that the design procedure attempts to treat uncertainty, albeit in a crude manner, is one of the strengths of the method. It seems most certain to the author that the wide variations in pavement response measured along roadways of "uniform subgrade and the same design" are being treated intuitively by designers that select pavements based upon their experience. In fact, they are frequently using a very high confidence level in their design selections. Therefore, it is imperative that researchers attempt to quantify variability and treat it in the design procedures that are to supplement this experience.

Another strength in the approach lies in the ease in which followup research and verification of designs can be made. It is relatively simple to test the predicted deflections versus the actual deflections. (It might also appear easy to follow the performance of the roads after overlaying. However, Scrivner (Ref. 8) has shown that with the accuracy of readily available serviceability index measuring equipment, trends are rather difficult to measure over short time periods.) Other strengths have been discussed elsewhere when describing the overall design system. (Ref. 9).

The most glaring weaknesses in the overlay subsystem must be in the performance equation and the assumption that succeeding level-ups will permit continuous re-use of the pavement with no deterioration in its strength. The performance equation itself was derived from AASHO Road Test data and has all the limitations often expressed when trying to extrapolate from this one experiment. Additionally, an equation that relates performance to a displacement parameter, rather than to the ratio of stress to ultimate stress or strain to ultimate strain, must be considered incomplete. This is not to say that a better performance equation is available or will be available anytime in the forseeable future. It merely points out that theory, experiment, and measurement in this important area have lagged behind other aspects of pavement design.

Another important weakness is the fact that the subsystem does not consider uncertainty in most inputs and models. Additionally, the confidence level that is computed on each performance period is not really the confidence level of interest to the designer. He is more interested in the confidence that a particular total design strategy will last the entire analysis period, rather than the confidence that each overlay will last its performance period.

Additional weaknesses include dependence on engineering judgment to determine minimum overlay thickness, minimum time between overlays, and to answer the question "Is an ACP overlay a proper action?" However, dependence upon good engineering judgment for some design considerations is not unique. All useable design procedures require it.

REFERENCES

1. Zube, Ernest, and Raymond Forsyth, "Flexible Pavement Requirements as Determined by Deflection Measurements", Research Report No. M & R 231288-2, Materials and Research Section, California Division of Highways, January 1966.

2. Dehlen, G. L., "Flexure of a Road Surfacing, its Relations to Fatigue Cracking, and Factors Determining its Severity", Highway Research Bulletin No. 321, Highway Research Board, 1962.

3. Scrivner, F. H., "Application of the AASHO Road Test Results to Texas Conditions", Research Study Proposal to the Texas Highway Department, June 1965.

4. Brown, James L., "Design of Pavement Overlays Based on Deflection Measurements", Informal Discussion Presented at the Fall Meeting of The Texas Section of the ASCE, September 1966.

5. Brown, James L., "Utilizing Deflection Measurements to Up-Grade Pavement Structures", Research Study Proposal to the Texas Highway Department, April 1969.

6. Scrivner, F. H., W. M. Moore, W. F. McFarland, and G. R. Carey, "A Systems Approach to the Flexible Pavement Design Problem", Research Report 32-11, Texas Transportation Institute, 1968.

7. Scrivner, F. H., and W. M. Moore, "An Empirical Equation for Predicting Pavement Deflection", Research Report 32-12, Texas Transportation Institute, 1968.

8. Scrivner, F. H., and Chester H. Michalak, "Flexible Pavement Performance Related to Deflections, Axle Applications, Temperature and Foundation Movements", Research Report 32-13, Texas Transportation Institute, 1969.

9. Hudson, W. R., B. F. McCullough, F. H. Scrivner, and James L. Brown, "A Systems Approach Applied to Pavement Design and Research", Research Report 123-1, Texas Highway Department, Texas Transportation Institute, Center for Highway Research, The University of Texas at Austin, Austin, 1970.

10. Brown, James L., Larry J. Buttler, and Hugo E. Orellana, "A Recommended Texas Highway Department Pavement Design System User's Manual", Research Report 123-2, Texas Highway Department, March 1970.

11. "Texas Highway Department Pavement Design System, Part I, Flexible Pavement Designer's Manual", Texas Highway Department, 1970.

12. Scrivner, F. H., and W. M. Moore, "An Electro-Mechanical System for Measuring the Dynamic Deflection of a Road Surface by an Oscillating Load", Research Report 32-4, Texas Transportation Institute, December, 1964.

REFERENCES (Continued)

13. Scrivner, F. H., and W. M. Moore, "Some Recent Findings in Flexible Pavement Research", Research Report 32-9, Texas Transportation Institute, July 1967.

14. "Operators Manual for the Dynaflect Dynamic Deflection Determination System", LANE-WELLS Company, a Division of Dresser Industries, Inc., Houston, Texas, 1965.

15. Cogill, W. H., "Analytical Methods Applied to the Measurements of Deflections and Wave Velocities on Highway Pavements: Part 1, Measurements of Deflections", Research Report 32-14, Texas Transportation Institute, March 1969.

16. Hodgman, Charles D., "Mathematical Tables from Handbook of Chemistry and Physics", Chemical Rubber Publishing Co., Cleveland, Ohio, September, 1951.

APPENDIX A

DATA COLLECTION

APPENDIX A. DATA COLLECTION

The Dynaflect (Ref. 12, 13, 14) was used to take before and after deflection measurements on 11 sections located in eight Districts throughout the State.

The "before" deflection data for this study was collected during the summers of 1966 and 1967. The data was recorded on a specially designed data sheet labeled "FLEXIBLE PAVEMENT - DEFLECTION STUDY DATA SHEET DYNAFLECT" (See Figure A-1).

This data sheet made provision for recording project identification information and deflection measurements. The project identification section of the code sheet included: control, section, county, district number, date, highway number, and any remarks concerning the section under consideration. It also made provision for writing the initials of the person recording the information.

For each deflection measurement, the following information was recorded: station or mileage where the measurements were taken, distance right or left from ℄, the Dynaflect readings for sensors 1 thru 5 (geophones) with their respective multipliers, temperature of the pavement, time and remarks. After a few runs, recording of the pavement temperature was discarded. The accuracy of the available thermometers was suspect plus the time required for them to reach equilibrium would have greatly slowed the data collection.

On nine of the eleven sections deflection measurements were taken every 0.100 mile. The procedure employed was as follows:

A road Inventory Map was obtained from Planning Survey Division (D-10). This map, among other things, shows the following:

a) Center Line Bearing
b) Mile post mileage at the beginning and ending of major structures, at the ℄ intersection of minor structures, and at the ℄ of highway intersections
c) Control and section numbers

With the aid of these maps, a fixed reference point was chosen as the starting point (or Zero Mile), for a given section. After calibration of the Dynaflect (Ref. 14), the load wheels were set at the starting point and a reading was taken. Readings were then taken every 0.100 of a mile.

The 0.100 mile was measured with an A. E. Sheehan Survey Meter, Model 100-P, installed in the towing vehicle; a 1966 Ford Sedan especially equipped with heavy duty shock absorbers and a specially mounted trailer hitch. From the zero mile or starting point, the distances indicated by the Survey Meter were checked against the mile post distances shown on the Road Inventory Map.

Checks were made at the beginning of culverts, bridges, or at intersections. If discrepancies were found between the distances measured by the Survey Meter and the mile post readings, the Survey Meter was reset to match the mile post readings.

In two sections, one located on IH 35 (District 21) and the other on US 67 (District 19), stakes were set every 500 feet along the right of way line by District personnel. The load wheels of the Dynaflect trailer were set approximately in line with the stakes and measurements were taken at these points. It is the writer's opinion that having a survey crew set stakes to locate points for the before and

FLEXIBLE PAVEMENT — DEFLECTION STUDY DATA SHEET DYNAFLECT

1 2 3 4	5 6	7 8	9 10 11	12 13	14 15 16 17 18 19
Control	Sec.	Job	County	Dist.	Date

20 21 22	23 24 25 26 27 28 29 30 31 32 33 34 35 36 37	38 39 40	41 42 43 44 45 46	47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
Card	Project Number (s)	Party Chief	Hwy No.	Project Remarks

Type	Station	℄	L/R	DYNAFLECT READING										Temp Pvt	Grade	Sect.	Super	Time	Remarks
				Sc	1	Sc	2	Sc	3	Sc	4	Sc	5						
20 21 22	23 24 25 26 27 28 29	30 31	32	33 34	35 36 37	38 39	40 41 42	43 44	45 46 47	48 49	50 51 52	53 54	55 56 57	58 59 60	61	62 63 64	65	66 67 68 69 70	71 72 73 74 75 76 77 78 79 80

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after measurements results in better accuracy with less overall effort.

The after deflection data was taken approximately one year after the road had been overlayed. The procedure employed in taking these measurements was the same as that for the before data. All of the after measurements are estimated to be within 50 feet of the corresponding before measurements; with most measurements falling within 10 feet.

All Dynaflect measurements were taken in the outside wheel path. No measurements were taken on culverts, approach slabs, or bridges. Calibration of the Dynaflect took approximately 20 minutes, and it was done twice a day before the morning and afternoon runs. The average time to take a before deflection measurement was approximately 4 minutes, and the after measurements the average time was about 2 minutes. The difference in time required was because the Dynaflect could travel faster over the smooth overlays.

In addition to the personnel used for traffic protection, two people were needed in the operation of the Dynaflect system. The driver of the towing vehicle also operated the Dynaflect control box. The recorder of the data aligned the Dynaflect load wheels with the stakes in those two projects having stakes.

APPENDIX B

DATA ANALYSIS

APPENDIX B. DATA ANALYSIS

The primary data for analysis in this research project consisted of the before and after Dynaflect deflection measurements taken on the overlay projects as summarized in Figures 1.2 thru 1.6. At each measurement location, five deflection readings were taken with the Dynaflect using the standard geophone configuration (Ref. 13). The before measurements were used to characterize the existing roadway structure. The after measurements were used to characterize the total structure after overlaying. The difference in the two measurements, therefore should reflect the effect of the asphaltic concrete overlays.

The remaining available data consisted of the thickness of the asphaltic concrete overlays. This thickness was "plan quantity" thickness; not a thickness measured at each of the specific points of deflection measurements.

Possible deflection parameters for the characterization described above included W_1, SCI, and other measures of curvature. SCI is obtained by taking the difference between W_1 and W_2. Other finite difference equations that utilize more than two geophone readings could have been used to obtain more accurate measures of curvature. A cursory examination of the data indicated that such finesse was not warranted.

When the data analysis was actually undertaken, it had become apparent that Scrivner's model for predicting pavement deflections (Ref. 7) was going to be used in a new pavement design system for the Texas Highway Department. In addition, his performance equation (Ref. 8); which utilized SCI, would be the basis for predicting performance in the design system. Therefore, it was almost essential that the selected deflection model be one that would predict SCI after an overlay and preferably it would be Scrivner's deflection model.

The first attempt at using Scrivner's deflection model was not successful. The pavements, prior to overlaying, were assumed to be two-layer structures as is done in the THD design system (Ref. 6, 7, 11). Stiffness coefficients for the pavement and subgrade were then computed using the before data as inputs along with an average pavement thickness for each project. For the after data it was assumed that no change had occured in the stiffness coefficient for the existing pavement and that a three-layer pavement structure (overlay, pavement, and subgrade) now existed. Using the after data, it was attempted to compute the two unknown stiffness coefficients. Unrealistic answers were frequently obtained.

Further examination of Scrivner's model showed that while it predicts deflections reasonably well for a several layered pavement when stiffness coefficients are known; the reverse process will not work for more than two layers. Occasionally, several sets of stiffness coefficients can be found that will predict the same deflection. Cogill examined in detail the computation of materials parameters from the Dynaflect deflections and drew similar conclusions (Ref. 15)

The following use of Scrivner's model yielded reasonable answers which are the basis for the design subsystem of this report. First, the pavement structure before an overlay was simulated as a one-layer structure of infinite thickness. Equation (1) is Scrivner's model for deflection at geophone 1 for such a structure. Equation (2) is for the deflection at geophone 2 for such a structure. The other symbols are as defined in the List of Symbols.

$$(1) \quad W_1 = \frac{C}{a C_1} \left(\frac{1}{r_1^2} \right)$$

$$(2) \quad W_2 = \frac{C}{a C_1} \left(\frac{1}{r_2^2} \right)$$

Substracting W_2 from W_1 yields the SCI for the before structure.

$$(3)\quad SCI = W_1 - W_2$$

$$= \frac{C}{a^{C_1}}\left(\frac{1}{r_1^2} - \frac{1}{r_2^2}\right)$$

Equation (3) was solved for A_B using the average before SCI for each of the eleven projects.

The after pavement structure was simulated as a two layer pavement using Scrivner's model. Equation (4) is the two layer model for the deflection at geophone 1 and equation (5) is the model for the deflection at geophone 2.

$$(4)\quad W_1 = \frac{C}{a_1^{C_1}}\left(\frac{1}{r_1^2} - \frac{1}{r_1^2 + C_2(a_1 D_1)^2}\right) + \frac{C}{a_2^{C_1}}\left(\frac{1}{r_1^2 + C_2(a_1 D_1)^2}\right)$$

$$(5)\quad W_2 = \frac{C}{a_1^{C_1}}\left(\frac{1}{r_2^2} - \frac{1}{r_2^2 + C_2(a_1 D_1)^2}\right) + \frac{C}{a_2^{C_1}}\left(\frac{1}{r_2^2 + C_2(a_1 D_1)^2}\right)$$

The SCI for such a structure was obtained by substracing W_1 from W_2.

$$(6)\quad SCI = W_1 - W_2 = (4) - (5)$$

Substituting the subscript 0 for overlay, B for before, and A for after data yields the equation for the SCI after an overlay. Equation (6A) is written with the familiar stiffness coefficient terms. Solving equation (3) for stiffness coefficients before overlay in terms of SCI and substituting this value in equation (6A) yields equation (6B), an equation for SCI after an overlay as a function of SCI before an overlay.

$$(6A)\quad SCI_A = \frac{C}{a_0^{C_1}}\left(\frac{1}{r_1^2} - \frac{1}{r_1^2 + C_2(a_0 D_0)^2}\right) + \frac{C}{a_B^{C_1}}\left(\frac{1}{r_1^2 + C_2(a_0 D_0)^2}\right) - \left[\frac{C}{a_0^{C_1}}\left(\frac{1}{r_2^2} - \frac{1}{r_2^2 + C_2(a_0 D_0)^2}\right) + \frac{C}{a_B^{C_1}}\left(\frac{1}{r_2 + C_2(a_0 D_0)^2}\right)\right]$$

$$(6B)\quad SCI_A = \frac{C}{a_0^{C_1}}\left(\frac{1}{r_1^2} - \frac{1}{r_1^2 + C_2(a_0 D_0)^2}\right) + \frac{SCI_B}{\frac{1}{r_1^2} - \frac{1}{r_2^2}}\left(\frac{1}{r_1^2 + C_2(a_0 D_0)^2}\right) - \left[\frac{C}{a_0^{C_1}}\left(\frac{1}{r_2^2} - \frac{1}{r_2^2 + C_2(a_0 D_0)^2}\right) + \frac{SCI_B}{\frac{1}{r_1^2} - \frac{1}{r_2^2}}\left(\frac{1}{r_2 + C_2(a_0 D_0)^2}\right)\right]$$

Using the average data point on each individual project, the only unknown in equation (6B) is the stiffness coefficient for the overlay. That is; the average SCI before and after an overlay for each project and the average thickness of overlay were known. An iterative procedure was used to solve for the stiffness coefficient for the average data point for each of the eleven projects. The procedure is as follows:

1. Set the stiffness coefficient of the overlay equal to the stiffness coefficient for the before pavement structure and compute a SCI.

2. Is this SCI equal to the SCI measured after overlaying, plus or minus 1%? If the answer is "Yes", stop and consider the solution completed.

3. If "No", set the overlay stiffness coefficient equal to that used in Step 1 minus 1% of the error in computing SCI times the stiffness coefficient tried.

4. Repeat steps 2 and 3 until a SCI equal to the measured SCI plus or minus 1% occurs or until 10,000 trials have occured.

As stated above the stiffness coefficients through the average data point for each of the eleven projects was computed in this manner.

Plots of the SCI before and after overlaying are shown in Figures B-1 thru B-11. Equation (3) using the individual project stiffness coefficients is plotted as a dashed line on each graph. The project average stiffness coefficients range from 0.67 in District 19 to 1.57 for the thin overlay in District 21.

An overall weighted average stiffness coefficient was obtained by (1) multiplying the project average times the number of points in a project, (2) summing these products, and (3) dividing by the total number of points used. This overall average stiffness coefficient of 0.956 is considered to be the best number available for designers to use on asphaltic concrete. It has been inserted in the overlay design subsystem as the stiffness coefficient for overlay ACP. Equation (3) has been plotted on Figures B-1 thru B-11, as a solid line, using this stiffness coefficient. After examination of Figures B-1 through B-11 it was thought that a nonlinear equation might fit the data a little better; especially the thicker overlays of District 6, 19 and 21. If Scrivner's complex model was not going to be used; a simple one relating SCI_B, thickness of overlay, and the overlay material property to SCI_A; was desirable. Equation (7) is the model tried.

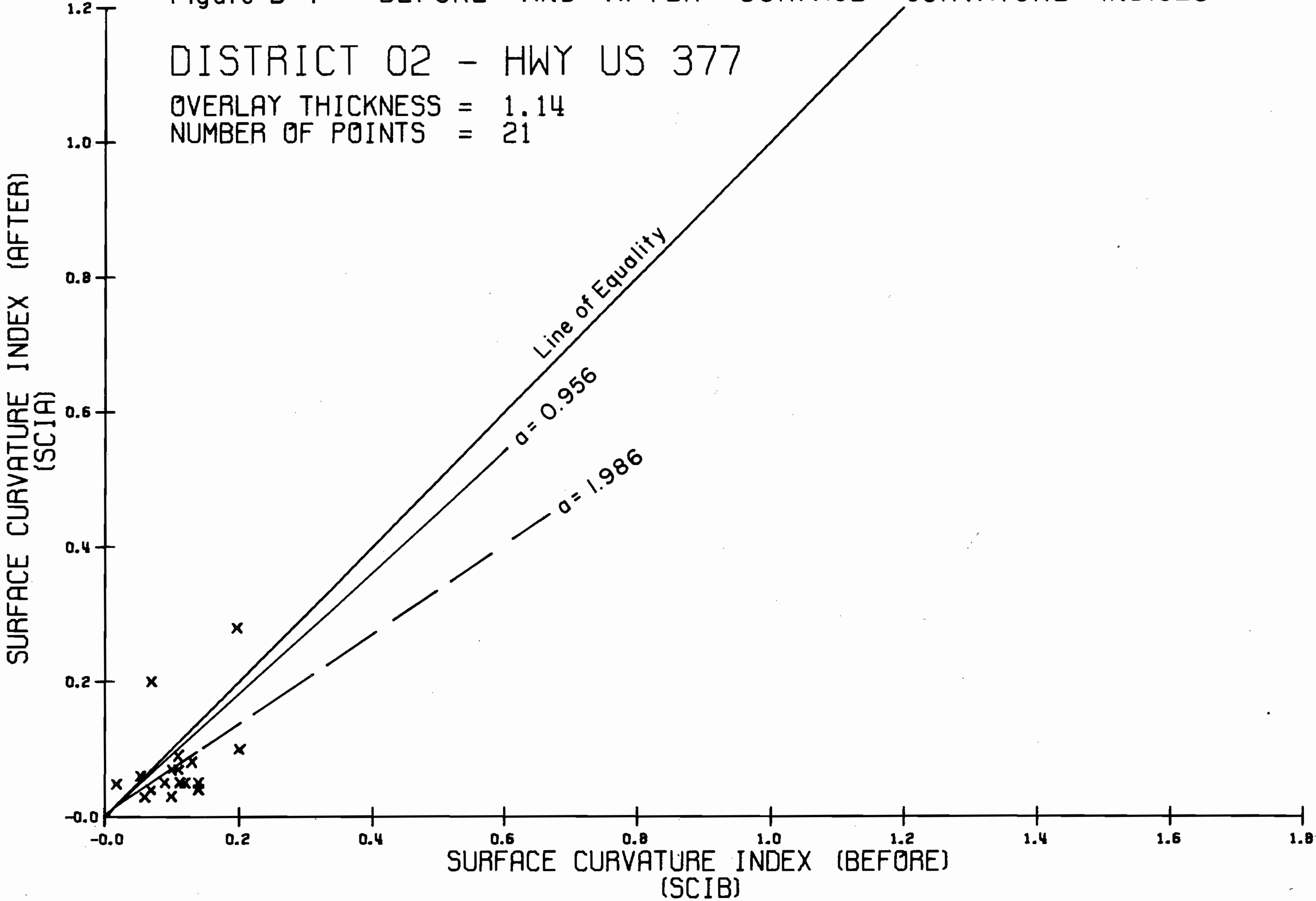
$$(7) \quad SCI_A = SCI_B - A\,(SCI_B)^N$$

Where A is a constant related to the overlay stiffness and thickness. The exponent, N, determines the amount of nonlinearity in the model.

It was felt that N should be selected such that the slope of the equation was positive over the range of SCI_B data available. The largest N (most curvature) that could be used and meet this condition for the average data point of the thick overlay of District 21 was 1.25. (A slight blunder was made in thinking this project controlled as far as the requirement that a negative slope not be used. The District 6 project actually controlled). From a few hand calculations varying N through the average data point for some of the projects; it appeared that N = 5/4 would give a good fit.

SCRIVNER'S MODEL

Figure B-1 BEFORE AND AFTER SURFACE CURVATURE INDICES



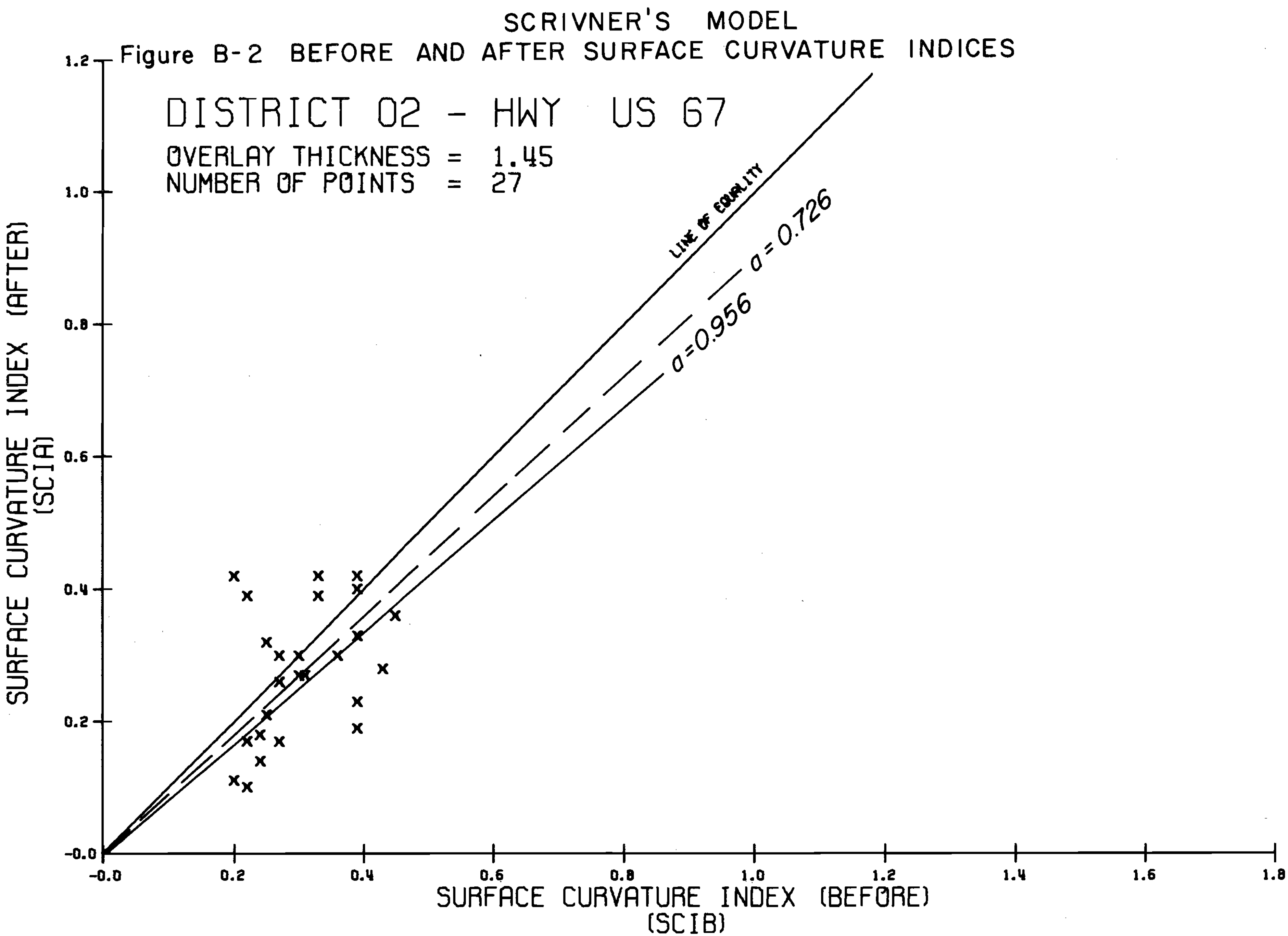
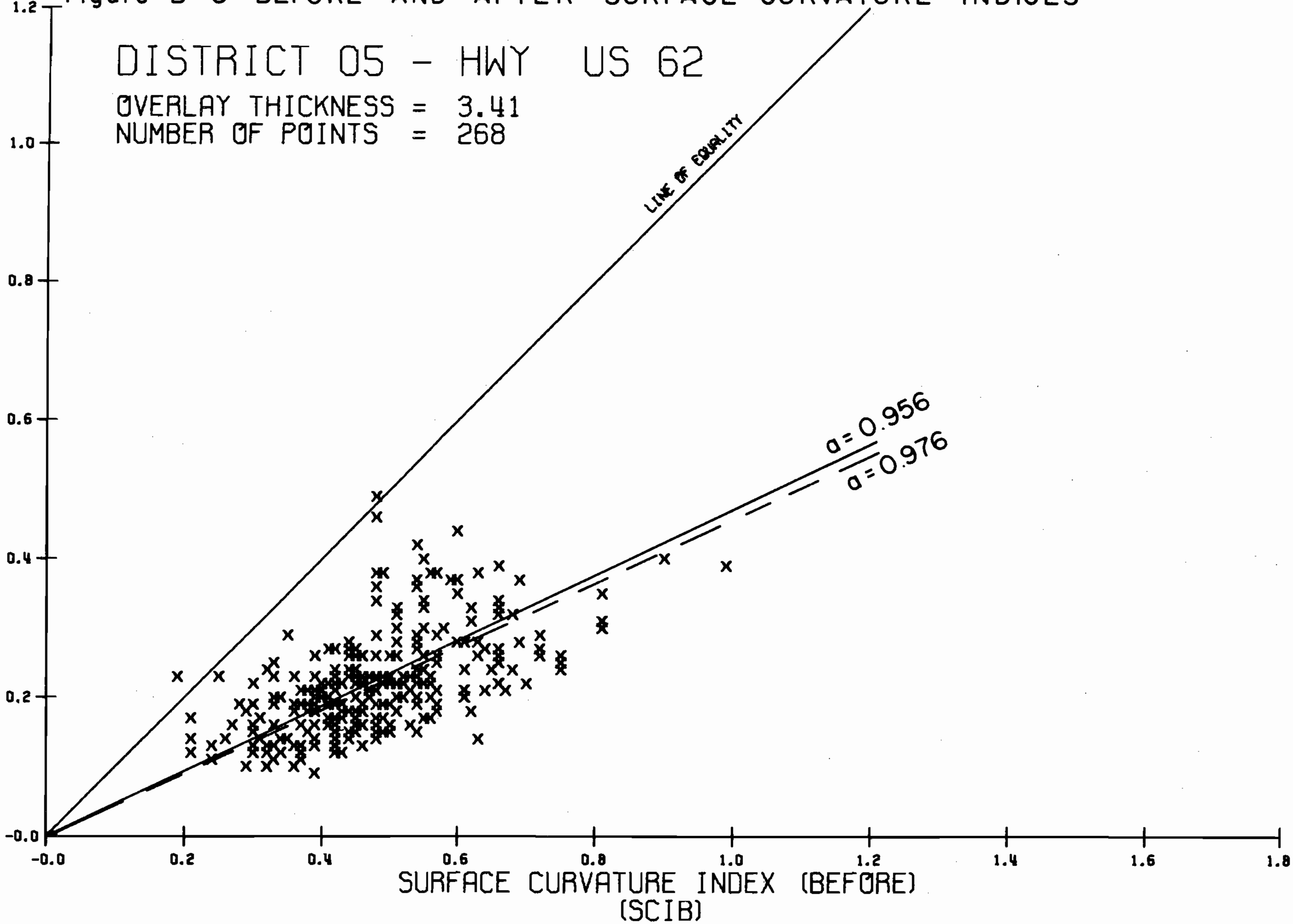


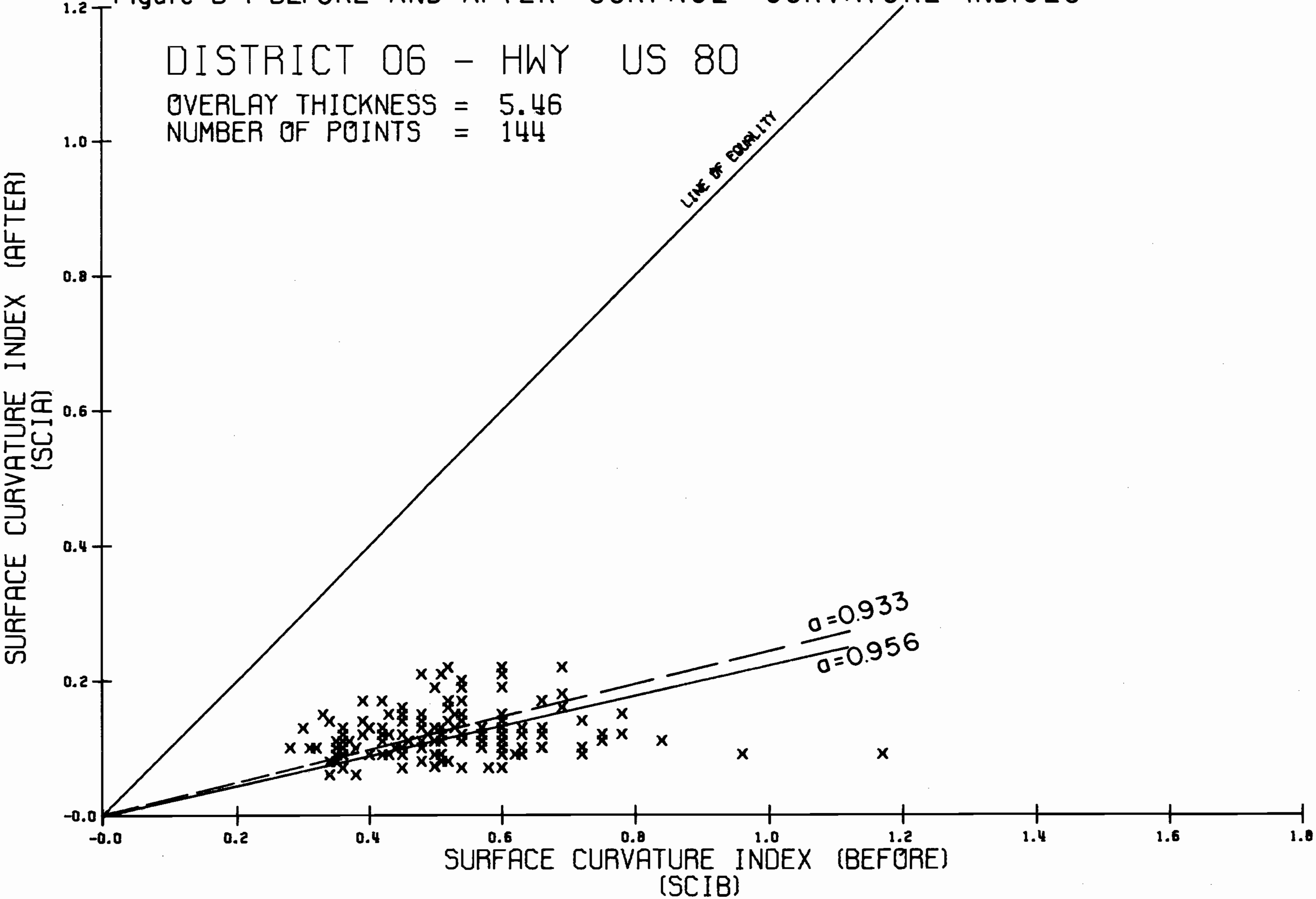
Figure B-2 BEFORE AND AFTER SURFACE CURVATURE INDICES

SCRIVNER'S MODEL

Figure B-3 BEFORE AND AFTER SURFACE CURVATURE INDICES

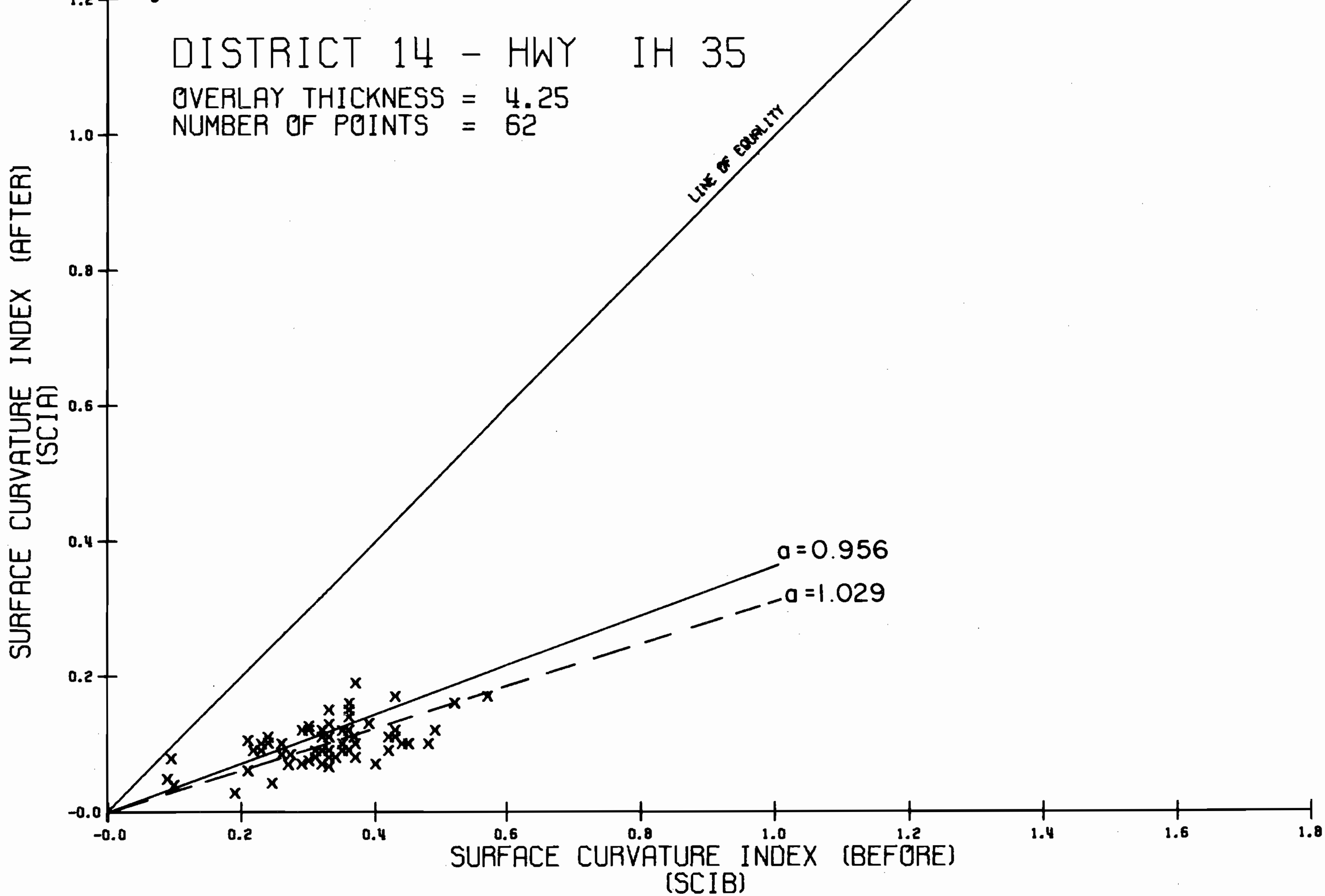


SCRIVNER'S MODEL
Figure B-4 BEFORE AND AFTER SURFACE CURVATURE INDICES



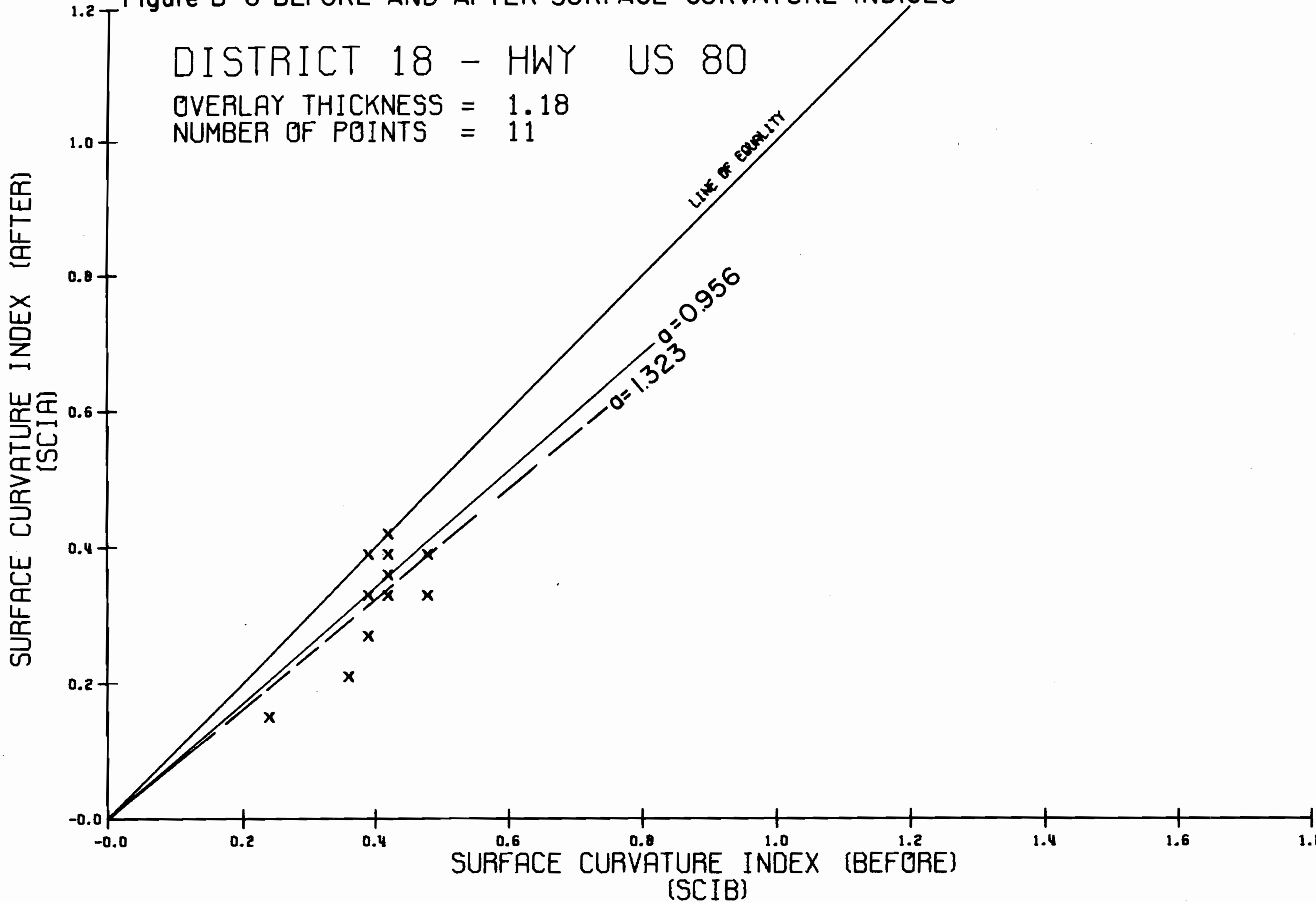
SCRIVNER'S MODEL

Figure B-5 BEFORE AND AFTER SURFACE CURVATURE INDICES



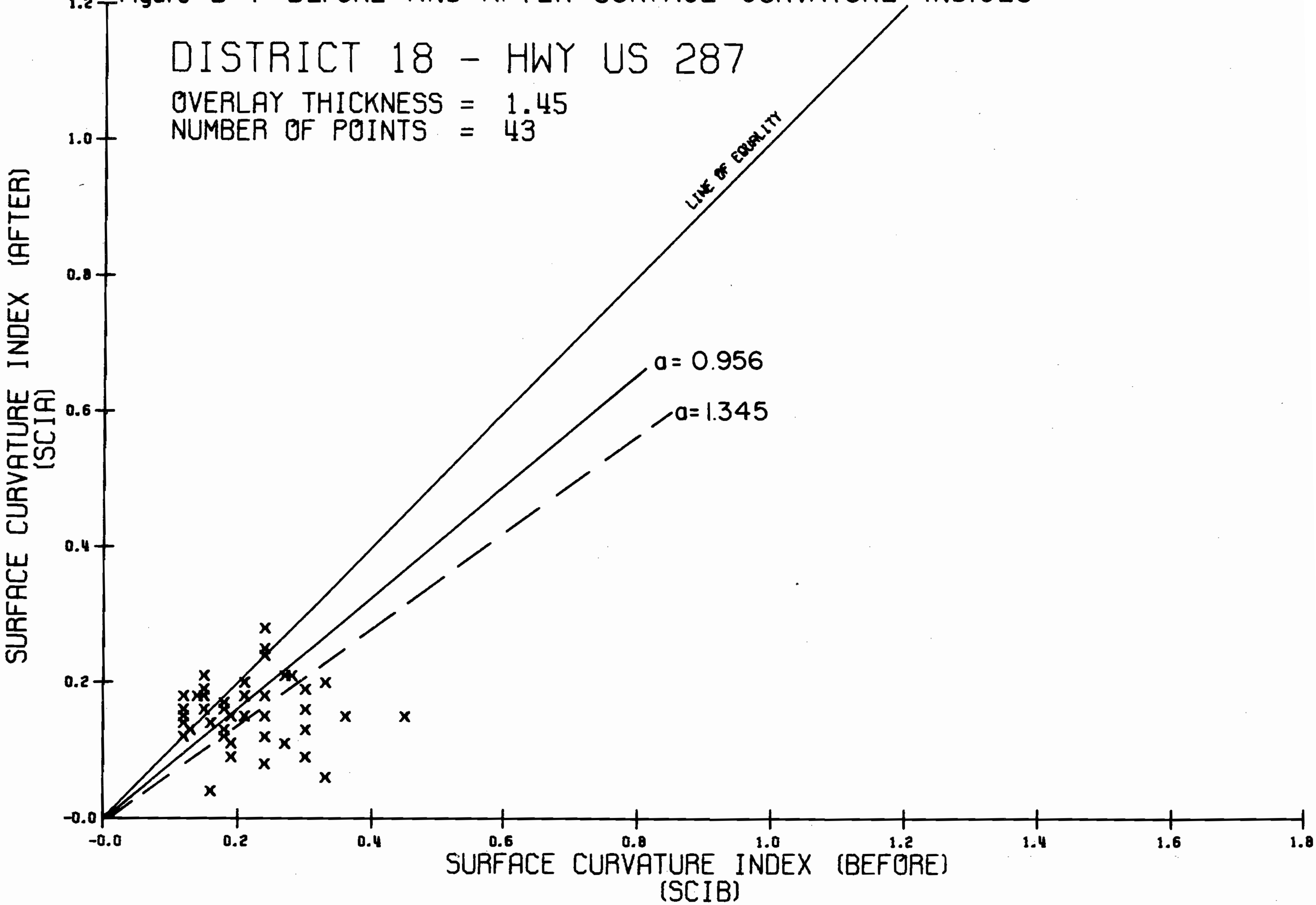
SCRIVNER'S MODEL

Figure B-6 BEFORE AND AFTER SURFACE CURVATURE INDICES



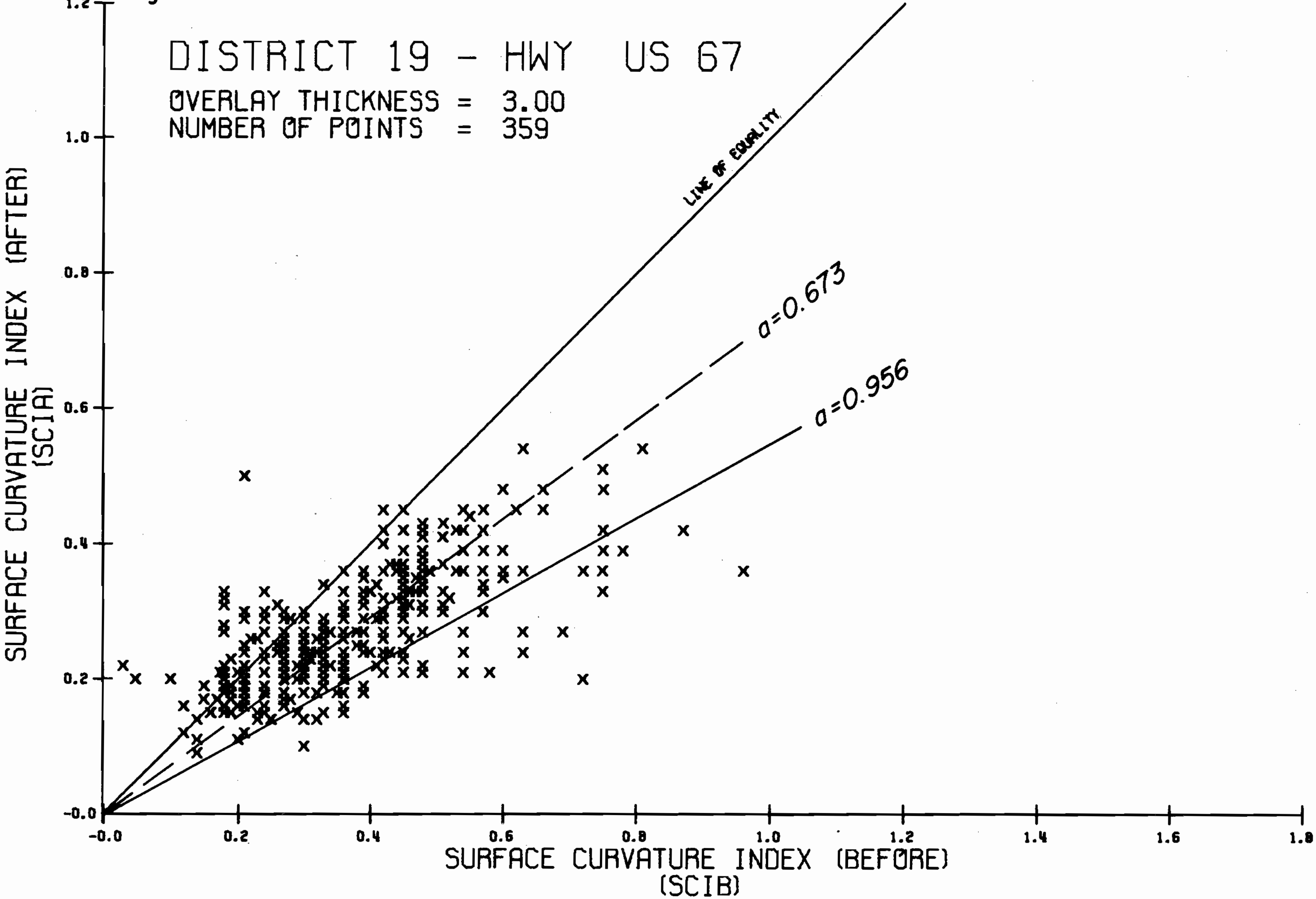
SCRIVNER'S MODEL

Figure B-7 BEFORE AND AFTER SURFACE CURVATURE INDICES



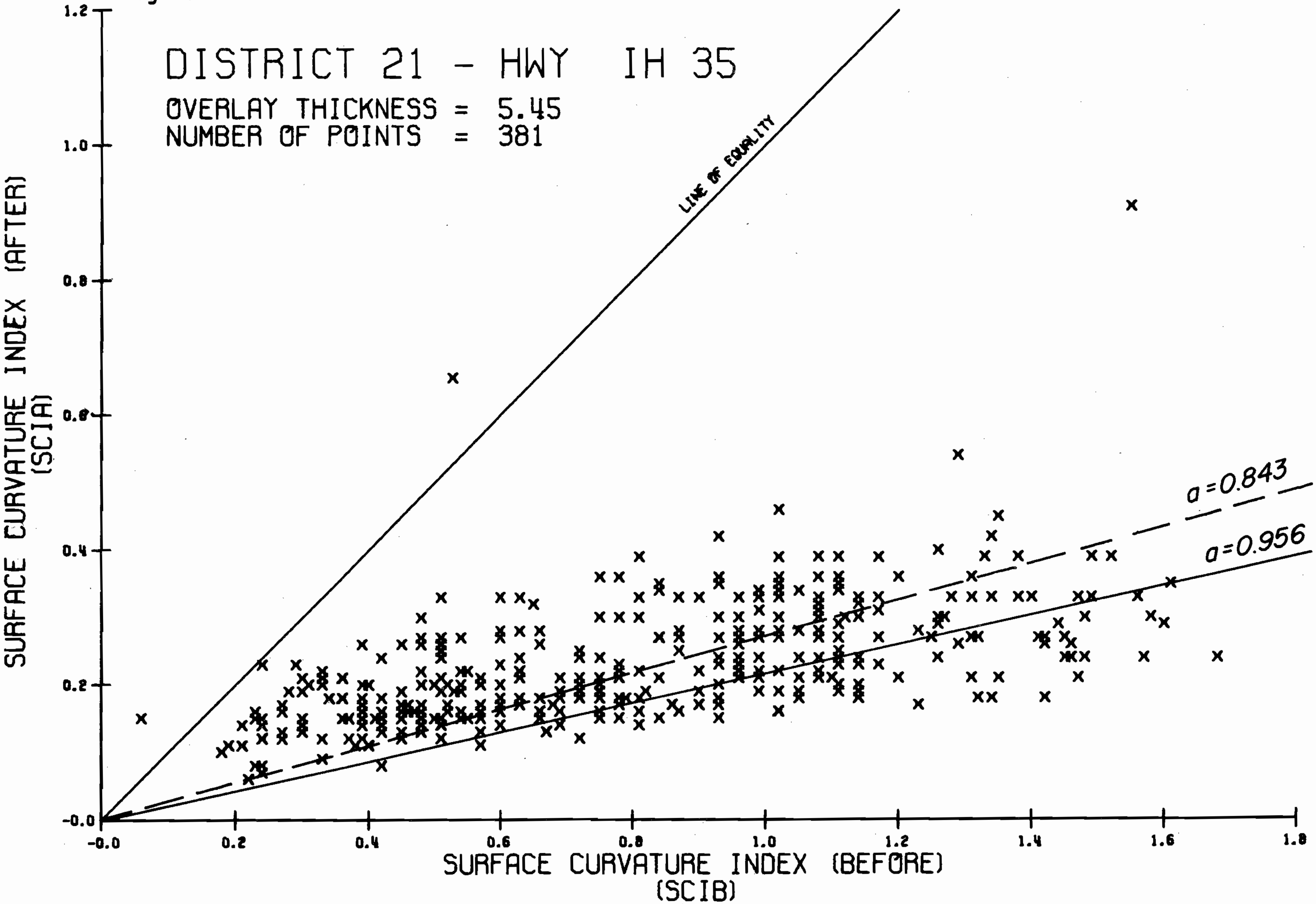
SCRIVNER'S MODEL

Figure B-8 BEFORE AND AFTER SURFACE CURVATURE INDICES



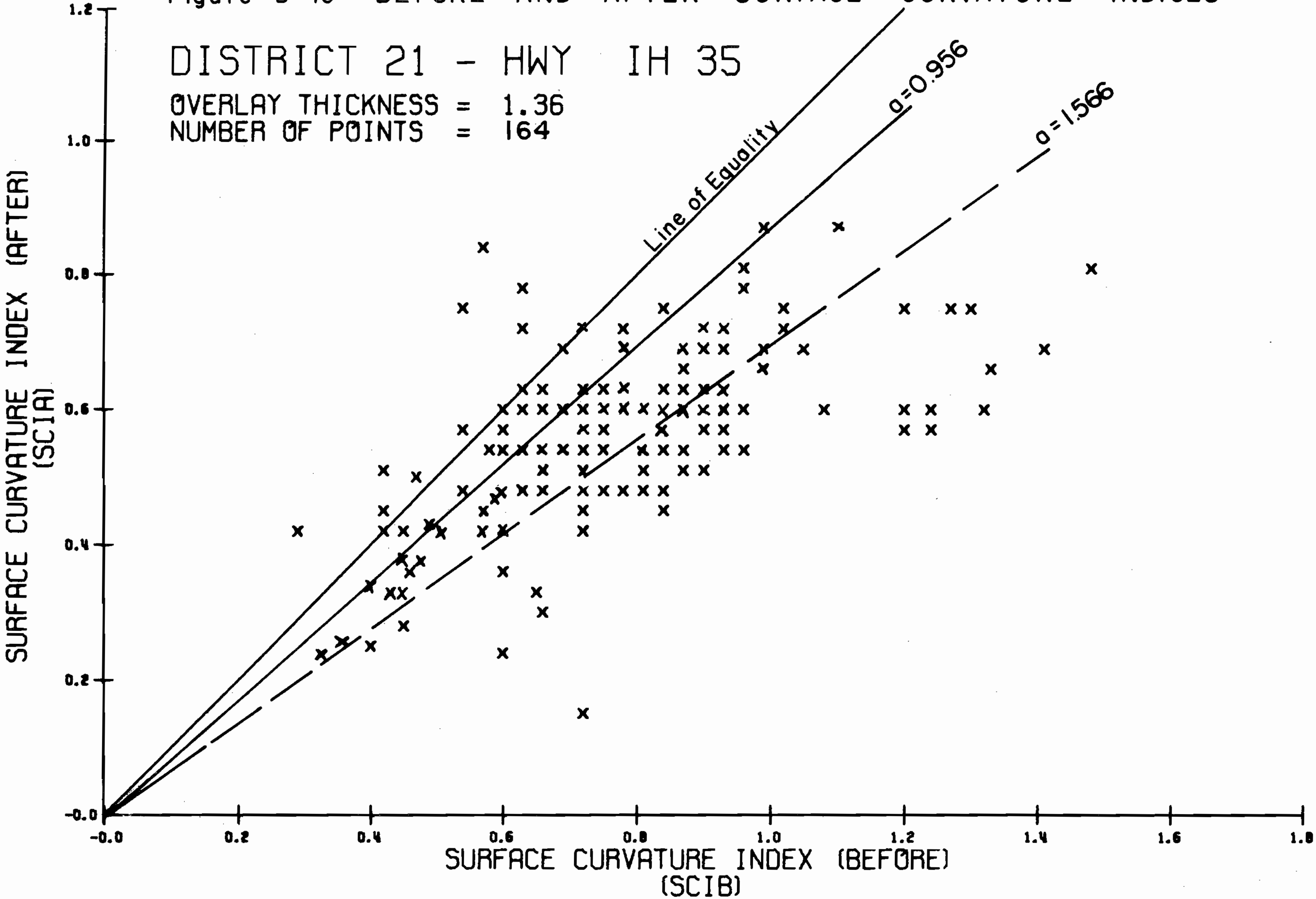
SCRIVNER'S MODEL

Figure B-9 BEFORE AND AFTER SURFACE CURVATURE INDICES



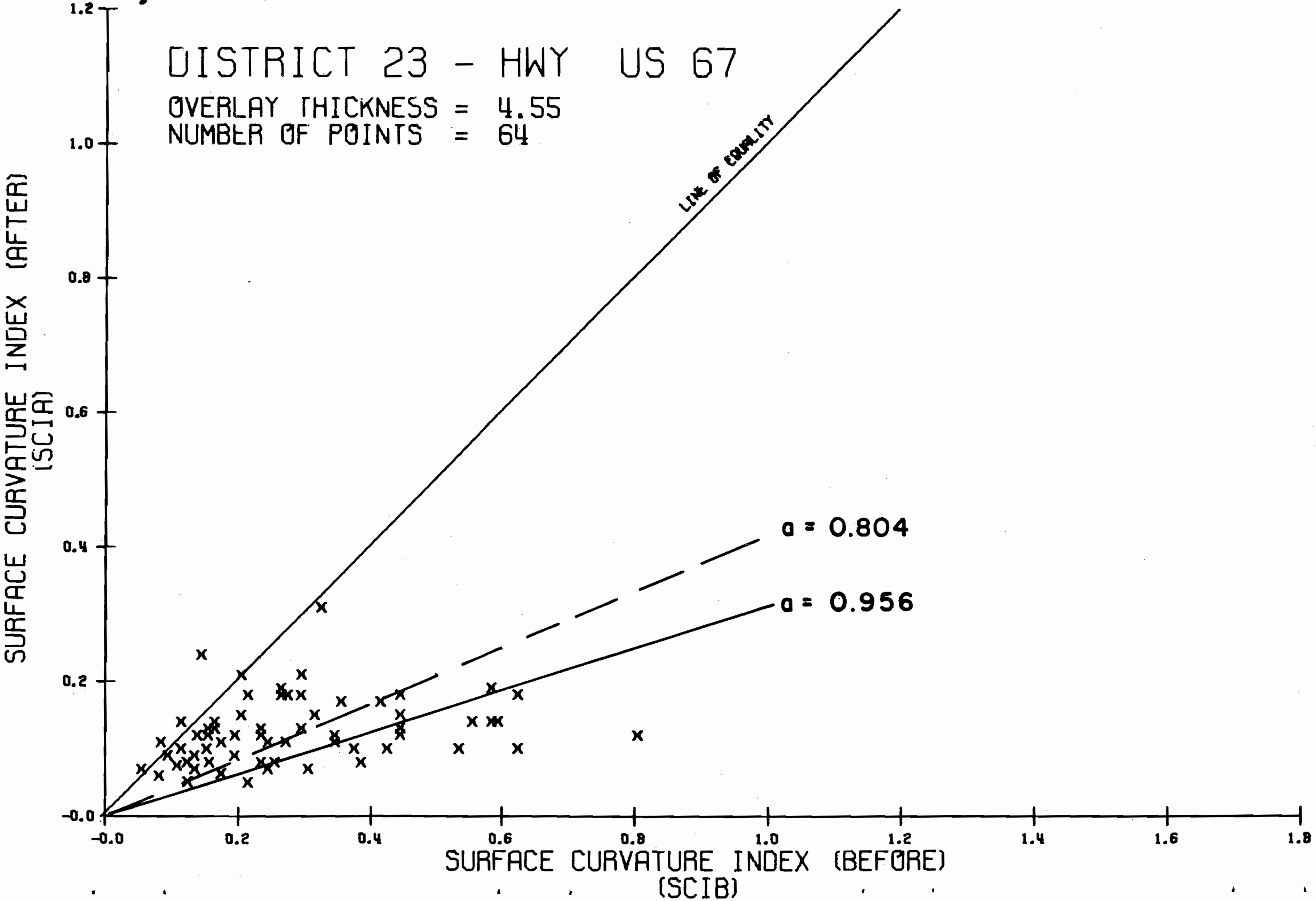
SCRIVNER'S MODEL

Figure B-10 BEFORE AND AFTER SURFACE CURVATURE INDICES



SCRIVNER'S MODEL

Figure B-11 BEFORE AND AFTER SURFACE CURVATURE INDICES



Using N = 5/4, the constant A was determined for the average point for each of the eleven projects. The resulting equation is plotted as a dashed line for the before and after data on each project on Figures B-12, through B-22.

Figure B-23 shows the calculated A's plotted versus overlay thickness and a regression line forced through the orgin. This regression was weighted by the number of measurements available from each specific project. On Figures B-12 through B-22, the equation resulting from using the overall materials coefficients, 0.153, is plotted as a solid line.

Figure B-25 compares the computed SCI with the measured SCI using the direct solution model. Figure 3.1 is the same type plot using Scrivner's model.

To better compare the goodness of fit of the two models the root-mean-squared error or standard error was computed. An error was defined as illustrated in Figure B-24 as being the difference between the measured SCI after overlaying and that predicted by the equation. Root-mean-squared errors were obtained by taking the square root of the sum of the errors squared divided by the number of points minus one.

Table B-1 summarizes the stiffness coefficient from the Scrivner model, the material coefficients from the direct solution model, and the standard errors. Note that there is a negligible difference in the overall standard error between the two models. Combining this fact with the need to use the same model in the overlay subsystem as is being used in the overall pavement design system; it seemed logical to select the Scrivner model with its stiffness coefficient for the overlay subsystem.

The reader is invited to note the following points about the scatter in the data shown in Figures B-1 through B-22, B-25 and 3-1.

1. For the average data point, each overlay gave some reduction in SCI.

2. The scatter in the data was of the same order of magnitude for stiff existing pavement structures as it was for those with larger SCI's. In other words, the scatter was independent of the stiffness of the existing pavement.

3. The scatter was roughly the same size on all projects except the thin ACP overlay in District 21.

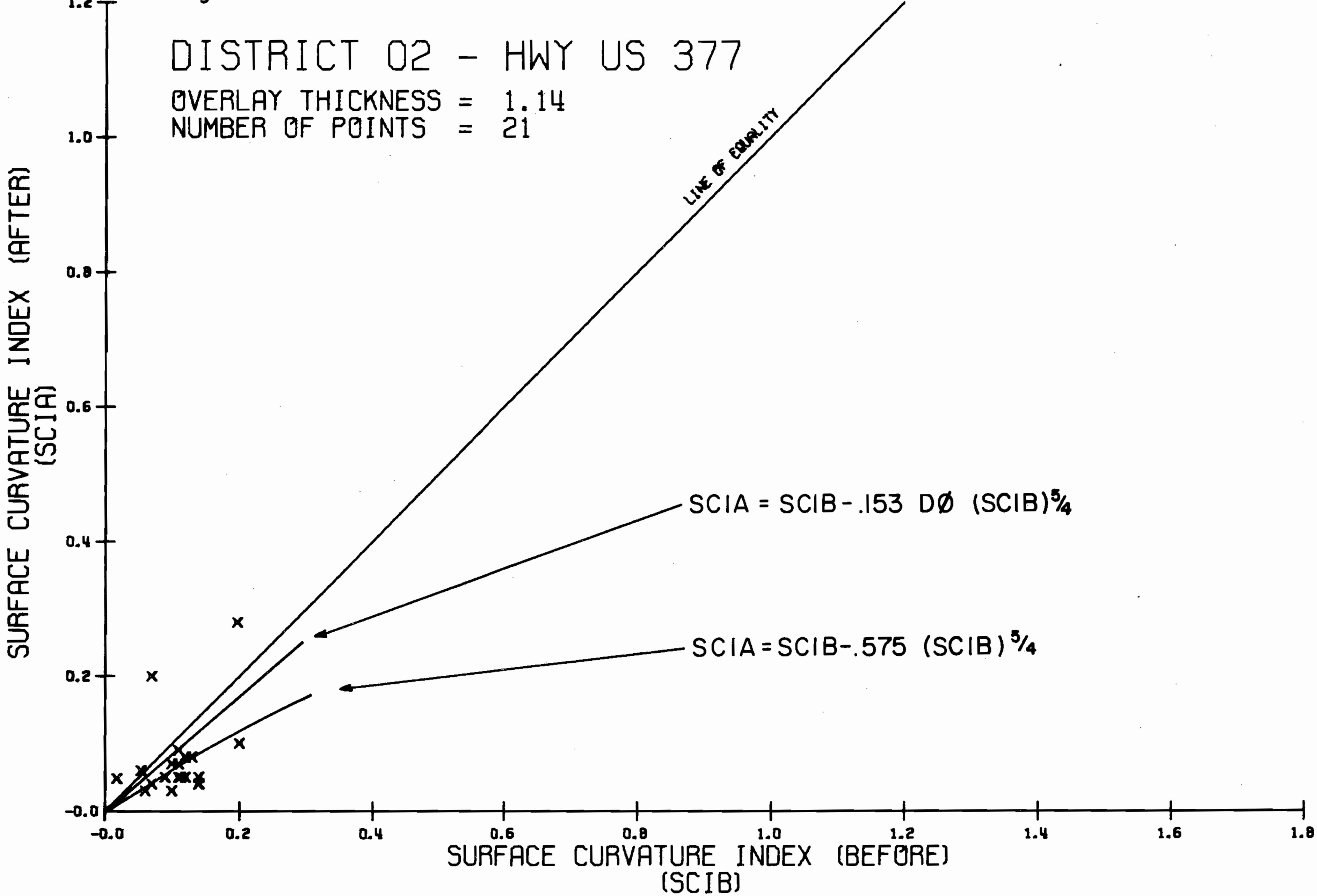
4. The scatter on all of the thin overlays (less than 1½ inches) was so large that the overall average stiffness coefficient fit the data nearly as well as the individual project average coefficient. For the thicker overlays, three inches or thicker, the overall project average was quite close to the individual project average coefficient.

5. In all cases the thin overlay in District 21 contributed the most scatter, (see Table B-1). As was stated earlier, the thickness used in calculating these constants was the plan quantity thickness. In District 21, considerable level-up (highly varying thickness) was used. This probably caused the large amount of scatter shown for the thin overlay.

6. More sophisticated data fitting (minimizing errors, etc.) could be used with the data. It is the author's opinion that little would be gained with such sophistication.

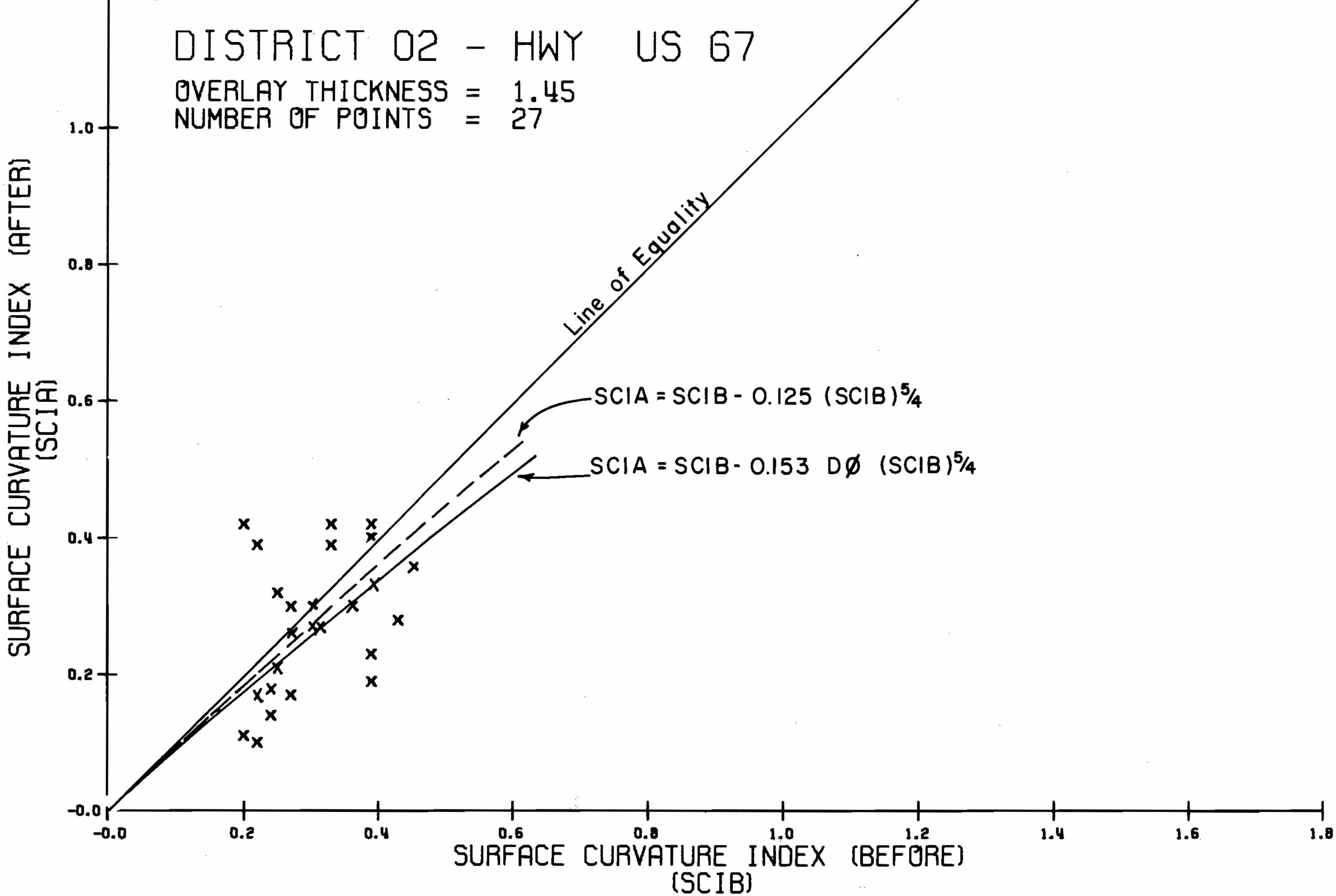
DIRECT SOLUTION MODEL

Figure B-12 BEFORE AND AFTER SURFACE CURVATURE INDICES



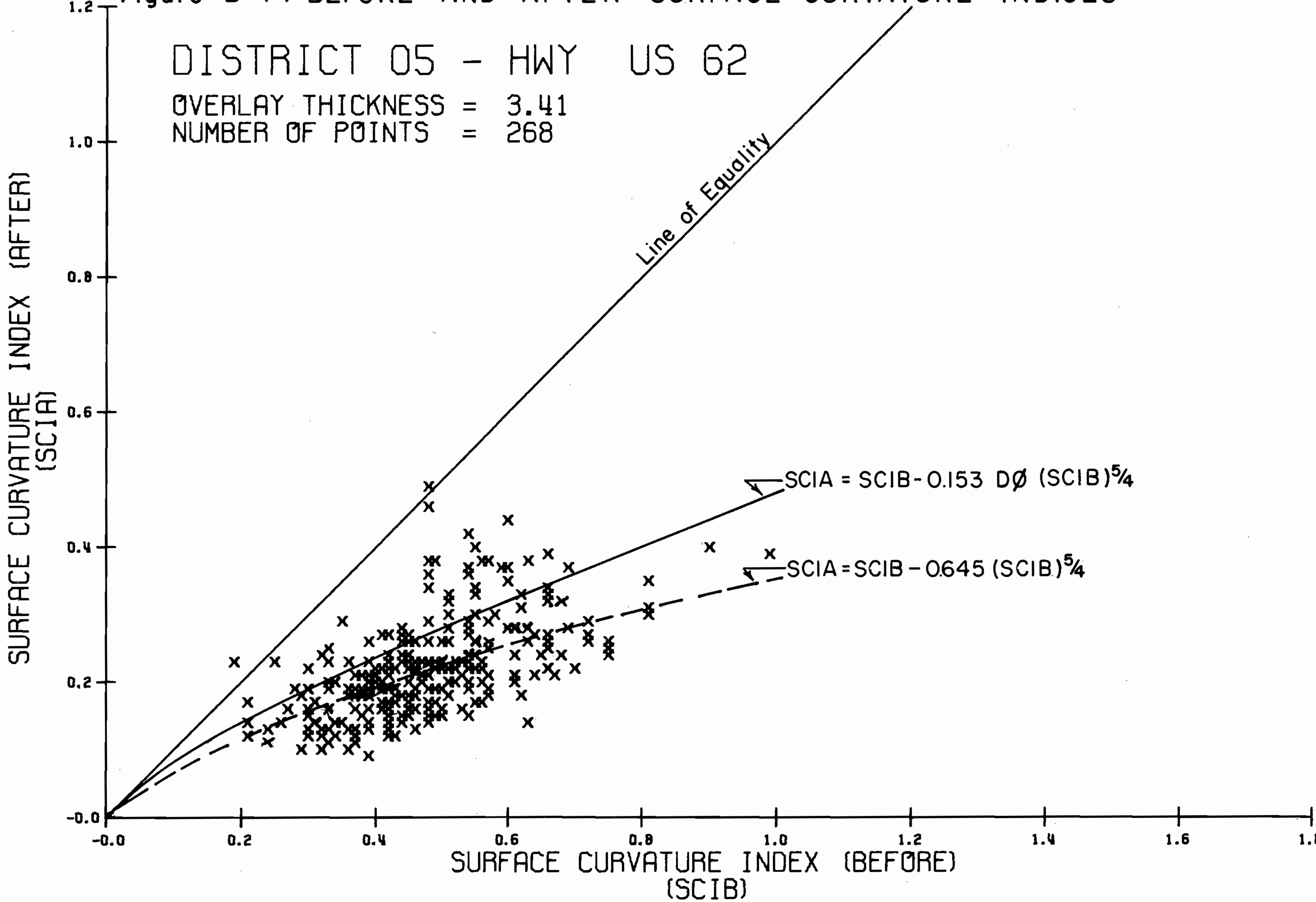
DIRECT SOLUTION MODEL

Figure B-13 BEFORE AND AFTER SURFACE CURVATURE INDICES



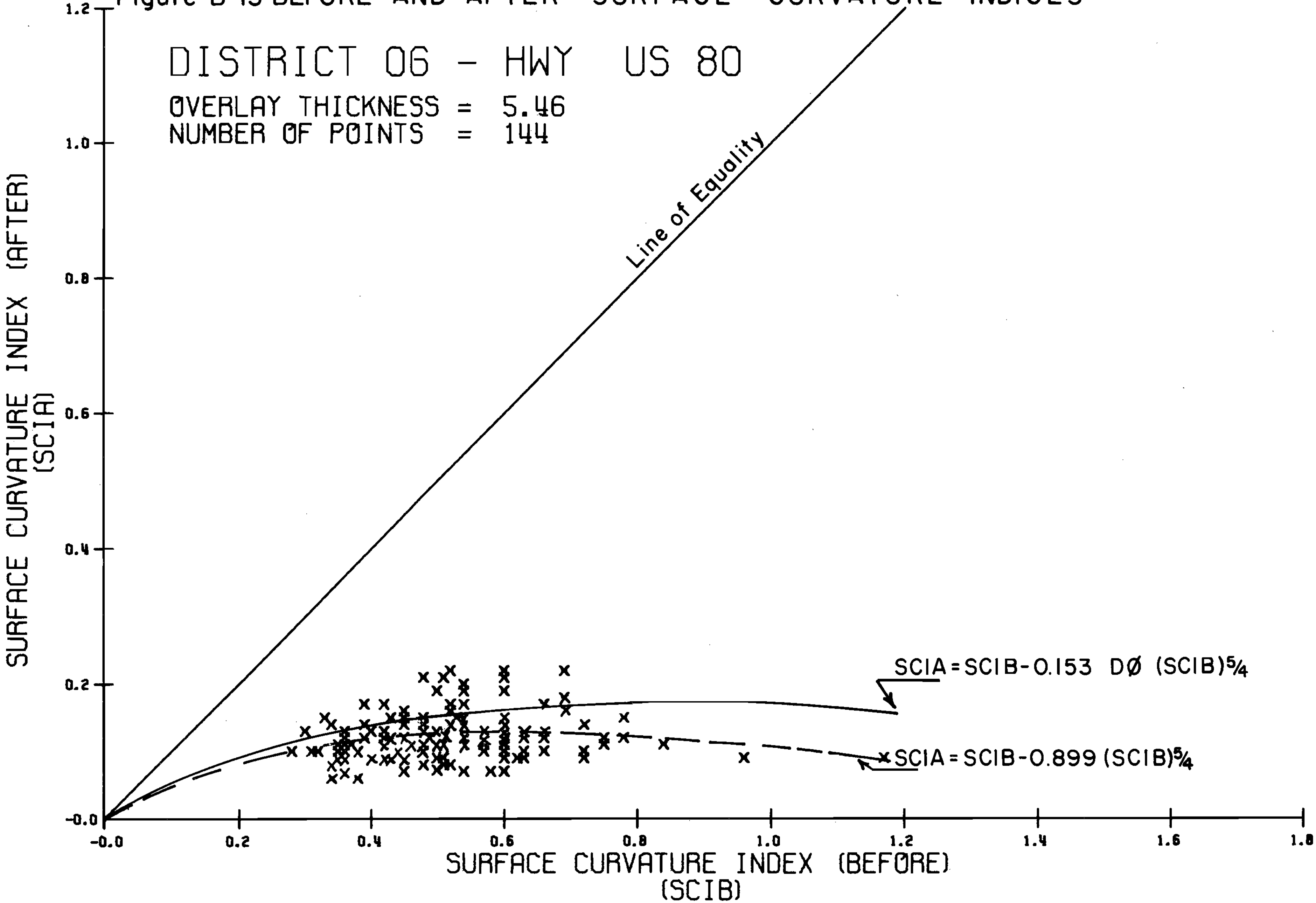
DIRECT SOLUTION MODEL

Figure B-14 BEFORE AND AFTER SURFACE CURVATURE INDICES



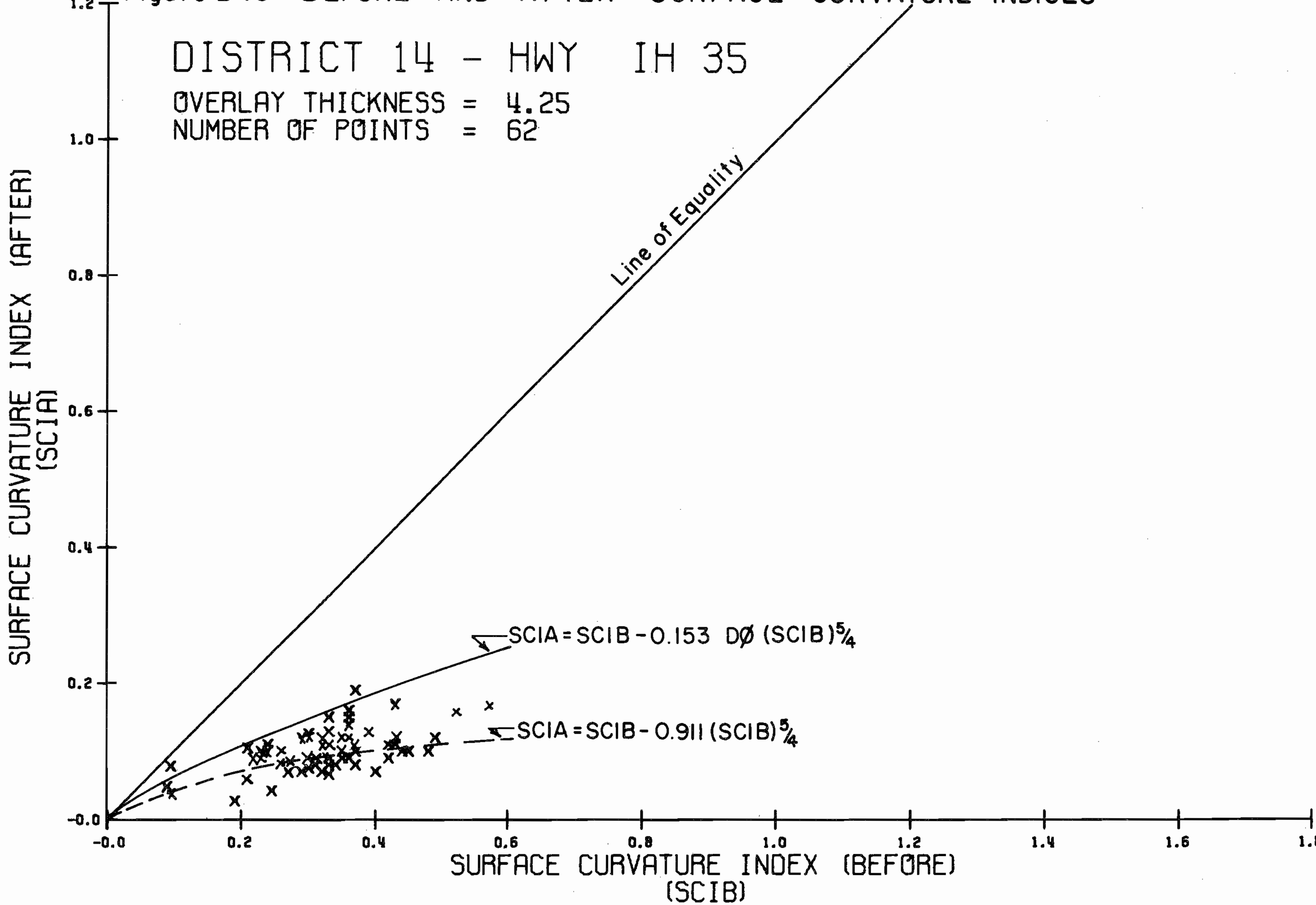
DIRECT SOLUTION MODEL

Figure B-15 BEFORE AND AFTER SURFACE CURVATURE INDICES



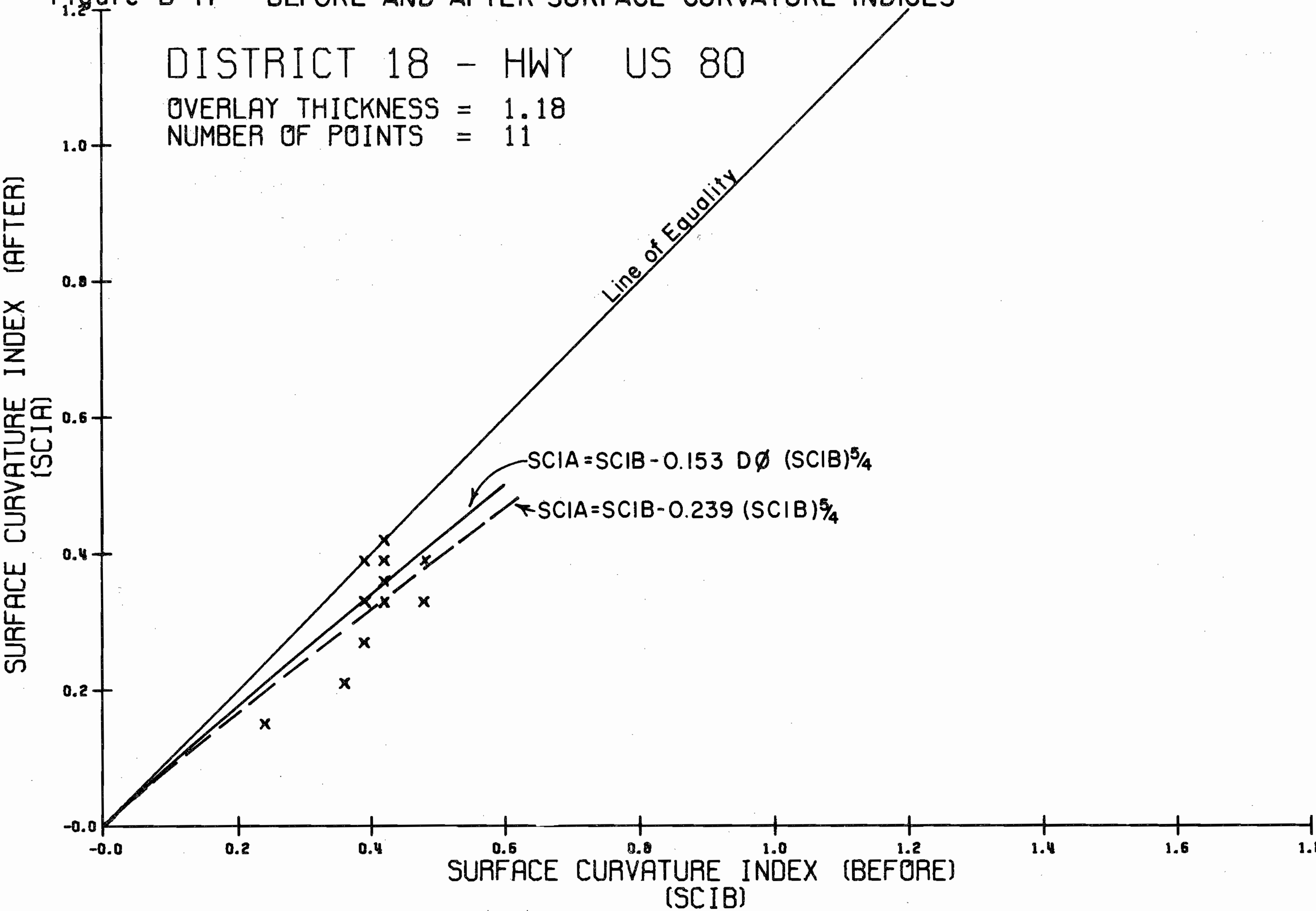
DIRECT SOLUTION MODEL

Figure B-16 BEFORE AND AFTER SURFACE CURVATURE INDICES



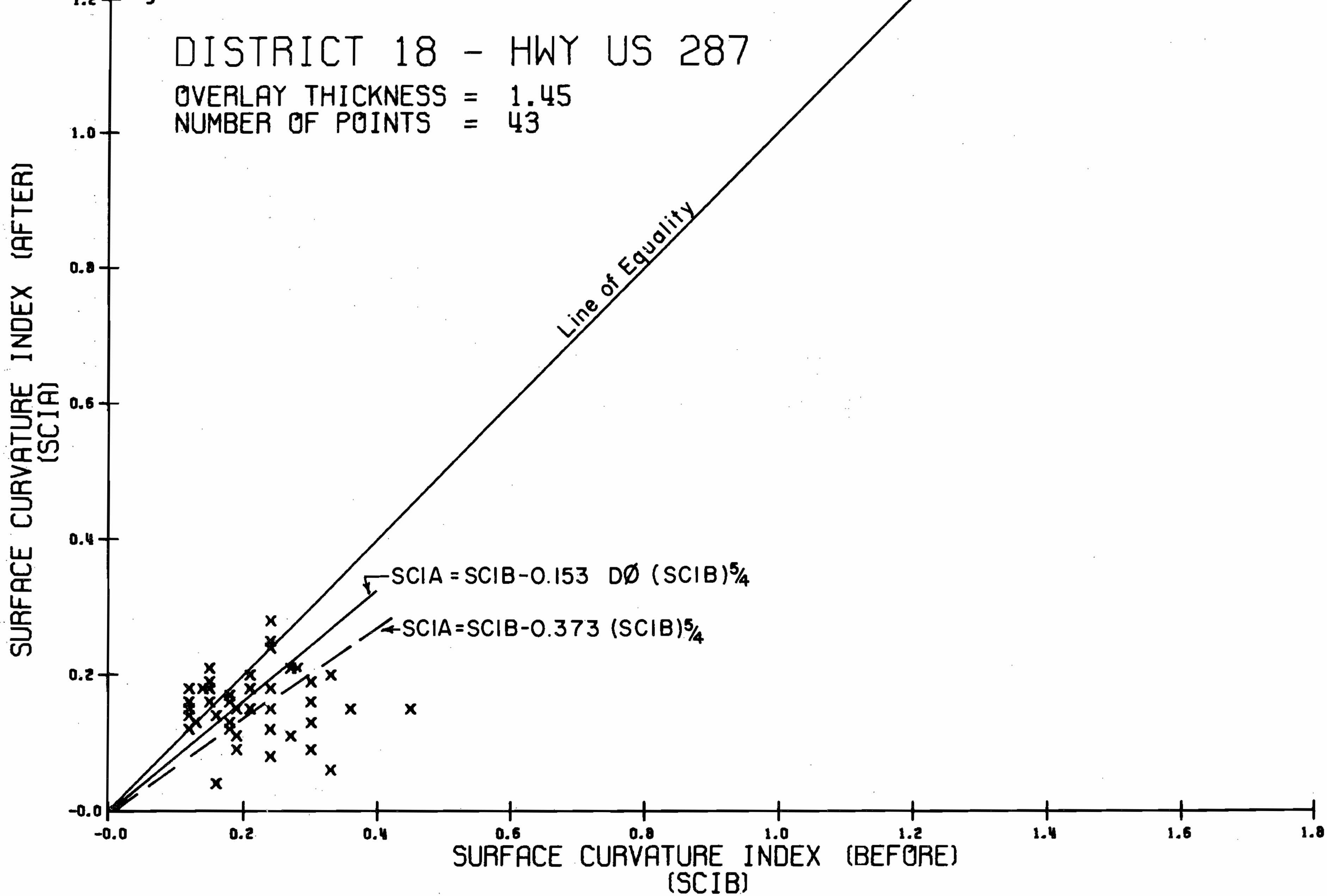
DIRECT SOLUTION MODEL

Figure B-17 BEFORE AND AFTER SURFACE CURVATURE INDICES



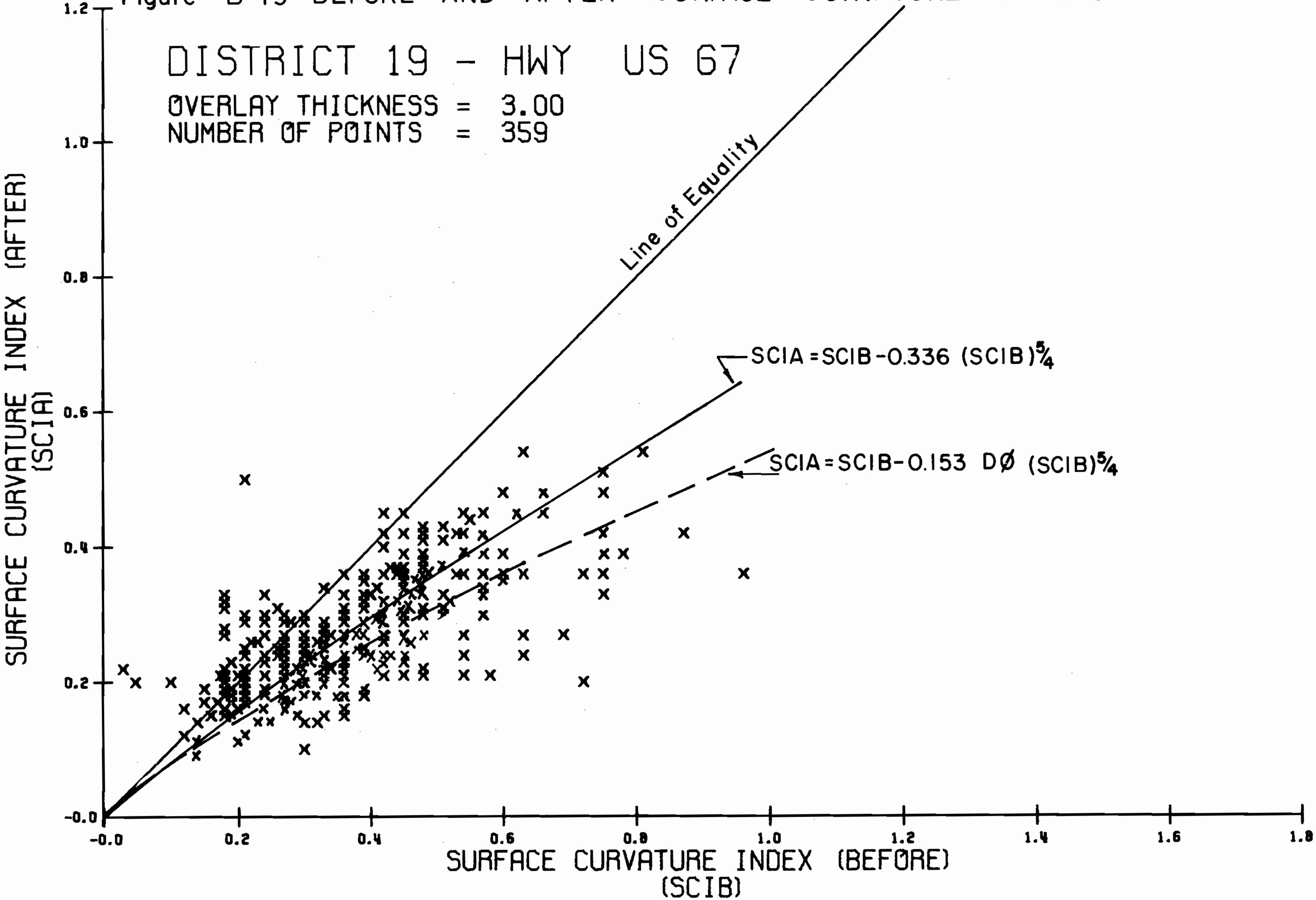
DIRECT SOLUTION MODEL

Figure B-18 BEFORE AND AFTER SURFACE CURVATURE INDICES



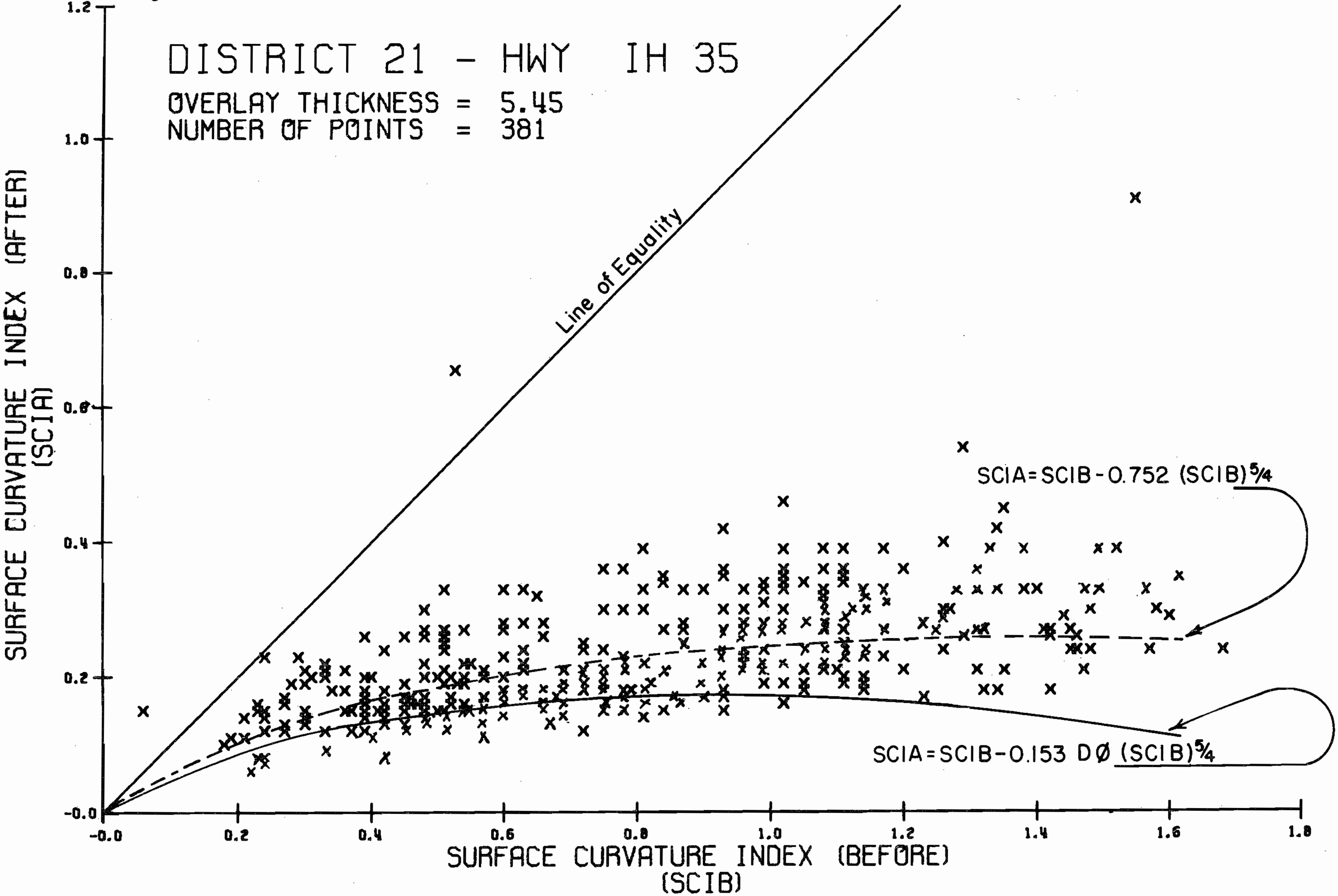
DIRECT SOLUTION MODEL

Figure B-19 BEFORE AND AFTER SURFACE CURVATURE INDICES



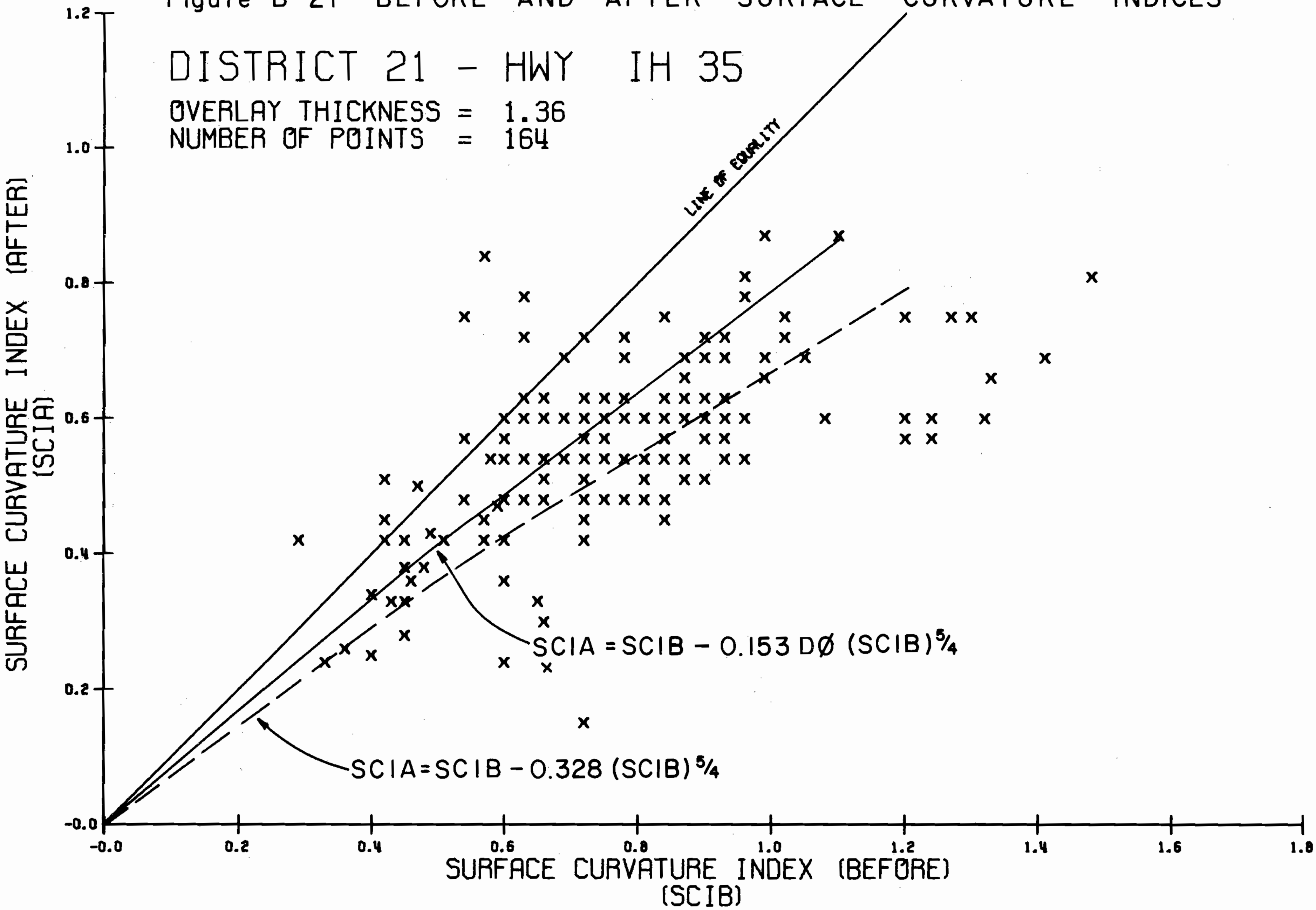
DIRECT SOLUTION MODEL

Figure B-20 BEFORE AND AFTER SURFACE CURVATURE INDICES



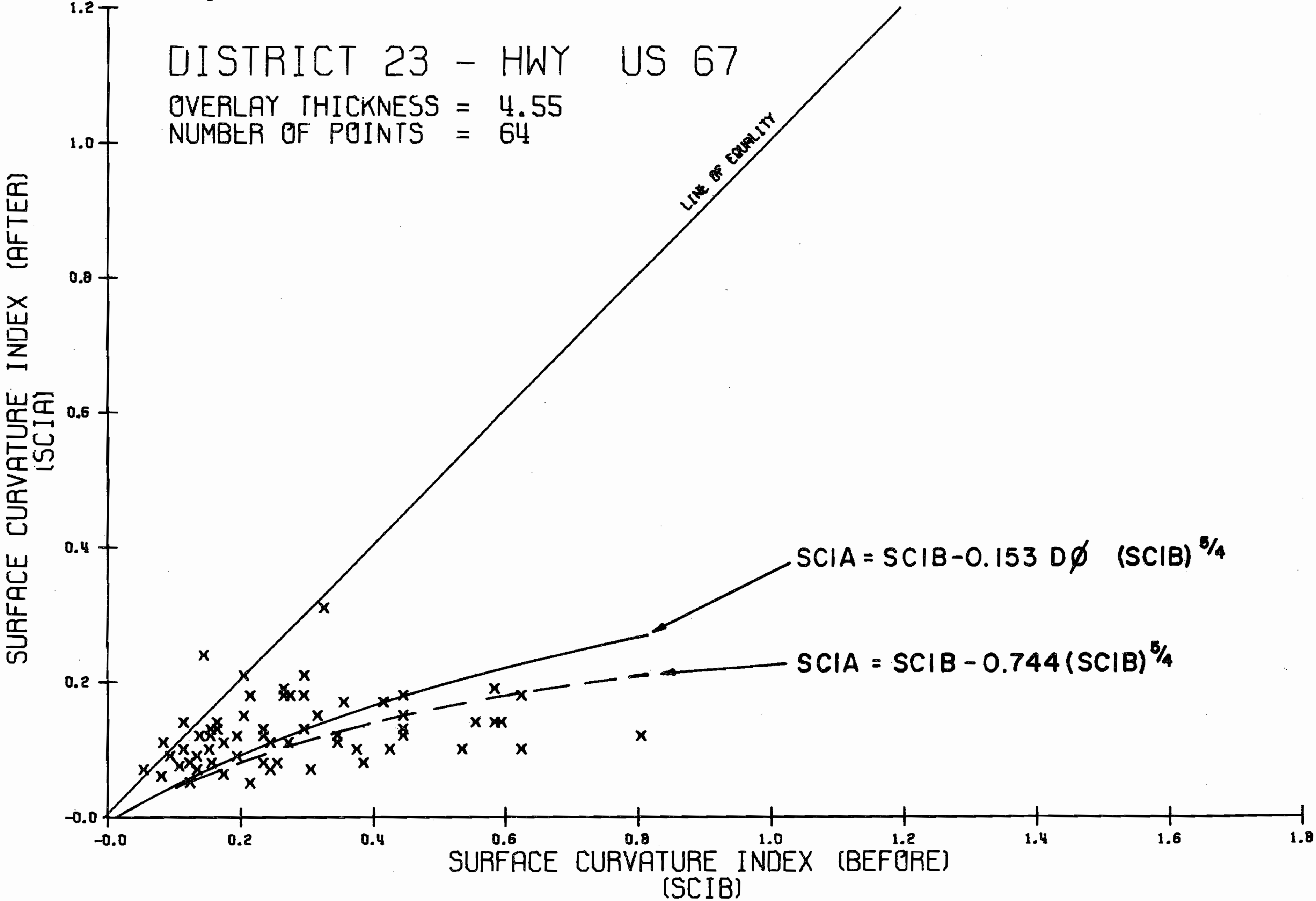
DIRECT SOLUTION MODEL

Figure B-21 BEFORE AND AFTER SURFACE CURVATURE INDICES



DIRECT SOLUTION MODEL

Figure B-22 BEFORE AND AFTER SURFACE CURVATURE INDICES



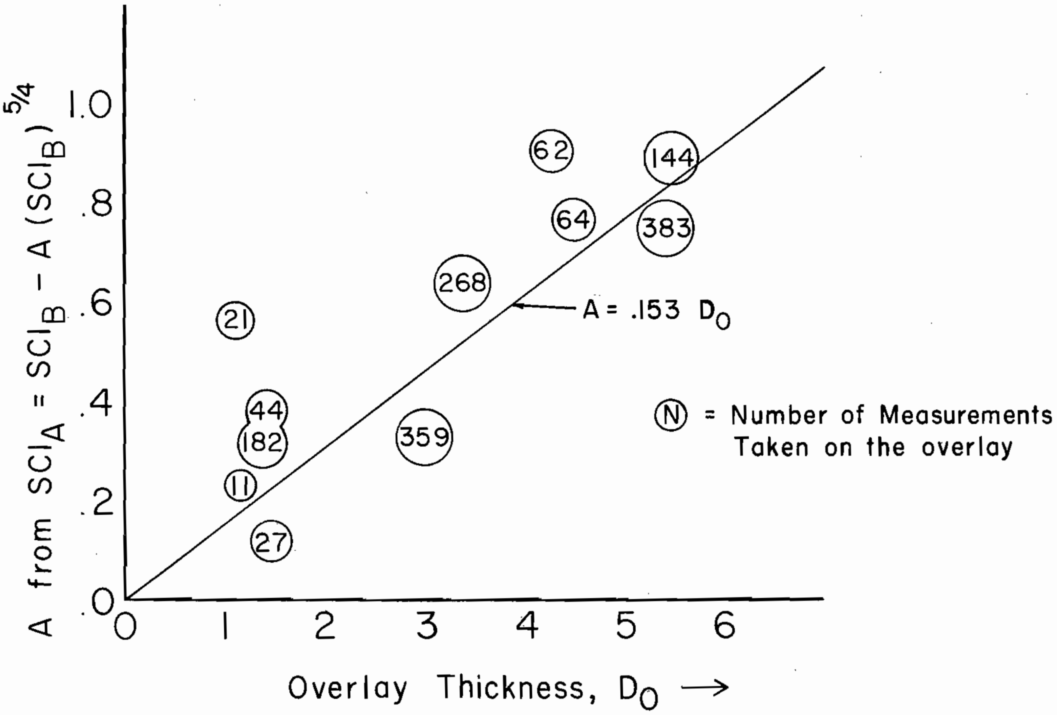


FIGURE B-23 AVERAGE MATERIAL COEFFICIENT

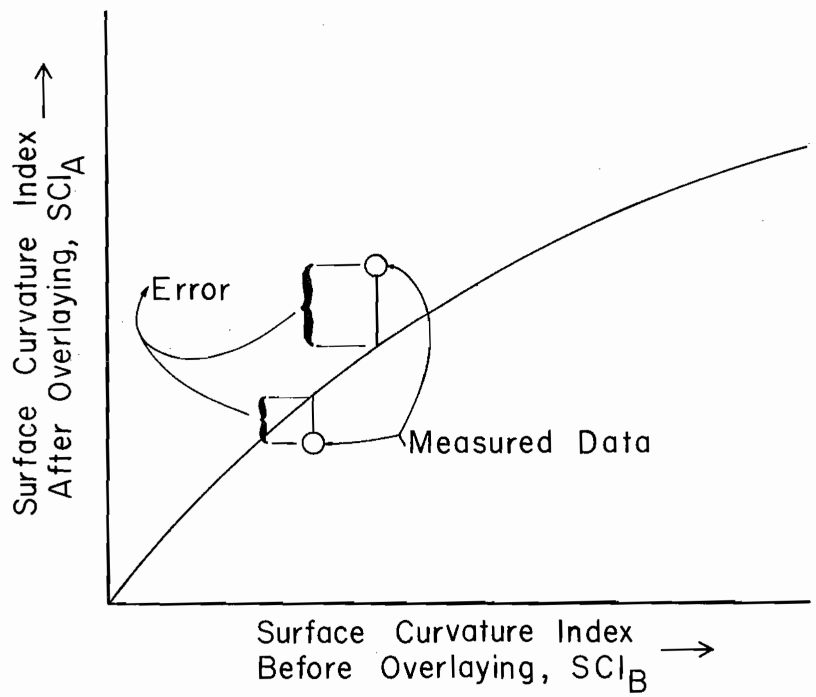


FIGURE B-24 GRAPH ILLUSTRATING ERROR DEFINITION

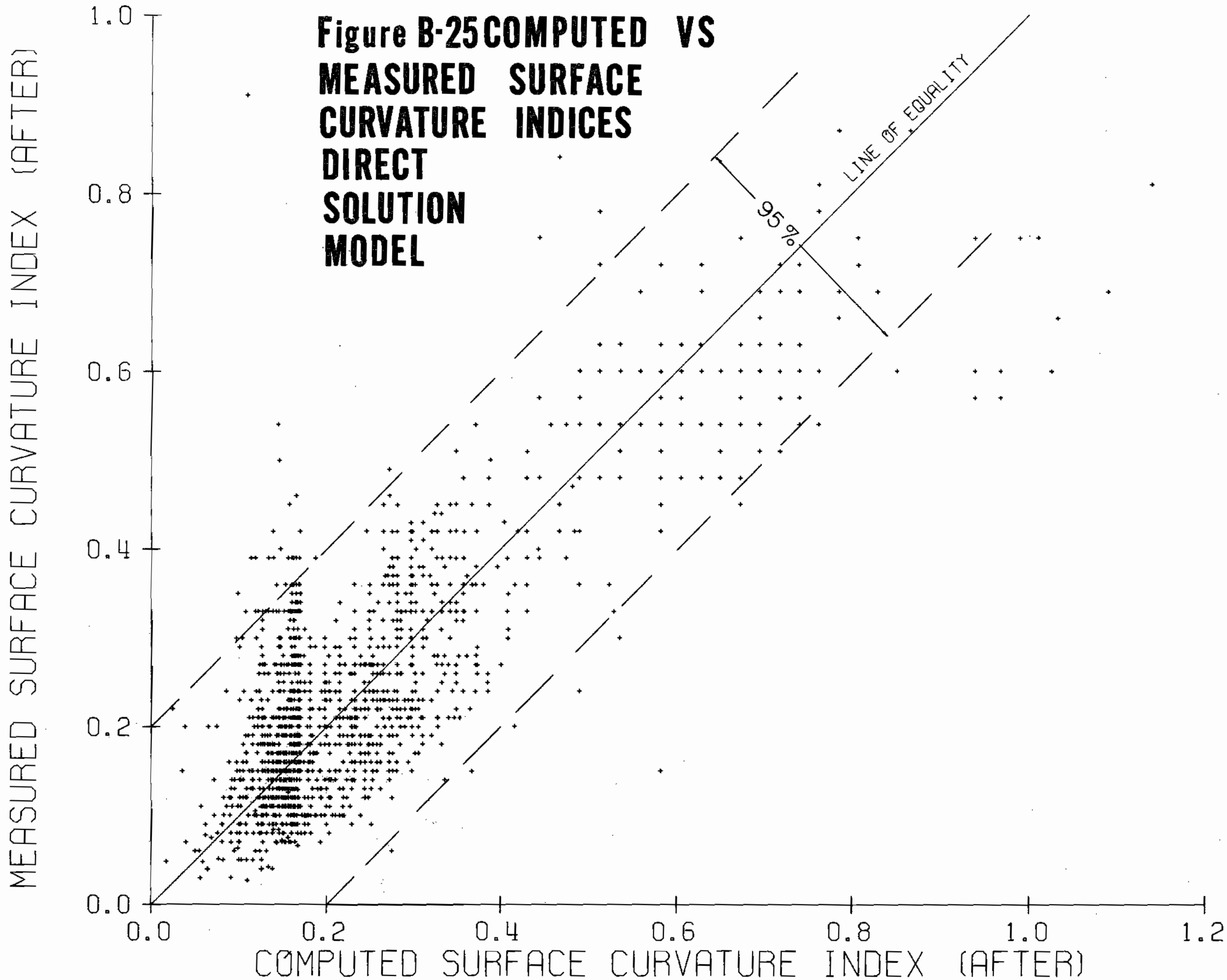


Figure B-25 COMPUTED VS MEASURED SURFACE CURVATURE INDICES DIRECT SOLUTION MODEL

TABLE B-1. SUMMARY OF DATA ANALYSIS

PROJECT DATA				SCRIVNER'S MODEL				DIRECT SOLUTION MODEL			
DISTRICT	HIGHWAY	NUMBER OF POINTS	OVERLAY THICKNESS (INCHES)	INDIVIDUAL PROJECT STIFFNESS COEFFICIENT	STANDARD ERROR IN SCI_A, s.e.p	OVERALL AVERAGE STIFFNESS COEFFICIENT	STANDARD ERROR IN SCI_A, s.e.p	INDIVIDUAL PROJECT MATERIAL COEFFICIENT	STANDARD ERROR IN SCI_A, s.e.p	OVERALL AVERAGE MATERIAL COEFFICIENT COEFFICIENT	STANDARD ERROR IN SCI_A, s.e.p
2	U.S. 377	21	1.14	1.197	±.06	0.956	±.06	.504	±.06	.153	±.06
18	U.S. 80	11	1.18	1.32	±.05	0.956	±.06	.203	±.05	.153	±.06
21	I.H. 35	164	1.36	1.57	±.13	0.956	±.18	.241	±.12	.153	±.14
2	U.S. 67	27	1.45	0.73	±.09	0.956	±.09	.086	±.09	.153	±.09
18	U.S. 287	44	1.45	1.35	±.07	0.956	±.08	.271	±.07	.153	±.08
19	U.S. 67	359	3.00	0.67	±.08	0.956	±.09	.112	±.07	.153	±.07
5	U.S. 62 & 82	268	3.41	0.98	±.06	0.956	±.07	.189	±.06	.153	±.08
14	I.H. 35	62	4.25	1.03	±.03	0.956	±.03	.214	±.03	.153	±.07
23	U.S. 67 & 84	64	4.55	0.80	±.07	0.956	±.07	.170	±.05	.153	±.06
21	I.H. 35	381	5.45	0.84	±.08	0.956	±.09	.138	±.07	.153	±.12
6	U.S. 80	144	5.46	0.93	±.04	0.956	±.04	.165	±.03	.153	±.04
ALL PROJECTS		1545				0.956	±.095			.153	±.094

APPENDIX C

TREATMENT OF UNCERTAINTY IN THE OVERLAY DESIGN SYSTEM

APPENDIX C. TREATMENT OF UNCERTAINTY IN THE OVERLAY DESIGN SUBSYSTEM

An overlay designer is faced with many uncertainties with his design predictions. He has inexact knowledge about all inputs to the design equations coupled with imperfect equations in most cases. Structural engineers treat uncertainty with a safety factor. Such a safety factor has especially been used when lives are endangered if a structural failure occurs. The engineer usually has a high confidence that his design will not fail structurally when safety factors are used.

When life is not endangered, as in pavement design, a simple safety factor against structural failure is frequently inappropriate. Minimization of costs, while satisfying certain performance restraints, is the objective of the overlay design subsystem. The use of a structural safety factor may be in direct conflict with this objective and may result in selection of a design strategy that does not minimize cost. However, the designer that does not treat uncertainty has only a 50% chance that he will satisfy the aforementioned performance requirements.

A third consideration in the dilemma of how to treat uncertainty is the fact that for most variability, the designer has little or no quantitative information about its magnitude.

With the preceeding thoughts in mind, the following procedure has been adopted and is recommended for use in the overlay design subsystem. First, two types of variability are treated quantitatively in the program. They are treated quantitatively because they have a large effect on the answers and because quantitative information is available about them. They are variability of the existing pavement structure along the roadway and the variability in overlay materials that will be used throughout the design analysis period for the roadway.

The variation in the existing pavement structure at the time of overlay is treated in two ways. First, large and consistent changes in SCI along the roadway are handled by breaking the project into design sections as described in Chapter 3 and Appendix D. There is always remaining random variation in SCI within each of these design sections. A measure of this variation, the standard deviation, s, is computed by the program PROFILE ANALYSIS.

Equation (6B) of Appendix B gives an average SCI_A when the average SCI_B is used. The variation in the design section prior to overlay should reflect as some variation after overlaying. Equation (6B) which is used in Overlay-1 is written as below:

(8) $$SCI_A = a + b\ (SCI_B)$$

Where a and b are functions of the thickness and stiffness of the overlay material only.

Figure C-1 shows the relationship assumed for computing the component of variation of SCI after an overlay due to the variation along the roadway before an overlay. The variation in overlay material itself also causes or introduces a component of variation in SCI predicted after overlaying.

It is believed that these two components of variation are independent. That is, the probability of getting a weak batch of overlay material to fall in a weak place is remote.

This component of variation in SCI after an overlay is therefore combined with the overall standard error found in computing the average stiffness coefficient for overlay materials (See Table B-1). The commonly used formula for

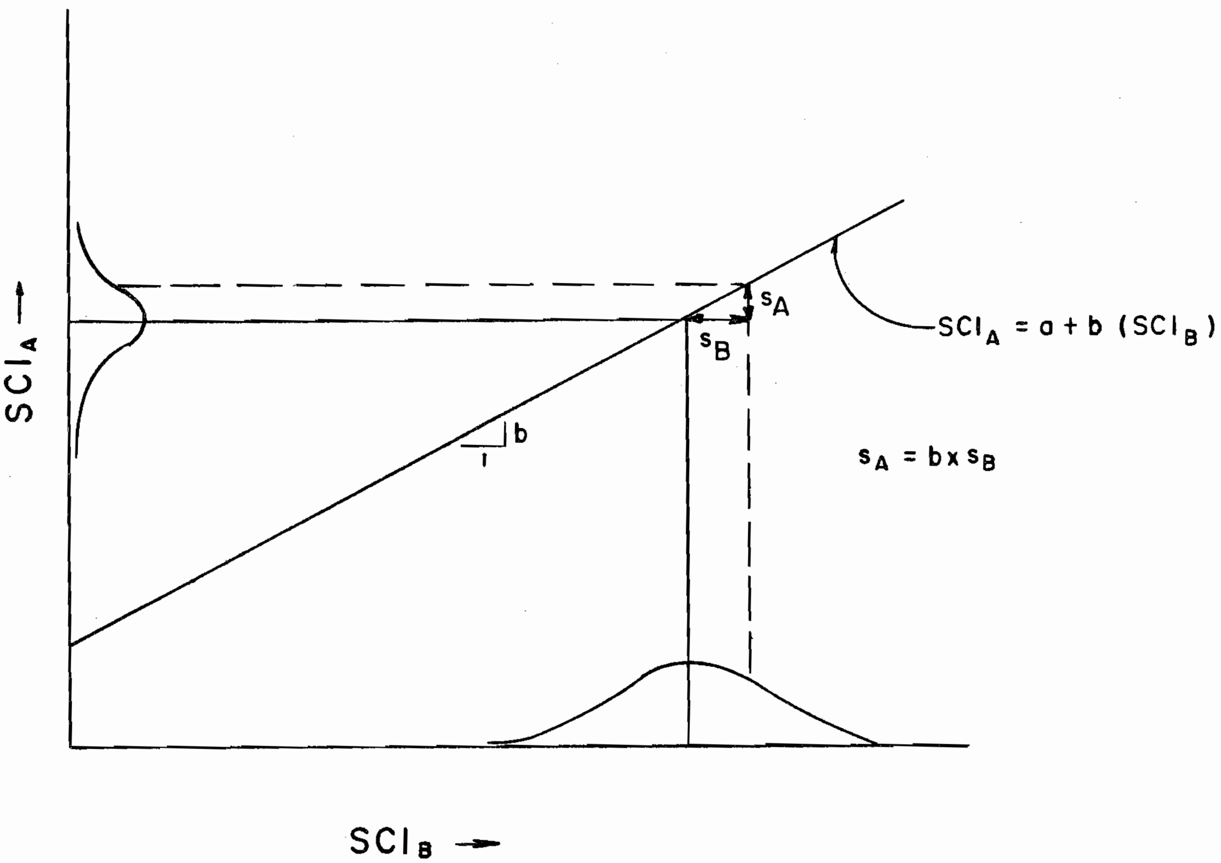


Figure C-1 – Diagram Illustrating Computation of Standard Deviation in SCI$_A$ as a Result of Standard Deviation in SCI$_B$

combining variances (Equation (10) as shown below) is used in the program to compute an overall standard error in estimating SCI after each overlay.

$$(10) \quad S.E. = \pm\sqrt{(s.e._t)^2 + (s)^2}$$

Again, assuming a normal distribution for this overall standard error, S.E., 1.645 times S.E. is added to the computed SCI after overlays if a designer specifies a 95% confidence level and 2.33 times S.E. is added for a 99% confidence level. (Ref. 16 contains a "Table for Areas, Ordinates, and Derivatives of the Normal Curve of Error.")

The specification of a "95% confidence level" should assure a designer of having a SCI after each and every overlay equal to or less than that computed 19 out of 20 times. Likewise a "99% confidence level" should assure him a SCI less than that computed 99 out of a 100 times.

It is suggested that a designer handle all other uncertainties in the only way available to him at this time, that is, by selecting a final design strategy that to him appears correct after having considered all the information available to him.

APPENDIX D

SUPPLEMENT TO THE PAVEMENT DESIGN SYSTEM USER'S MANUAL

APPENDIX D. SUPPLEMENT TO THE PAVEMENT DESIGN SYSTEM USER'S MANUAL

This supplement contains instructions so that the pavement designer may use the THD Pavement Design System to design asphaltic concrete overlays for existing flexible pavement roadways.

Such overlays may be made for a variety of reasons. They include to correct slipperiness, bad appearance, roughness, leaking surfaces, and to strengthen the pavement structure by adding additional thickness of high quality material. Prior to deciding to use the overlay design subsystem described herein, the Pavement Designer should determine why he is placing an overlay. The design system does not consider the skid resistance, appearance, or sealing function of overlays. If these are a consideration, they must be handled independently by the designer in making final design selections. The design subsystem for overlays does attempt to handle or design for the leveling and strengthening functions of overlays. Some of the inputs to the design subsystem are used to design for one problem and some for the other. It is imperative that the designer anticipate which type of problem or combination of the two he is trying to overcome so that he may correctly select some of the key inputs.

The roughness problem exhibits itself in the following ways throughout the state. In areas with swelling clays, pavements are almost continually being leveled; either with heavy maintenance patches or asphaltic concrete overlays. In other areas, particularly those with high water tables along the Coast or in river flood plains, combinations of both swell and settlement create level-up problems. In some places these conditions are compounded by extremely non-uniform conditions that lead to traffic compaction following construction. All of these conditions are handled in the program with the "swelling clay" parameter, b_1, discussed on pages 3.8 through 3.11 of the User's Manual. The same recommendations for selection of b_1 to use in the overlay routine are applicable with the following exception: the overlays designed with this program are usually being placed on an existing roadway where some stabilization or equalization of movement and moisture should have occured. Therefore, it is recommended that for the heavy swell conditions, $b_1 = .06$, be used; for moderate swell conditions, $b_1 = .02$, be used; and for light swell conditions, $b_1 = 0$, be used. The designer should remember that, in general, the larger the b_1 the more frequently the program will recommend overlaying. Additionally, the more frequently the overlays are placed, the thinner they can be.

In addition to b_1, the designer must input the amount of asphaltic concrete to be used for level-up on the initial overlay. On future overlays one inch is placed by the program for level-up. In both cases, this level-up is given no structural value because of its variable thickness.

Strengthening overlays are placed to combat cracking. This cracking may result from fatigue; shrinkage due to drying, temperature changes, or chemical changes; and combinations of these. The cracks themselves are seldom directly the cause of loss of service of the pavement. Frequently, however, intrusion of moisture through them results either in loss of support by weakening of the underlying materials or pumping of the underlying materials. In some locations with some pavement structures, cracks have not resulted in deterioration of the pavement structure.

Cracks frequently reflect through ACP overlays. If the designer desires to try to prevent reflective cracking, he must select a minimum thickness overlay which he thinks will prevent reflective cracking on the particular roadway in question.

A second key input concerned primarily with the strengthening function of an asphaltic concrete overlay is the confidence level the designer selects. Selection of this confidence level can be thought of as selection of a safety factor against traffic deterioration of the overlaid pavement. Though not exactly correct, the designer may also think of the selection of a 95% confidence level as permitting roughly five percent of the roadway to deteriorate below the design minimum serviceability index during each performance period. Likewise, selection of a 99% confidence level would permit one percent to deteriorate below this minimum level. Obviously, the designer should choose a higher confidence level for higher type roads.

The third important input is the minimum time between overlays. This judgement input can have considerable effect on the optimum design strategy indicated by the program. Two different situations can occur. First, if there is no swelling clay present ($b_1 = 0$) and if the designer permits thin overlays, the program generally will recommend a series of these thin overlays - only thick enough to last the minimum time between overlays. If the designer gets an output that recommends many thin overlays placed too frequently, he should re-submit the problem using a longer minimum time between overlays.

The second condition exists where a relatively large swelling clay parameter is input. If the designer has also input too long a minimum time between overlays, the program will either not be able to find an answer or will find overlays that are unreasonably thick. (The program needed to place overlays more frequently in order to combat the swell problem.) If the designer gets an output that indicates either no solutions possible or unreasonably thick solutions, he should re-input the problem relaxing his restriction on minimum time between overlays.

Occasionally a designer may be tempted to use an overlay to solve problems of instability in an existing roadway. This instability, resulting either from too thin a pavement structure on a weak subgrade or weak layers of pavement, rarely can be cured with an economical asphaltic concrete overlay. Such problems should be cured by reconstruction of the pavement structure.

In summary, before using this subroutine, the designer should determine (1) that an asphaltic concrete overlay is a solution to his problem, (2) the type of problem or problems that he is trying to solve and (3) carefully select the key inputs to fit the particular problem at hand.

The Dynaflect is used to make a deflection profile along the roadway. The measurements are recorded on the STIFFNESS COEFFICIENTS Code Sheets. The deflection parameter, SURFACE CURVATURE INDEX (SCI for short), is used to characterize the existing pavement.

From the recorded deflection measurements the SCI may be computed directly by substracting the deflection at Geophone 2 from the deflection at Geophone 1, or the Stiffness Coefficients Code Sheets may be submitted to the Computer Center for processing. The profile of SCI's is then analyzed using the PROFILE ANALYSIS PROGRAM as described below:

> The engineer should plot the SCI profile on graph paper and select sections that appear to have a significant difference in SCI. The point where the section changes is referred to as a "break point". The number of sections selected, the break

points, and the SCI's are coded on a PROFILE ANALYSIS Code Sheet for submission to the Computer Center as is done with the subgrade stiffness coefficients for routine pavement design. The PROFILE ANALYSIS Program makes the necessary calculations to statistically verify the engineer's selection of SCI design section. Each statistically different SCI section is now designed using OVERLAY-1.

The designer must select from the various possible overlay strategies, output from OVERLAY-1, those which he considers the best for the overall project. He should consider very carefully the fact that if two overlays must be made in the future for some sections of the road, at least two will probably have to be made on all sections. That is, he should select design strategies that have similar future work to be done on each SCI section. This is discussed further on page 19 in Chapter 3 of Texas Highway Department Research Report 101-1F, An Asphaltic Concrete Overlay Design Subsystem.

OVERLAY-1. CODING INSTRUCTIONS

The input for this program is accomplished with the aid of five code sheets. Code sheets 1 thru 4 of the FPS-7 PROGRAM should be used for coding problems for OVERLAY-1 (see pp 4.21 thru 4.36 of FLEXIBLE PAVEMENT DESIGNER'S MANUAL) and should be filled in the same way as in FPS-7, with the following exceptions:

Code Sheet 1 delete variable 2.2 NUMBER OF MATERIALS

Code Sheet 2 delete variable 3.2 INITIAL SERVICEABILITY INDEX

Code Sheet 3 delete variables 5.1 MINIMUM TIME TO FIRST OVERLAY and change variable 5.6 to read THE LEVEL-UP REQUIRED ON THE FIRST OVERLAY

Code Sheets 1 thru 4, strike out FPS-7 and write OVERLAY-1

Code Sheet 5 of OVERLAY-1 contains a set of new inputs for this program grouped under the heading OVERLAY AND EXISTING PAVEMENT - CARD NO. 9. The coding instructions for this code sheet, as well as examples of all the code sheets for OVERLAY-1 are included in this Supplement.

OVERLAY-1
(EXPLANATION OF DATA CODING)

OVERLAY AND EXISTING PAVEMENT-CARD NO.9

(Columns 6-10)

9.1 IN PLACE COST/COMP.-C.Y. OF PROPOSED ACP ________ [| | • | |] 6 7 8 9 10

The cost per compacted cubic yard of the proposed ACP is to be inserted in these columns, provision has been made to write up to two decimal places.

(Columns 16-18 of Card #9)

9.2 PROPOSED ACP's SALVAGE VALUE AS % OF ORIGINAL COST ________ [| |] 16 17 18

The estimated salvage value of the material (at the end of the analysis period), as a % of the original cost is to be inserted in these columns to the right side (right justified). Only numbers are to be used.

(Columns 26-30 of Card #9)

9.3 IN-PLACE, VALUE OF EXISTING PAVEMENT/ COMP.-C.Y. ________ [| | • | |] 26 27 28 29 30

The estimated cost per compacted cubic yard of the existing pavement structure is to be inserted in these columns, provision has been made to write-up to two decimal places.

(Columns 36-38 of Card #9)

9.4 EXISTING PAVEMENT'S SALVAGE VALUE AS % OF PRESENT VALUE ________ [| |] 36 37 38

The estimated salvage value of the existing pavement structure (at the end of the analysis period), as a % of the present value is to be inserted in these columns to the right side (right justified). Only numbers are to be used.

(Columns 46-50 of Card #9)

9.5 THE COMPOSITE THICKNESS OF THE EXISTING PAVEMENT (INCHES) [| | • | |] 46 47 48 49 50

The composite thickness of the existing pavement structure is to be inserted in these columns. Provision has been made to write up to two decimal places.

(Columns 56-60 of Card #9)

9.6 AVERAGE SCI OF THE EXISTING PAVEMENT [| • | | |] 56 57 58 59 60

The average Surface Curvature Index of the pavement is to be inserted in these columns. Provision has been made to write up to three decimal places.

(Columns 66-70 of Card #9)

9.7 STANDARD DEVIATION OF SCI [| • | | |] 66 67 68 69 70

The standard deviation associated with the average SCI (VARIABLE 9.6), is inserted in these columns. Provision has been made to write up to three decimal places.

(Columns 78-79 of Card #9)

9.8 DESIGN CONFIDENCE LEVEL (Use either 95 or 99 Percent) [|] 78 79

The desired design confidence level is to be inserted in these columns. (Either 95 or 99 Percent)

FLEXIBLE PAVEMENT DESIGN SYSTEM
OVERLAY-1

9.1 IN PLACE COST/COMP.-C.Y. OF PROPOSED ACP ______ [6 | 7 | 8• | 9 | 10]

9.2 PROPOSED ACP'S SALVAGE VALUE AS % OF ORIGINAL COST ______ [16 | 17 | 18• | 19 | 20]

9.3 IN-PLACE, VALUE OF EXISTING PAVEMENT/COMP. C.Y. ______ [26 | 27 | 28• | 29 | 30]

9.4 EXISTING PAVEMENT'S SALVAGE VALUE AS % OF PRESENT VALUE ______ [36 | 37 | 38• | 39 | 40]

9.5 THE COMPOSITE THICKNESS OF THE EXISTING PAVEMENT (INCHES) ______ [46 | 47 | 48• | 49 | 50]

9.6 AVERAGE SCI OF THE EXISTING PAVEMENT ______ [56 | 57• | 58 | 59 | 60]

9.7 STANDARD DEVIATION OF SCI ______ [66 | 67• | 68 | 69 | 70]

9.8 DESIGN CONFIDENCE LEVEL (USE EITHER 95 OR 99 PERCENT) ______ [78 | 79]

APPENDIX E

PROGRAM LISTINGS AND FLOW CHARTS FOR PROFILE ANALYSIS AND OVERLAY-1

APPENDIX E. PROGRAM LISTINGS AND FLOW CHARTS FOR PROFILE ANALYSIS AND OVERLAY-1

PROFILE ANALYSIS PROGRAM

The computer program "PROFILE ANALYSIS" consists of a main program and two subroutines.

The main program has the following functions.

a) Reads and writes the input data
b) Organizes the data to be used by subroutine ANOVAR
c) Compares the F value calculated by subroutine ANOVAR versus a table value supplied by subroutine FTAB
d) Calculates averages and standard deviations
e) Prints results in a tabulated form

Subroutine ANOVAR performs a statistical analysis of variance on the data supplied by main and calculates F values.

Subroutine FTAB contains a table of F values at the 95% confidence level.

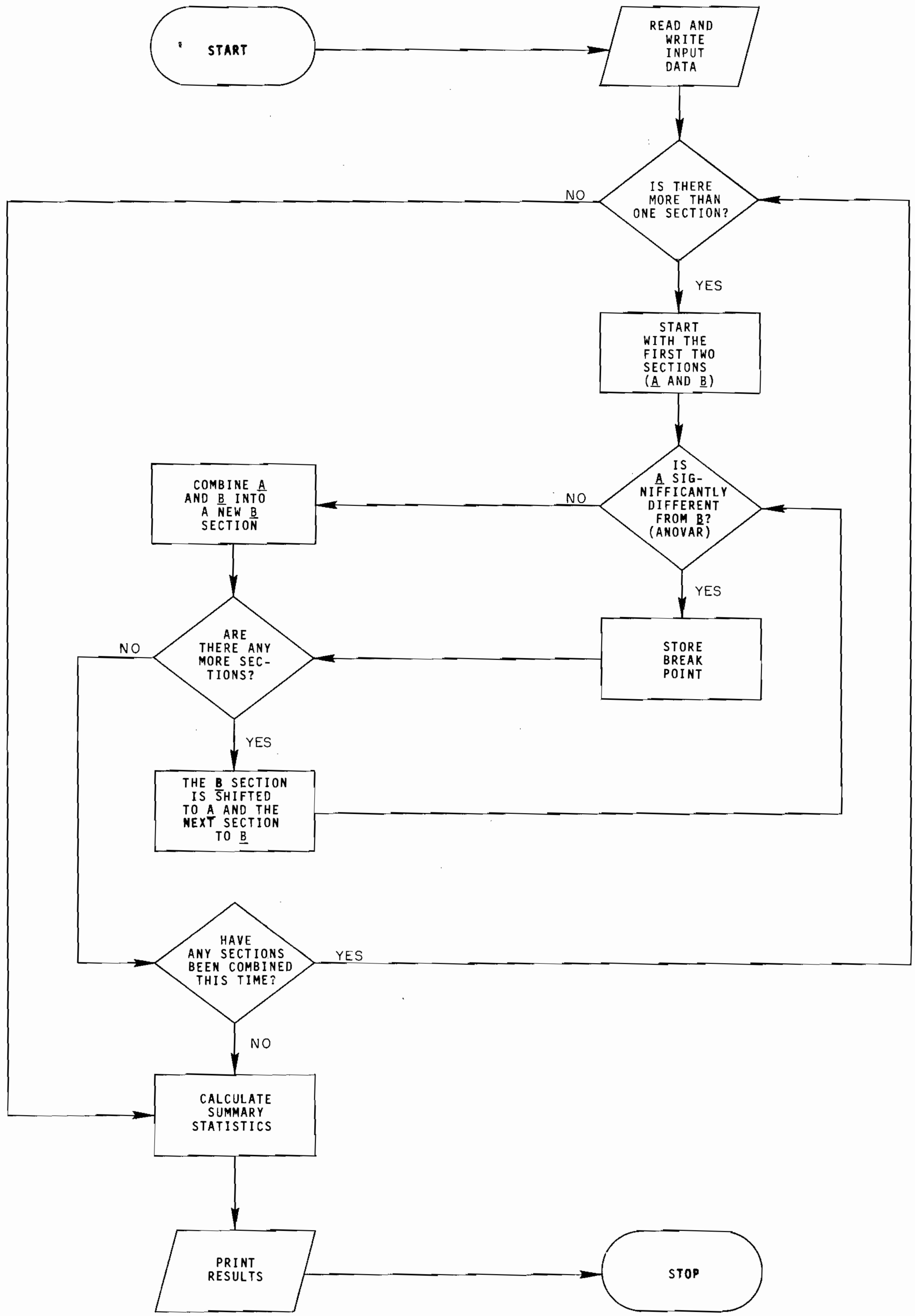


Figure E-1 SUMMARY FLOW CHART FOR PROGRAM PROFILE ANALYSIS

```
      REAL*8 STA
      DIMENSION STA(500),X1(500),NN(21),KOUNT(21),IXDATE(2)
      COMMON X(250,2),NUM(2)
  800 READ(5,1,END=829) IDIST,CO1,CO2,CO3,CO4,ICONT,ISECT,IJOB,HWY1,HWY2
     *,DATE1,DATE2,NOSE
    1 FORMAT(3X,I2,3A4,A2,I4,2I2,A4,A3,2A4,I2)
      PRINT 100
  100 FORMAT (1H1,///)
      PRINT 22
   22 FORMAT(33X,'TEXAS HIGHWAY DEPARTMENT',/)
      PRINT 33, IDIST
   33 FORMAT(31X,'DISTRICT ',I2,' - DESIGN SECTION',/)
      CALL DATE(IXDATE)
      PRINT 34, IXDATE
   34 FORMAT(30X,'THIS PROGRAM WAS RUN - ',2A4,/)
      PRINT 36,HWY1,HWY2
   36 FORMAT(30X,' PROFILE ANALYSIS FOR    ',A4,A3,/)
      PRINT 29
   29 FORMAT(7X,'DIST.       COUNTY       CONT.  SECT.  JOB  HIGHWAY    D
     1ATE   NO. OF SECT.')
      PRINT 57,IDIST,CO1,CO2,CO3,CO4,ICONT,ISECT,IJOB,HWY1,HWY2,DATE1,DA
     *TE2,NOSE
   57 FORMAT( 8X,I2,5X,3A4,A2,2X,I4,4X,I2,4X,I2,2X,A4,A3,3X,2A4,6X,I2,/)
C
C
C     NT    - NUMBER OF DATA POINTS IN PROJECT
C     X1(I) - LIST OF DATA POINTS AS RECORDED ON PROJECT
C
C
      N5 = 0
      KN = 1
      KOUNT(1) = 1
      NN(1) = 1
      K = NOSE + 1
      READ 99, (NN(I), I = 2,K)
   99 FORMAT(20I3)
      N = NN(K)
      DO 10 I = 1,N
   10 READ 3, STA(I),X1(I)
    3 FORMAT(A7,F5.3)
      NT=NN(K)
      PRINT 102
  102 FORMAT(31X,'REFERENCE        STA.        INPUT',/,
     1          31X,' POINTS                   DATA',/)
      NLINE = 0
      DO 190 I = 1,NT
      PRINT 101,I,STA(I),X1(I)
  101 FORMAT(33X,I3,7X,A7,2X,F10.3)
```

```
      NLINE = NLINE + 1
      IF (NLINE.LT. 40) GO TO 190
      PRINT 100
      PRINT 33,IDIST
      PRINT 36, HWY1,HWY2
      PRINT 102
      NLINE = 0
  190 CONTINUE
      PRINT 107,(NN(I),I=1,K)
  107 FORMAT(/,8X,'INPUT BREAK PTS. AT ',13(1X,I3),/,28X,8(1X,I3))
      IF ( N5.EQ.0) GO TO 193
  191 CONTINUE
      PRINT 100
      PRINT 22
      PRINT 33,IDIST
      PRINT 36, HWY1,HWY2
      CALL DATE(IXDATE)
      PRINT 34, IXDATE
      PRINT 29
      PRINT 57,IDIST,C01,C02,C03,C04,ICONT,ISECT,IJOB,HWY1,HWY2,DATE1,DA
     *TE2,NOSE
      PRINT 103
  103 FORMAT(//,21X,'AVERAGE AND STANDARD DEVIATION FOR DATA DIVIDED',/,
     1            21X,' INTO GROUPS OF SIGNIFICANT DIFFERENCE ', //   )
      PRINT 104, (NN(I), I = 1,K)
  104 FORMAT(  8X,'BREAK POINTS AT ',13(1X,I3),/,24X,8(1X,I3),/)
      PRINT 105
  105 FORMAT( 14X,'REF. POINTS        AVERAGE          STANDARD           F
     1            F',/,16X,'LIMITS               OF               DEVIATION
     2  CALC.        TABLE',/,14X,'OF SECTIONS        SECTIONS          OF S
     3ECTIONS                 VALUE',/)
C
  193 CONTINUE
      I = 0
      I = I + 1
      N1 = 1
      N2 = NN(2)
      GO TO 76
   75 N1 = NN(I) + 1
   73 N2=NN(I+1)
   76 CONTINUE
C
C     CALCULATE AVERAGE AND STANDARD DEVIATION
C     SUM - SUM OF GROUP IN ARRAY X1(I)
C     AK - NUMBER OF VARIABLES IN GROUPP (X1(N1 TO N2)
C     SD - STANDARD DEVIATION OF GROUP X1(N1 TO N2)
C
      SUM = 0.
```

```
      IF (N1 .EQ. N2) GO TO 86
      DO 80  J = N1,N2
   80 SUM =  SUM + X1(J)
      AK = N2 - N1 + 1
      AVR = SUM / AK
      SD = 0.
      DO 85  J= N1,N2
      IF ( AVR - X1(J) .EQ. 0.) GO TO 85
      SD = SD + (AVR -X1(J))**2
   85 CONTINUE
      IF ( SD .EQ. 0.) GO TO 90
      SD =  SQRT(SD /(AK -1))
      IF(N2.EQ.NT) GO TO 93
      GO TO 90
   86 AVR = X1(N2)
       SD = 0
   90 CONTINUE
C
C
C     OBTAIN F(CALCULATED ) AND F1(TABLE VALUE) FOR ANALYSIS
C       OF VARIANCE FOR X1(N1-N2) COMPARED WITH X1(N3-N4)
C
C
      L = 0
      DO 91 J = N1, N2
       L = L+1
   91 X(L,1) = X1(J)
      N3 = N2 + 1
      IF (N3 .GT. NN(K) ) GO TO 93
      N4 = NN(I +2)
      LL = 0
      DO 92 J = N3, N4
      LL = LL + 1
   92 X(LL,2) = X1(J)
      NUM(1) = L
      NUM(2) = LL
      CALL FTAB (F1)
      CALL ANOVAR (F)
      IF(F-F1) 95,95,94
   93 F = 0.
      F1 = 0.
C
   94 CONTINUE
      IF(N5.EQ.0) GO TO 96
      PRINT 106, N1, N2, AVR, SD, F, F1
  106 FORMAT(14X,I3,'  TO ',I3,3X,F10.3,8X,F10.3,5X,F7.3,6X,F7.3)
   96 CONTINUE
      KN = KN + 1
```

```
      KOUNT(KN) = N2
C
   95 CONTINUE
      IF (N2.EQ.NT) GO TO 200
      I = I + 1
      IF(F1.GT.F) GO TO 73
      GO TO 75
  200 CONTINUE
      NN(1) = KOUNT(1)
      DO 201 J = 2,KN
  201 NN(J) = KOUNT(J)
      KN1 = KN
      IF ( N5.EQ.1) GO TO 800
      IF(KN1.EQ.K)  N5=1
      K = KN
      NOSE = KN- 1
      KN = 1
      IF(N5)829,193,191
  829 CONTINUE
      STOP
      END
```

```
      SUBROUTINE FTAB (F1)
      COMMON X(250,2),NUM(2)
      DIMENSION FT(30)
C
C
      DATA FT /161.0,18.5,10.1,7.71,6.61,
     1            5.99,5.59,5.32,5.12,4.96,
     2            4.84,4.75,4.67,4.60,4.54,
     3            4.49,4.45,4.41,4.38,4.35,
     4            4.32,4.30,4.28,4.26,4.24,
     5            4.17,4.08,4.00,3.92,3.84/
C
C
      ID = NUM(1) + NUM(2) - 2
      A = ID
      IF (ID - 25) 40, 40, 15
   15 IF (ID - 30) 45, 45, 20
   20 IF (ID - 40) 50, 50, 25
   25 IF (ID - 60) 55, 55, 30
   30 IF (ID -120) 60, 60, 35
   35 F1 = FT(29)
      GO TO 65
   40 F1 = FT(ID)
      GO TO 65
   45 F1 = FT(25) +((A -25.)/5.)* (FT(26) - FT(25))
      GO TO 65
   50 F1 = FT(26) +((A -30.)/10.)* (FT(27) - FT(26))
      GO TO 65
   55 F1 = FT(27) +((A -40.)/20.)* (FT(28) - FT(27))
      GO TO 65
   60 F1 = FT(28) +((A -60.)/60.)* (FT(29) - FT(28))
   65 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE  ANOVAR(F)
      COMMON X(250,2),NUM(2)
      K = 0
      M=0
      SUM=0.
      SS1=0.
      SST1=0.
      DO 200 J=1,2
      SUM1=0.0
      N=0
      LL = NUM(J)
      DO 100 I=1,LL
      IF(X(I,J).EQ.0) GO TO 99
      SUM1= SUM1 + X(I,J)
      SS1 = SS1 + X(I,J)**2
   99 N=N+1
      M=M+1
  100 CONTINUE
      K=K+1
      IF ( SUM1 .EQ. 0.) GO TO 200
      SST1=SST1+((SUM1**2)/N)
      SUM=SUM+SUM1
  200 CONTINUE
      IF (SUM .EQ. 0.) GO TO 201
      C=(SUM**2)/M
      SS=SS1-C
      SST=SST1-C
      SSE=SS-SST
      IF ( SST.EQ.0.0 )  GO TO 201
      IF ( SSE.EQ.0.0 )  GO TO 201
      ITDF=M-1
      IDFBM=K-1
      IDFWS=M-K
      F=(SST*IDFWS)/(SSE*IDFBM)
      IF (F .GT. 0.) GO TO 202
  201 F = 0.
  202 CONTINUE
      RETURN
      END
```

OVERLAY-1 PROGRAM

The computer program "OVERLAY-1" consists of the main program and 8 subroutines. Basically, "OVERLAY-1" follows the logic of FPS-7, except an initial design is not calculated. The program begins by placing an overlay on the in-place pavement.

The main program reads the input data, checks the input for coding errors and writes out a summary table of the cheapest overlay schemes in order of increasing total cost.

The subroutine OUTPUT writes out a complete listing of the input data. The subroutine OVERLAY calculates the SCI's, the overlay schemes, and the overlay costs.

The subroutine CHECK eliminates all overlay schemes that are not true alternates.

The subroutine STORE sorts the cheapest overlay schemes into ascending order and saves a set of the cheapest schemes. This set of cheapest schemes will be printed by the main program at the end of the calculations.

The subroutine TIME is an iterative process which uses the serviceability loss equation and the traffic equation to determine the number of equivalent 18-kip applications and the length of time (in years) before the serviceability index has been reduced to its minimum acceptable value.

The subroutine USER determines the user cost during construction of an overlay by using one of five possible detour models and three of the following tables (depending on whether the structure is rural or urban).

a) Cost of slowing down in a rural area
b) Cost of slowing down in an urban area
c) Cost of operating at a reduced speed
d) Cost of delay

The subroutine PWRM determines the present worth per square yard of routine maintenance (increases linearly) which is performed during the i^{th} overlay period.

The subroutine SEAL determines the present worth per square yard of all seal coats which will be performed during the analysis period.

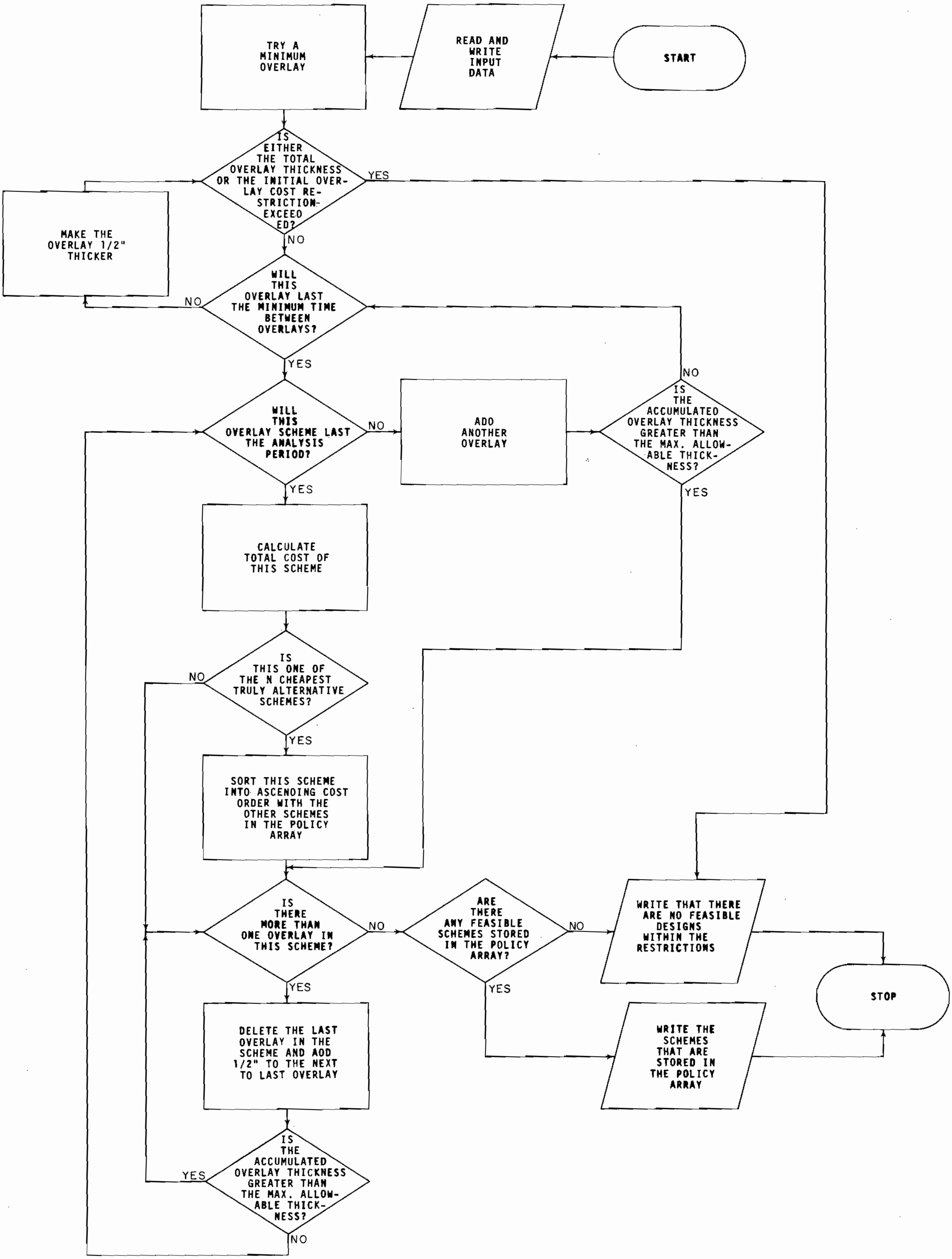


Figure E-2 SUMMARY FLOW CHART FOR PROGRAM OVERLAY 1

```
      COMMON COSTI,COST2,FLU,TT(20),ALPHA,P1,P2,XNC,RO,RC,CL,NM,P2P,BONE
     1,CMAX,DOVER(5),XTBO,ACPR,ACCD,PROP,HPD,ITYPE,RATE,OVMIN,OVMAX,PPO2
     2,PPN2,DDO2,DDN2,AAS,ASO,ASN,C1,C2,MCDEL,XLSO,XLSN,XLW,SCC,TTSC,
     3TBSC,CM1,CM2,SC,SCIB1,PSVGE1,PSVGE2,NLFC,NLRN,ITEST,NMB,AN1(32),
     4DATE(2),DIST,HWY(3),CONT,SECT,PIE,CCM(6),SCIB(20),DIP,IIIK,XLSD,
     5SIGMAB(20),T2,SIGMB1
      DIMENSION IDUMMY(24),STAR(33),CCMMTS(20),POLICY(50,24)
      DATA BLANK/1H /                                                   00001300
      DATA STAR/32*4H****,2H**/                                         00001400
C
C*********************************************************************000015CC
C*********************************************************************
C  READ IN THE PROGRAM AND PROBLEM IDENTIFICATION (CARD NO. 1).
C
   14 READ(5,780,END=872) (DATE(I),I=1,2),DIST,(HWY(I),I=1,3),CONT,SECT,THD 18CC
     1PIE,(COM(I),I=1,6)
  780 FORMAT(2A4,A2,2A4,A3,A4,A2,A4,6A4)
C*********************************************************************
C  READ MISCELLANEOUS INPUTS (CARD NO. 2).
C
      READ(5,790) NMB,CL,XLW
  790 FORMAT(I10,10X,2F10.2)
C  NMB-THE NUMBER OF OUTPUT PAGES FOR THE SUMMARY TABLE(8 DESIGNS/PAGE).000022CC
C  CL-THE LENGTH OF THE ANALYSIS PERIOD IN YEARS.                       000024CC
C  XLW-THE WIDTH OF EACH LANE(FEET).                                    000025CC
C*********************************************************************000028CC
C  READ IN THE PERFORMANCE VARIABLES (CARD NO. 3).
C
      READ(5,793) ALPHA,P1,P2,P2P,BONE
  793 FORMAT(F10.2,10X,3F10.2,F10.4)
C  ALPHA-THE DISTRICT OR REGIONAL TEMPERATURE CONSTANT.                 000032CC
C  P1-THE BEGINNING SERVICEABILITY INDEX OF THE PAVEMENT                000034CC
C     AFTER AN OVERLAY.                                                 000035CC
C  P2-THE MINIMUM ALLOWED VALUE OF THE SERVICEABILITY INDEX             000036CC
C     (POINT AT WHICH AN OVERLAY MUST BE APPLIED).                      000037CC
C  P2P-NON-TRAFFIC DETERIORATION PARAMETER-THE LOWER BOUND ON THE       000038CC
C       SERVICEABILITY INDEX WHICH WOULD BE ACHIEVED IN INFINITE        000039CC
C       TIME WITH NO TRAFFIC.                                           000040CC
C  BONE-NON-TRAFFIC DETERIORATION PARAMETER-THE CONSTANT WHICH          000041CC
C        DETERMINES THE EFFECT THAT SWELLING CLAY WILL HAVE UPON THE    000042CC
C        SERVICEABILITY LOSS OF THE PAVEMENT DURING A FINITE            000043CC
C        TIME INTERVAL.                                                 00004400
C*********************************************************************000045CC
C  READ IN THE TRAFFIC VARIABLES (CARD NO. 4).
C
      READ(5,795) RO,RC,XNC,PROP,ITYPE                                  000047CC
  795 FORMAT(3F10.0,F10.2,I10)                                          000048CC
C  RO-THE ONE-DIRECTION AVERAGE DAILY TRAFFIC AT THE BEGINNING OF THE   000049CC
```

```
C      ANALYSIS PERIOD.
C   RC-THE ONE-DIRECTION AVERAGE DAILY TRAFFIC AT THE END OF THE
C      ANALYSIS PERIOD.
C   XNC-THE ONE-DIRECTION ACCUMULATED NUMBER OF EQUIVALENT 18-KIP AXLES
C        DURING THE ANALYSIS PERIOD.
C   PROP-THE PERCENT OF ADT WHICH WILL PASS THROUGH THE OVERLAY ZONE
C          DURING EACH HOUR WHILE OVERLAYING TAKES PLACE(NORMALLY ABOUT
C          6 PERCENT FOR RURAL AREAS AND 5.5 PERCENT FOR URBAN AREAS).
C   ITYPE-IS A CODE FOR THE TYPE OF ROAD UNDER CONSIDERATION.
C            ITYPE=1 DESIGNATES A RURAL ROAD AND ITYPE=2 DESIGNATES AN
C            URBAN ROAD.
C***********************************************************************
C   READ IN THE VALUES OF THE RESTRICTION VARIABLES (CARD NO. 5).
C
        READ(5,798) XTBO,TTSC,TBSC,CMAX,FLU,OVMIN,OVMAX
  798 FORMAT(10X,3F10.1,4F10.2)
C   XTBO-THE MINIMUM ALLOWED TIME BETWEEN OVERLAYS PERMITTED.
C   TTSC-THE MINIMUM TIME TO THE FIRST SEAL COAT AFTER INITIAL
C          OR OVERLAY CONSTRUCTION.
C   TBSC-THE MINIMUM TIME BETWEEN SEAL COATS.
C   CMAX-THE MAXIMUM FUNDS AVAILABLE PER SQ. YD. FOR FIRST OVERLAY
C   FLU-THE LEVEL UP FOR THE FIRST OVERLAY(INCHES).
C   OVMIN-THE MINIMUM THICKNESS OF AN INDIVIDUAL OVERLAY.
C   OVMAX-THE ACCUMULATED MAXIMUM THICKNESS OF ALL OVERLAYS.
C***********************************************************************
C   READ IN OVERLAY PARAMETERS ASSOCIATED WITH OVERLAY
C   AND ROAD GEOMETRICS (CARD NO. 6).
C
        READ(5,800)  ACPR,ACCD,XLSO,XLSN,XLSD,HPD,NLRO,NLRN
  800 FORMAT(6F10.2,2I10)
C   ACPR-ASPHALTIC CONCRETE PRODUCTION RATE(TONS PER HOUR)
C   ACCD-ASPHALTIC CONCRETE COMPACTED DENSITY(TONS/COMPACTED CY)
C   XLSO-THE DISTANCE,MEASURED ALONG THE C.L.,OVER WHICH TRAFFIC IS
C          SLOWED IN THE OVERLAY DIRECTION.
C   XLSN-THE DISTANCE,MEASURED ALONG THE C.L.,OVER WHICH TRAFFIC IS
C          SLOWED IN THE NON-OVERLAY DIRECTION.
C   XLSD-THE DISTANCE ,MEASURED ALONG THE DETOUR,AROUND THE OVERLAY ZONE.
C   HPD-THE NUMBER OF HOURS PER DAY THAT OVERLAY CONSTRUCTION TAKES PLACE
C   THE PRODUCT OF PROP*HPD SHOULD NOT BE GREATER THAN 1.  IF THE STRIP
C   IS UNDER CONSTRUCTION FOR 24 HOURS EACH DAY, PROP*HPD = 1.
C   NLRO-THE NUMBER OF OPEN LANES IN THE OVERLAY DIRECTION IN THE
C          RESTRICTED ZONE.
C   NLRN-THE NUMBER OF OPEN LANES IN THE NON-OVERLAY DIRECTION IN THE
C          RESTRICTED ZONE.
C***********************************************************************
C   READ IN OTHER OVERLAY PARAMETERS ASSOCIATED WITH TRAFFIC
C   SPEEDS AND DELAYS (CARD NO. 7).
C
```

```
      READ(5,805) PPO2,PPN2,DDO2,DDN2,AAS,ASO,ASN,MODEL                 00010100
  805 FORMAT(2F10.2,2F10.4,3F10.2,I10)                                  00010200
C  PPO2-THE PERCENT OF VEHICLES THAT WILL BE STOPPED IN THE OVERLAY
C       DIRECTION BECAUSE OF MOVEMENT OF PERSONNEL OR EQUIPMENT.        00010400
C  PPN2-THE PERCENT OF VEHICLES THAT WILL BE STOPPED IN THE
C       NON-OVERLAY DIRECTION BECAUSE OF PERSONNEL OR EQUIPMENT.        00010600
C  DDO2-THE AVERAGE DELAY PER VEHICLE STOPPED IN THE OVERLAY DIRECTION
C       BECAUSE OF MOVEMENT OF OVERLAY PERSONNEL AND EQUIPMENT IN THE   00010800
C       RESTRICTED ZONE.                                                00010900
C  DDN2-THE AVERAGE DELAY PER VEHICLE STOPPED IN THE NON-OVERLAY
C       DIRECTION BECAUSE OF MOVEMENT OF PERSONNEL OR EQUIPMENT.        00011100
C  AAS-THE AVERAGE APPROACH SPEED TO THE OVERLAY AREA,ASSUMED TO BE     00011200
C       THE SAME FOR BOTH DIRECTIONS.                                   00011300
C  ASO-THE AVERAGE SPEED THROUGH THE OVERLAY AREA, IN THE OVERLAY       00011400
C       DIRECTION.                                                      00011500
C  ASN-THE AVERAGE SPEED THROUGH THE OVERLAY AREA, IN THE               00011600
C       NON-OVERLAY DIRECTION.                                          00011700
C  MODEL-THE MODEL NUMBER WHICH DESCRIBES THE TRAFFIC SITUATION.        00011800
C***********************************************************************00011900
C  READ COST CONSIDERATIONS (CARD NO. 8).
C
      READ(5,807)  CM1,CM2,SC,RATE                                      00012100
  807 FORMAT(4F10.2)                                                    00012200
C  CM1-ANNUAL ROUTINE MAINTENANCE COST PER LANE MILE FOR THE FIRST YEAR 00012300
C     AFTER CONSTRUCTION OR AN OVERLAY.                                 00012400
C  CM2-ANNUAL INCREMENTAL INCREASE IN ROUTINE MAINTENANCE COST PER      00012500
C     LANE MILE.                                                        00012600
C   SC -THE COST OF A SEAL COAT PER LANE MILE.                          00012700
C  RATE-THE INTEREST RATE OR TIME VALUE OF MONEY(PERCENT).              00012800
C***********************************************************************
C  READ MATERIAL PARAMETERS (CARD NO. 9).
C
      READ(5,903) COST1,PSVGE1,COST2,PSVGE2,DIP,SCIB1,SIGMB1,CLEVEL
  903 FORMAT(5F10.2,2F10.3,F10.1)
C  COST1-THE COST OF THE PROPOSED ACP.
C  PSVGE1-SALVAGE VALUE OF PROPOSED ACP AT END OF ANALYSIS PERIOD.
C  COST2-THE IN-PLACE PRESENT VALUE OF EXISTING PAVEMENT(DOLLARS/CY).
C  PSVGE2-SALVAGE VALUE OF PRESENT STRUCTURE AT END OF ANALYSIS PERIOD.
C  DIP-THE COMPOSITE THICKNESS OF THE CURRENT PAVEMENT.
C   SCIB1-THE AVERAGE SCI OF THE PRESENT PAVEMENT.
C   SIGMBI-THE STANDARD DEVIATION OF SCI.
C  CLEVEL-THE DESIGN CONFIDENCE LEVEL (USE EITHER 95 OR 99%).
C
C***********************************************************************
C***********************************************************************
      IF( (PROP*HPD) .GT. 100.)  WRITE(6,803)                           00009400
  803 FORMAT(1H1,5X,13H***WARNING***/10X,47HAS INPUT,THE PRODUCT OF HPD 00009500
     1AND PROP IS GREATER/10X,39HTHAN 100.0 PERCENT -- PROGRAM CONTINUES00009600
```

```
      2)                                                                 00009700
       T2=0.
       IF(CLEVEL.EQ.95.) T2=1.645
       IF(CLEVEL.EQ.99.) T2=2.33
       IF(T2.EQ.0.) CLEVEL=50.
       CALL OUTPUT(CLEVEL)
       CALL ERRORS(NLRN,MODEL,NLRC,NMB,XLW,ITYPE,AAS,ASO,ASN,TBSC,CL,
     1      XTBO,RO,RC,ALPHA,P1,P2,P2P,XNC,IERROR,DATE,DIST,HWY,CONT,
     2      SECT,PIE,COM,ACPR,PRCP,HPD)
       IF(IERROR.EQ.1) GO TO 14
       KNTOL = 0                                                         00017200
       C1 =CM1*9.0/(5280. * XLW )                                        00012900
       C2 =CM2*9.0/(5280. * XLW )                                        00013000
       SCC = SC *9.0/(5280. * XLW)                                       00013100
       DO 732 IK=1,50
       DO 731 JK=1,24
       POLICY(IK,JK)=0.0
   731 CONTINUE
   732 CONTINUE
       NMBEST = NMB * 8                                                  00021700
       DOVER(1)=0.
       DOVER(2)=DIP
       RATE = RATE/100.                                                  00057200
       COST1=COST1/36.
       COST2=COST2/36.
       CALL OVRLAY(SS,KNTOL,POLICY,NMBEST,LLL,ERROR2)
C                                                                        00027500
C***********************************************************************
C***********************************************************************
C  THE REMAINDER OF THIS PROGRAM WRITES OUT THE SUMMARY TABLE.
C                                                                        00027700
   298 L = 1                                                             00027800
       LL = 8                                                            00027900
       NMBT = 20                                                         00028000
       DO 207  JJ = 1, NMB                                               00028100
       IF( L .GT. KNTOL )  GO TO 207                                     00028200
       IF( LL .GT. KNTOL )  LL = KNTOL                                   00028300
       WRITE(6,953)
   953 FORMAT(1H1,///33X,16HOVERLAY-1 OUTPUT)
       WRITE(6,904) SCIB1,CLEVEL
   904 FORMAT(/12X,13HAVERAGE SCI =,F6.3,18X,18HCONFIDENCE LEVEL =,F5.1,1
      1H%)
       WRITE(6,950)
   950 FORMAT(/6X,64HDATE    DIST.    HIGHWAY     CONT.  SECT.  IPE
     1     COMMENTS,13X,7HI--TRIM)
       WRITE(6,875) (DATE(I),I=1,2),DIST,(HWY(I),I=1,3),CONT,SECT,PIE,(CO
     *M(I),I=1,6)
   875 FORMAT (4X,2A4,3X,A2,4X,2A4,A3,2X,A4,4X,A2,3X,A4,6X,6A4)
```

```
      WRITE (6,830)  (I, I = L,LL)                                          000286CC
  830 FORMAT(/25X,35HSUMMARY OF THE BEST CVERLAY SCHEMES/26X,
     1   33HIN ORDER OF INCREASING TCTAL CCST//21X,8I7)
  127 WRITE (6,831)  (STAR(I) , I=1,NMBT)                                   000303CC
  831 FORMAT(2X,32A4,A2)                                                    000304CC
      WRITE(6,832)(POLICY(10,I),I=L,LL)
  832 FORMAT(2X,15HINITIAL OVERLAY/5X,17HCCNSTRUCTION COST,1X,8F7.2)
      WRITE(6,833)(POLICY(2,I),I=L,LL)
  833 FORMAT(5X,9HUSER COST,9X,8F7.2)
      WRITE (6,836)  (POLICY(3,I), I = L,LL)                                000315CC
  836 FORMAT(2X,17HFUTURE OVERLAY(S)/5X,17HCCNSTRUCTION COST,1X,8F7.2)
      WRITE (6,838)  (POLICY(4,I),  I = L,LL)                               000317CC
  838 FORMAT(5X,9HUSER COST,9X,8F7.2)
      WRITE (6,840)  (POLICY(5,I), I = L, LL)                               000319CC
  840 FORMAT(2X,14HSEAL COAT COST,7X,8F7.2)
      WRITE (6,842)  (POLICY(6,I), I = L,LL)                                00032100
  842 FORMAT(2X,19HROUTINE MAINT. COST,2X,8F7.2)
      WRITE (6,844) (POLICY(7,I), I = L,LL)                                 00032300
  844 FORMAT(2X,13HSALVAGE VALUE,8X,8F7.2)
      WRITE (6,831)  (STAR(I) , I=1,NMBT)                                   000325CC
      WRITE (6,831)  (STAR(I) , I=1,NMBT)                                   000326CC
      WRITE (6,846)  (POLICY(8,I), I = L, LL)                               000327CC
  846 FORMAT(2X,10HTOTAL COST,11X,8F7.2)
      WRITE (6,831)  (STAR(I) , I=1,NMBT)                                   000329CC
      WRITE (6,831)  (STAR(I) , I=1,NMBT)                                   000330CC
      DO 135 I = L,LL                                                       000339CC
  135 IDUMMY(I) = POLICY(20,I)                                              000340CC
      WRITE (6,852)  (IDUMMY(I),  I=L,LL)                                   00034300
  852 FORMAT(2X,18HNO.OF PERF.PERIODS,1X,8I7)
      WRITE (6,831)  (STAR(I), I= 1,NMBT)                                   00034500
      WRITE(6,853)                                                          000346CC
  853 FORMAT( 2X,18HPERF. TIME (YEARS) )                                    000347CC
      DO 150 I=1,10                                                         000348CC
      NKOUNT = C                                                            000349CC
      DO 145 K = L,LL                                                       00035000
      IF( IDUMMY(K) .GE. I )  GO TO 140                                     0003510C
      POLICY(I+20,K) = 0.0                                                  000352CC
      GO TO 145                                                             00035300
  140 NKOUNT = NKOUNT + 1                                                   00035400
  145 CONTINUE                                                              0003550C
      IF( NKOUNT .EQ. 0 )  GO TO 155                                        00035600
      WRITE (6,854)  I, (POLICY(I+20, J), J= L,LL)                          000357CC
  854 FORMAT(7X,2HT(,I1,2H) ,10X,8F7.1)
  150 CONTINUE                                                              000359CC
  155 WRITE (6,831)  (STAR(I) , I=1,NMBT)                                   000360CC
      WRITE(6,848)(POLICY(9,I),I=L,LL)
  848 FORMAT(2X,20H1ST LEVEL-UP(INCHES),8F7.1)
      WRITE(6,849)(POLICY(1,I),I=L,LL)
```

```
  849 FORMAT(2X,18HFUTURE LEVEL-UP(S),2X,8F7.1)
      WRITE(6,831)(STAR(I),I=1,NMBT)
      WRITE(6,856)                                                      00036100
  856 FORMAT(2X,20HOVERLAY POLICY(INCH)/2X,20H(INCLUDING LEVEL-UP))
      DO 170 I=1,10
      NKOUNT = 0                                                        00036400
      DO 165 K = L,LL                                                   00036500
      IF(IDUMMY(K).GE.I) GO TO 160
      POLICY(I+30,K) = 0.0                                              00036700
      GO TO 165                                                         00036800
  160 NKOUNT = NKOUNT + 1                                               00036900
C  ADD LEVEL-UP TO THE OVERLAYS
      IF(I.EQ.1) GO TO 87
      POLICY(I+30,K)=POLICY(I+30,K)+1.0
      GO TO 165
   87 POLICY(I+30,K)=POLICY(I+30,K)+FLU
  165 CONTINUE                                                          00037000
      IF(NKOUNT.EQ.0) GO TO 175
      WRITE (6,858)  I, (POLICY(I+30,J), J= L,LL)                       00037200
  858 FORMAT( 7X,2HO( ,I1,2H) ,10X,8F7.1)
  170 CONTINUE                                                          00037400
  175 DO 180 I = L,LL                                                   00037500
  180 IDUMMY(I) = POLICY(40,I)                                          00037600
      WRITE(6,831)(STAR(I),I=1,NMBT)
      WRITE (6,860)  (IDUMMY(I), I = L,LL)                              00037800
  860 FORMAT(2X,20HNUMBER OF SEAL COATS,3X,I3,7(4X,I3))
      WRITE (6,831)  (STAR(I) , I=1,NMBT)                               00038000
      WRITE(6,862)                                                      00038100
  862 FORMAT( 2X,18HSEAL COAT SCHEDULE/5X, 7H(YEARS) )                  00038200
      DO 195 I=1,8                                                      00038300
      NKOUNT = 0                                                        00038400
      DO 190 K = L,LL                                                   00038500
      IF( IDUMMY(K) .GE. I )  GO TO 185                                 00038600
      POLICY(I+40,K) = 0.0                                              00038700
      GO TO 190                                                         00038800
  185 NKOUNT = NKOUNT + 1                                               00038900
  190 CONTINUE                                                          00039000
      IF( NKOUNT .EQ. 0 )  GO TO 200                                    00039100
      WRITE (6,864)  I, (POLICY(I+40,J), J=L,LL)                        00039200
  864 FORMAT(5X,3HSC(,I1,2H) ,11X,8F7.1)
  195 CONTINUE                                                          00039400
  200 CONTINUE                                                          00039500
      WRITE (6,831)  (STAR(I) , I=1,NMBT)                               00039600
      L = L + 8                                                         00039700
      LL = LL + 8                                                       00039800
  207 CONTINUE                                                          00039900
      IF(LLL.EQ.1.AND.KNTOL.EQ.0) WRITE(6,904) SCIB1,CLEVEL
      IF(IIIK.EQ.1.AND.KNTOL.EQ.0) WRITE(6,904) SCIB1,CLEVEL
```

```
      WRITE(6,866) KNTOL                                                000400CC
  866 FORMAT(//10X,59HTHE TOTAL NUMBER OF FEASIBLE OVERLAY SCHEMES CONSI
     1DERED WAS,I10/)
      KNTOL2=KNTOL+1
      IF(IIIK.EQ.1.AND.KNTOL.EQ.0) WRITE(6,777) KNTOL2
  777 FORMAT(/3X,55HTHE COST OF THE FIRST OVERLAY FOR OVERLAY SCHEME NUM
     1BER,I3,20H IS GREATER THAN THE/4X,34HFUNDS AVAILABLE FOR A 1ST OVE
     2RLAY.)
      IF(LLL.EQ.1.AND.KNTOL.EQ.0) WRITE(6,779) KNTOL2
  779 FORMAT(/3X,67HTHE ACCUMULATED THICKNESS OF ALL OVERLAYS FOR OVERLA
     1Y SCHEME NUMBER,I3,3H IS/4X,67HGREATER THAN THE MAXIMUM ALLOWABLE
     2THICKNESS FOR AN OVERLAY SCHEME.)
      GO TO 14                                                          000408CC
  872 STOP                                                              000409CC
      END                                                               000410CC
```

```
      SUBROUTINE OUTPUT(CLEVEL)
      COMMON COST1,COST2,FLU,TT(20),ALPHA,P1,P2,XNC,RO,RC,CL,NM,P2P,BONE
     1,CMAX,DOVER(5),XTBO,ACPR,ACCD,PRCP,HPD,ITYPE,RATE,OVMIN,OVMAX,PPO2
     2,PPN2,DDO2,DDN2,AAS,ASO,ASN,C1,C2,MCDEL,XLSO,XLSN,XLW,SCC,TTSC,
     3TBSC,CM1,CM2,SC,SCIB1,PSVGE1,PSVGE2,NLRO,NLRN,ITEST,NMB,AN1(32),
     4DATE(2),DIST,HWY(3),CONT,SECT,PIE,CCM(6),SCIB(20),DIP,IIIK,XLSD,
     5SIGMAB(20),T2,SIGMB1
C***********************************************************************
C   THIS SUBROUTINE WRITES OUT A LISTING OF THE INPUT DATA.
C***********************************************************************
C
      WRITE(6,954)
  954 FORMAT(1H1,//31X,20HOVERLAY-1 INPUT DATA)
      WRITE(6,950)
  950 FORMAT(/6X,64HDATE     DIST.    HIGHWAY      CONT.   SECT.   IPE
     1     COMMENTS,13X,7HI--TRIM)
      WRITE(6,875) (DATE(I),I=1,2),DIST,(HWY(I),I=1,3),CONT,SECT,PIE,(CO
     *M(I),I=1,6)
  875 FORMAT (4X,2A4,3X,A2,4X,2A4,A3,2X,A4,4X,A2,3X,A4,6X,6A4)
      WRITE(6,901) SCIB1,SIGMB1,DIP,COST2,PSVGE2
  901 FORMAT (/4X,39HTHE AVERAGE SCI OF THE PRESENT PAVEMENT,28X,F8.3/4X
     *,33HTHE STANDARD DEVIATION OF THE SCI,34X,F8.3/4X,
     156HTHE COMPOSITE THICKNESS OF THE CURRENT PAVEMENT (INCHES),15X,
     2F4.1/4X,63HTHE IN-PLACE PRESENT VALUE OF THE EXISTING PAVEMENT(DOL
     3LARS/CY),3X,F9.2/4X,69HSALVAGE VALUE OF PRESENT STRUCTURE AT END O
     4F ANALYSIS PERIOD(PERCENT),2X,F4.1)
      WRITE(6,902) COST1,PSVGE1
  902 FORMAT(/4X,28HTHE COST OF THE PROPOSED ACP,38X,F9.2/4X,65HSALVAGE
     1VALUE OF PROPOSED ACP AT END OF ANALYSIS PERIOD (PERCENT),6X,F4.1)
      WRITE(6,919) NMB,CL,XLW
  919 FORMAT(/4X,46HNUMBER OF OUTPUT PAGES DESIRED(8 DESIGNS/PAGE),24X, 0005080C
     2  I5/4X,37HLENGTH OF THE ANALYSIS PERIOD (YEARS),33X,F5.1/4X,     0005100C
     3  25HWIDTH OF EACH LANE (FEET),45X,F5.1)                          0005110C
      WRITE(6,924)ALPHA,P1,P2,P2P,BONE
  924 FORMAT( /4X,29HDISTRICT TEMPERATURE CONSTANT,41X,F5.1/ 4X,        0005130C
     2  40HSERVICEABILITY INDEX P1 AFTER AN OVERLAY,30X,F5.1/ 4X,       0005150C
     3  31HMINIMUM SERVICEABILITY INDEX P2,39X,F5.1/ 4X,36HSWELLING CLAY0005160C
     4 PARAMETERS -- P2 PRIME,33X,F6.2/ 32X,2HB1,38X,F7.4)              0005170C
      WRITE(6,927)  RO,RC,CL,XNC,PROP                                   0005180C
  927 FORMAT( /4X,64HONE-DIRECTION ADT AT BEGINNING OF ANALYSIS PERIOD (0005190C
     1VEHICLES/DAY), 3X,F8.0/ 4X,58HONE-DIRECTION ADT AT END OF ANALYSIS0005200C
     2 PERIOD (VEHICLES/DAY), 9X,F8.0/4X,13HONE-DIRECTION,F4.0,46H-YR AC0005210C
     3CUMULATED NO. OF EQUIVALENT 18-KIP AXLES, 2X,F10.0/4X,62HPROPORTIO0005220C
     4N OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT),8X,F5.1)    0005230C
      IF( ITYPE .EQ. 2 )  GO TO 37                                      0005240C
      WRITE(6,938)                                                      0005250C
  938 FORMAT( 4X,28HTHE ROAD IS IN A RURAL AREA.)                       0005260C
      GO TO 39                                                          0005270C
```

```
 37 WRITE(6,939)                                                        000528CC
939 FORMAT( 4X,29HTHE ROAD IS IN AN URBAN AREA.)                        000529CC
 39 CONTINUE                                                            000530CC
    WRITE(6,930) XTBO,TTSC,TBSC
930 FORMAT(/4X,
   1  37HMINIMUM TIME BETWEEN OVERLAYS (YEARS),33X,F5.1/ 4X,62HTIME TO000533CC
   2 FIRST SEAL COAT AFTER INITIAL OR OVERLAY CONST.(YEARS),8X,         000534CC
   3  F5.1/ 4X,31HTIME BETWEEN SEAL COATS (YEARS),39X,F5.1)             000535CC
    WRITE(6,931) CMAX,FLU,CVMIN,CVMAX,CLEVEL
931 FORMAT(4X,58HMAX FUNDS AVAILABLE PER SQ.YD. FOR FIRST OVERLAY (DOL
   1LARS),12X,F5.2/4X,52HTHE LEVEL-UP REQUIRED FOR THE FIRST OVERLAY (
   2INCHES),19X,F4.1/4X,34HMINIMUM OVERLAY THICKNESS (INCHES),36X,F5.1
   3/4X,69HACCUMULATED MAXIMUM DEPTH OF ALL OVERLAYS(INCHES)(EXCLUDING
   4 LEVEL-UP),F6.1/4X,32HDESIGN CONFIDENCE LEVEL(PERCENT),38X,F5.1)
    WRITE(6,920) ACPR,ACCD,XLSO,XLSN                                    000542CC
920 FORMAT(/4X,46HASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR),24X,   000543CC
   1  F5.1/4X,48HASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.),22X,000544CC
   2  F5.2/ 4X,62HC.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE O.000545CC
   3D. (MILES), 8X,F5.2/ 4X,64HC.L. DISTANCE OVER WHICH TRAFFIC IS SLO000546CC
   4WED IN THE N.O.D. (MILES), 6X,F5.2)                                 000547CC
    WRITE(6,933)  XLSD,HPD                                              000548CC
933 FORMAT(4X,47HDETOUR DISTANCE AROUND THE OVERLAY ZONE (MILES),       000549CC
   1  23X,F5.2/4X,37HOVERLAY CONSTRUCTION TIME (HOURS/DAY),33X,F5.1)    000550CC
    WRITE(6,932)  NLRO,NLRN                                             000551CC
932 FORMAT( 4X,47HNUMBER OF OPEN LANES IN RESTRICTED ZONE IN O.D.,23X,000552CC
   1  I5/4X,49HNUMBER OF OPEN LANES IN RESTRICTED ZONE IN N.O.D.,       000553CC
   2  21X,I5)                                                           000554CC
    WRITE(6,943)  PPO2,PPN2,DDO2,DDN2                                   000555CC
943 FORMAT( /4X,66HPROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN000556CC
   1 O.D. (PERCENT), 4X,F5.2/ 4X,68HPROPORTION OF VEHICLES STOPPED BY 000557CC
   2ROAD EQUIPMENT IN N.O.D. (PERCENT),2X,F5.2/ 4X,54HAVERAGE TIME STO000558CC
   3PPED BY ROAD EQUIPMENT IN O.D. (HOURS),15X,F6.3/ 4X,56HAVERAGE TIM000559CC
   4E STOPPED BY ROAD EQUIPMENT IN N.O.D. (HOURS),13X,F6.3)             000560CC
    WRITE(6,944) AAS,ASO,ASN,MODEL                                      000561CC
944 FORMAT(4X,48HAVERAGE APPROACH SPEED TO THE OVERLAY ZONE (MPH),22X,000562CC
   1  F5.1/4X,48HAVERAGE SPEED THROUGH OVERLAY ZONE IN O.D. (MPH),      000563CC
   2  22X,F5.1/4X,50HAVERAGE SPEED THROUGH OVERLAY ZONE IN N.O.D. (MPH000564CC
   3),20X,F5.1/4X,34HTRAFFIC MODEL USED IN THE ANALYSIS,38X,I3)         000565CC
    WRITE(6,948)  CM1,CM2,SC,RATE                                       000566CC
948 FORMAT( /4X,58HFIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LAN000567CC
   1E MILE),10X,F7.2/ 4X,64HINCREMENTAL INCREASE IN MAINT. COST PER YE000568CC
   2AR (DOLLARS/LANE MILE), 4X,F7.2/ 4X,39HCOST OF A SEAL COAT (DOLLAR000569CC
   3S/LANE MILE),29X,F7.2/ 4X,46HINTEREST RATE OR TIME VALUE OF MONEY 000570CC
   4(PERCENT),24X,F5.1)                                                 000571CC
    RETURN
    END
```

```
      SUBROUTINE ERRORS(NLRN,MODEL,NLRO,NMB,XLW,ITYPE,AAS,ASO,ASN,TBSC,
     1      CL,XTBO,RO,RC,ALPHA,P1,P2,P2P,XNC,IERROR,DATE,DIST,HWY,
     2      CONT,SECT,PIE,COM,ACPR,PRCP,HPD)
C***********************************************************************
C  THIS SUBROUTINE CHECKS THE INPUT DATA FOR CODING ERRORS.
C***********************************************************************
C
      DIMENSION ERROR(100),IX(15),DATE(2),HWY(3),COM(6)
      DOUBLE PRECISION ERROR
      DATA ERROR/'VARIABLE',' 2.1 MUS','T BE 1,2',',OR 3.  ','        ',
     *'        ','VARIABLE',' 2.3,2.4',',4.4,5.2',', AND 5.4',' MUST BE',
     *' GT 0.  ','VARIABLE',' 3.1 MUS','T BE GT ','8 AND LT',' 39.    ',
     *'        ','VARIABLE',' 3.3 AND',' 3.4 MUS','T BE LT ','OR EQ 5.',
     *'        ','VARIABLE',' 4.1 AND',' 4.2 CAN',' NOT BOT','H BE 0. ',
     *'        ','VARIABLE',' 4.5 MUS','T BE 1 O','R 2.    ','        ',
     *'        ','VARIABLE',' 6.1 AND',' 6.6 MUS','T BE GT ','0.      ',
     *'        ','VARIABLE',' 6.7 AND',' 6.8 MUS','T BE GT ','0 AND LT',
     *' 4.     ','VARIABLE',' 7.5,7.6',',AND 7.7',' MUST BE',' GT 0.0.',
     *'        ','VARIABLE',' 7.8 MUS','T = 1,2,','3,4,OR 5','.       ',
     *'        '/
      IERROR=0
      DO 5 J=1,15
    5 IX(J)=0
      IF(NMB.LT.1.OR.NMB.GT.3) IX(1)=1
      IF(CL.LE.0.) IX(2)=1
      IF(XLW.LE.0.) IX(2)=1
      IF(PROP.LE.0.) IX(2)=1
      IF(XTBO.LE.0.) IX(2)=1
      IF(TBSC.LE.0.) IX(2)=1
      IF(ALPHA.LT.9.0.OR.ALPHA.GT.38.) IX(3)=1
      IF(P1.GT.5.) IX(4)=1
      IF(P2.GT.5.) IX(4)=1
      IF(RO.LE.0.0.AND.RC.LE.0.) IX(5)=1
      IF(ITYPE.LE.0.OR.ITYPE.GT.2) IX(6)=1
      IF(ACPR.LE.0.) IX(7)=1
      IF(HPD.LE.0.) IX(7)=1
      IF(NLRO.LT.1.OR.NLRO.GT.3) IX(8)=1
      IF(NLRN.LT.1.OR.NLRN.GT.3) IX(8)=1
      IF(AAS.LE.0.0) IX(9)=1
      IF(ASO.LE.0.0) IX(9)=1
      IF(ASN.LE.0.0) IX(9)=1
      IF(MODEL.LT.1.OR.MODEL.GT.5) IX(10)=1
      KK=0
      J=1
      L=0
      DO 10 K=1,10
      J=J+L
      IF(IX(K).EQ.0) GO TO 9
```

```
      IF(KK.EQ.1) GO TO 13
      WRITE(6,910)
  910 FORMAT(1H1,///30X,22HOVERLAY-1 INPUT ERRORS/)
      WRITE(6,950)
  950 FORMAT(/6X,64HDATE     DIST.     HIGHWAY      CONT.  SECT.  IPE
     1     COMMENTS,13X,7HI--TRIM)
      WRITE(6,875)(DATE(I),I=1,2),DIST,(HWY(I),I=1,3),CONT,SECT,PIE,(COM
     1(I),I=1,6)
  875 FORMAT(4X,2A4,3X,A2,4X,2A4,A3,2X,A4,4X,A2,3X,A4,6X,6A4/)
   13 M=J+5
      WRITE(6,900)(ERROR(N),N=J,M)
  900 FORMAT(8X,6A8)
      IERROR=1
      KK=1
    9 L=6
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE OVRLAY(SS,KNTCL,PCLICY,NMBEST,LLL,ERROR2)
      COMMON COST1,COST2,FLU,TT(20),ALPHA,P1,P2,XNC,RO,RC,CL,NM,P2P,BONE
     1,CMAX,DOVER(5),XTBO,ACPR,ACCD,PRCP,HPD,ITYPE,RATE,OVMIN,OVMAX,PPO2
     2,PPN2,DDO2,DDN2,AAS,ASO,ASN,C1,C2,MCDEL,XLSO,XLSN,XLW,SCC,TTSC,
     3TBSC,CM1,CM2,SC,SCIB1,PSVGE1,PSVGE2,NLRC,NLRN,ITEST,NMB,AN1(32),
     4DATE(2),DIST,HWY(3),CCNT,SECT,PIE,CCM(6),SCIB(20),DIP,IIIK,XLSC,
     5SIGMAB(20),T2,SIGMB1
      DIMENSION DADD(20),TN(20),XBI(20),DEXT(20),USERCT(20),RM(20),      00086900
     1OCCT(20),BTT(20),BDEXT(20),TSC(20),BTSC(20),POLICY(50,24)
C
C*********************************************************************
C  THIS SUBROUTINE CALCULATES THE OVERLAY SCHEMES AND THE OVERLAY SCHEME
C   CONSTRUCTION COST.
C*********************************************************************
C
      LLL=0
      IIIK=0
      BIP=BONE
      TPRIM = 0.C                                                        00087100
      XNPRIM = C.0                                                       00087200
      AMINCT = 1C.C**8                                                   00087300
      NOK = 0                                                            00087400
      USERCT(1) = C.C                                                    00087500
      OCCT(1) = C.                                                       00087600
      DADD(1) = 0.0                                                      00087700
      BI = BONE                                                          00087800
      DO 2 I=1,2C
      SCIB(I)=0.
      SIGMAB(I)=C.
    2 CONTINUE
      SCIB(1)=SCIB1
      SIGMAB(1)=SIGMB1
C THE REMAINDER OF THE OVERLAY OPTIMIZATICN RESEMBLES A ''TREE''. IT     00089600
C IS NECESSARY TO SELECT THE OVERLAY POLICY WITH THE LEAST COST.         00089700
      ABDD = 0.0                                                         00089800
C ABDD IS THE ACCUMULATED DEPTH OF ALL PREVICUS OVERLAYS.                00089900
      I=1
    8 DELD = OVMIN                                                       00090500
   10 DOVER(1)=ABDD+DELD
      IF(ABDD+DELD.GT.OVMAX) LLL=1
      IF( (ABDD + DELD) .GT. CVMAX )  GO TO 34                           00090900
C  CALCULATE SCIA AS A FUNCTICN OF SCIB.
      Y1=0.891/(.956)**4.5
      Y2=1./(1CC.+6.25*(.956**2.)*(DELD**2.))
      Y3=SCIB(I)/(1./100.-1./244.)
      Y4=1./(244.+6.25*(.956**2.)*(DELD**2.))
      C=169.444*(Y2-Y4)
      ERROR2=T2*SQRT((C*SIGMAB(I))**2.+0.011236)
```

```
      SS=Y1*(.01-Y2)+Y3*Y2-Y1*(1./244.-Y4)-Y3*Y4+ERROR2
C DETERMINE HOW LONG THIS OVERLAYED PAVEMENT WILL LAST.                  00091200
      P=P1
      CALL TIME(I,T,SS,XN,TPRIM,XNPRIM,ISW,BI,BIP,P)                     00091400
      IF( ISW .EQ. 0 )  GO TO 15                                          00091500
      DELD = DELD + 0.5                                                   00091600
      GO TO 10                                                            00091700
   15 DEXT(I) = DELD                                                      00091800
      ADT = RO + ((RC-RO)/CL)* TPRIM                                      00091900
C DETERMINE THE PRESENT WORTH OF USER COST DURING THE I TH PERFORMANCE  00092000
C PERIOD (DURING THE (I-1) OVERLAY).                                      00092100
      FLU1=1.
      IF(I.EQ.1) FLU1=FLU
      CALL USER(ADT,T,TPRIM,PWTSY,ITIME,DELD,FLU1)
      USERCT(I) = PWTSY                                                   00092300
C DETERMINE THE PRESENT WORTH OF OVERLAY CONSTRUCTION COST DURING THE I 00092400
C PERFORMANCE PERIOD.                                                     00092500
      OCCT(I)=(COST1*DEXT(I)+COST1*FLU1)/(1.+RATE)**ITIME
      IF(I.GT.1) GO TO 9
      IF(OCCT(1).GT.CMAX) GO TO 58
C DETERMINE THE PRESENT WORTH OF ROUTINE MAINTENANCE DURING THE          00092700
C  I TH PERF. PERIOD.                                                     00092800
    9 CALL PWRM(RMAINT,RATE,T,TPRIM,C1,C2,CL)
      RM(I) = RMAINT                                                      00093000
      DADD(I) = DELD                                                      00093100
      TT(I) = T                                                           00093200
      TN(I) = XN                                                          00093300
      XBI(I) = BIP                                                        00093400
C THE PREVIOUS OVERLAY WAS NOT SUFFICIENT TO LAST THROUGH THE ANALYSIS   00093500
C PERIOD IF T IS LESS THAN CL.                                            00093600
      IF( T .GE. CL )  GO TO 23                                           00093700
      IF(ABDD+DELD.GE.OVMAX) LLL=1
      IF( (ABDD + DELD) .GE. OVMAX )  GO TO 34                            00093800
      I = I + 1                                                           00093900
      IF(I.EQ.10) WRITE(6,302)
  302 FORMAT(1H1,////3X,44HTHE NUMBER OF OVERLAYS IS GREATER THAN NINE.)
      ABDD = ABDD + DADD(I-1)                                             00094300
      TPRIM = T                                                           00094000
      XNPRIM = XN                                                         00094100
      BI = BIP                                                            00094200
C  DETERMINE NEW SCIB.
      SCIB(I)=SS-ERROR2
      SIGMAB(I)=C*SIGMAB(I-1)
      GO TO 8                                                             00094400
C DETERMINE THE PRESENT WORTH OF ALL SEAL COATS THAT WILL BE REQUIRED    00094500
C DURING THIS ALTERNATIVE OVERLAY POLICY.                                 00094600
   23 CALL SEAL(TTSC,TBSC,TT,SCC,I,CL,RATE,PWSCC,NSC,TSC)                 00094700
C DETERMINE THE PRESENT WORTH OF THE SALVAGE VALUE OF THE PAVEMENT. THIS00094800
```

```
C WILL BE THE COST OF REBUILDING THE PAVEMENT AT THE END OF THE
C ANALYSIS PERIOD.
      SALVGE = 0.
      SALVGE=-(DOVER(1)*COST1*PSVGE1+DOVER(2)*COST2*PSVGE2)/100
      SALVGE = SALVGE/(1.0+RATE)**CL
      POCCT = 0.
      PRM = 0.0
      PTUC = 0.0
      PRM=PRM+RM(1)
      IF(I.LT.2) GO TO 33
      DO 27 J=2,I
      POCCT = POCCT + OCCT(J)
      PRM=PRM+RM(J)
   27 PTUC = PTUC + USERCT(J)
C EVALUATE THE COST OF THE ALTERNATIVE OVERLAY PROCEDURE AND COMPARE
C TO THE CHEAPEST COST SO FAR.
C TC-THE SUM OF ALL PRESENT WORTHS OF OVERLAY COSTS.
   33 TC=POCCT+PTUC+PRM+PWSCC+SALVGE+OCCT(1)+USERCT(1)
      CALL CHECK(DEXT,POLICY,I,KNTOL,JJ1,NMBEST)
      IF(JJ1.NE.1) GO TO 34
      CALL STORE(KNTOL,NMBEST,POCCT,PTUC,PRM,PWSCC,SALVGE,TC,I,
     1NSC,TSC,TT,DEXT,DOVER,POLICY,FLU,OCCT,USERCT,
     2SCIB,SIGMAB)
C SELECT A DIFFERENT OVERLAY POLICY(ANOTHER BRANCH OF THE TREE) AND
C GO BACK TO STATEMENT 10 TO DETERMINE THE OVERLAY COSTS.
   34 IF(I.LE.1) GO TO 60
      I=I-1
      DELD = DADD(I) + 0.5
      IF(I.EQ.1) GO TO 111
      IM = I - 1
      ABDD = 0.0
      DO 35 K=1,IM
   35 ABDD = ABDD + DADD(K)
      TPRIM = TT(IM)
      XNPRIM = TN(IM)
      BI = XBI(IM)
      GO TO 10
  111 ABDD=0.0
      TPRIM=0.0
      XNPRIM=0.0
      BI=BONE
      GO TO 10
   58 IIIK=1
   60 RETURN
      END
```

```
      SUBROUTINE CHECK(DEXT,POLICY,I,KNTOL,JJ1,NMBEST)
      DIMENSION DEXT(20),POLICY(50,24),KK3(24)
C***********************************************************************
C  THIS SUBROUTINE ELIMINATES ALL OVERLAY SCHEMES THAT ARE NOT
C   ALTERNATES.
C***********************************************************************
C
      KK1=0
      KK2=0
      JJ1=0
      DO 100 K=1,NMBEST
      KK3(K)=0
  100 CONTINUE
      IF(KNTOL.EQ.0) GO TO 360
      DO 340 NN=1,NMBEST
      IPOL=POLICY(20,NN)
      IF(IPOL.LT.1) GO TO 350
      IF(IPOL.NE.I) GO TO 340
      DO 330 J=1,I
      IF(DEXT(J)-POLICY(J+30,NN)) 10,330,20
   10 KK1=-1
      GO TO 330
   20 KK2=1
  330 CONTINUE
      KK3(NN)=KK1+KK2
      KK1=0
      KK2=0
  340 CONTINUE
  350 DO 355 K=1,NMBEST
      IF(KK3(K).NE.0) GO TO 370
  355 CONTINUE
  360 JJ1=1
  370 RETURN
      END
```

```
      SUBROUTINE STORE(KNTCL,NMBEST,BPCCCT,BPTUC,BPRM,BPWSCC,
     1BSAL,AMINCT,IBT,NBSC,BTSC,BTT,BDEXT,DOVER,POLICY,FLU,OCCT,USERCT,
     2SCIB,SIGMAB)
      DIMENSION BTSC(20),BTT(20),BDEXT(20),PCLICY(50,24),DOVER(5),
     1OCCT(20),USERCT(20),SCIB(20),SIGMAB(20)
C
C*********************************************************************
C  THIS SUBROUTINE SORTS THE CHEAPEST OVERLAY SCHEMES INTO ASCENDING
C   ORDER AND SAVES A SET OF THE CHEAPEST SCHEMES.
C*********************************************************************
C
      KNTOL = KNTOL + 1
      IF(KNTOL .NE. 1) GO TO 205
      NEW = 1
      GO TO 265
  205 INUM=NMBEST
      IF(KNTOL .GT. INUM ) GO TO 210
      INUM = KNTOL - 1
  210 IF (AMINCT .LT. POLICY(8,INUM)) GC TO 215
      IF (INUM .EQ. NMBEST) GO TC 300
      NEW = INUM + 1
      GO TO 265
  215 NEW = 1
  220 IF (AMINCT .LT. POLICY (8,NEW)) GC TO 225
      NEW = NEW + 1
      GO TO 220
  225 IF (NEW .EQ. NMBEST) GO TO 265
      II = INUM-NEW + 1
      IF (INUM .BQ. NMBEST) II=INUM-NEW
      DO 260 J=1,II
      JJ=INUM-J+1
      IF(INUM .EQ. NMBEST) JJ = INUM-J
C--THE COST OF THE CURRENT DESIGN UNDER CONSIDERATION IS AMONG THE
C--BEST NMBEST SO FAR.  THIS DESIGN GOES IN THE NEW TH COLUMN AND ALL OT
C--DESIGNS ARE SHIFTED DOWN ONE(FRCM THE J TH TO THE (J+1) ST COLUMN).
      DO 230 K=1,19
  230 POLICY (K,JJ+1) = POLICY (K,JJ)
C POLICY (20,JJ)CONTAINS THE NUMBER CF PERFCRMANCE PERIOD FOR THE DESIGN
C COLUMN JJ(CAN NOT BE MORE THAN 10).
      POLICY (20,JJ+1) = PCLICY (20,JJ)
      NP = POLICY (20,JJ) + 20
      IF( NP .GT. 30 )  NP = 30
      DO 240 I = 21,NP
  240 POLICY(I,JJ+1) = POLICY(I,JJ)
      KK=POLICY(20,JJ+1)+30
      IF (KK .EQ. 30 ) GO TO 250
      IF( KK .GT. 39 )  KK = 39
      DO 245 I= 31,KK
```

```
  245 POLICY (I,JJ+1) = POLICY (I,JJ)
C POLICY (40,JJ) CONTAINS THE NUMBER OF SEAL COATS FOR THE DESIGN IN
C COLUMN JJ(CAN NOT BE MORE THAN 10).
  250 POLICY (40,JJ+1) = POLICY (40,JJ)
      LL= POLICY (40,JJ) +40
C IF LL=40 THERE ARE NO SEALS COATS IN THE DESIGN IN COLUMN JJ
      IF (LL .EQ. 40 ) GO TO 260
      IF( LL .GT. 50 )  LL = 50
      DO 255 I=41, LL
  255 POLICY (I,JJ+1) = POLICY(I,JJ)
  260 CONTINUE
C--NOW INSERT THE CURRENT DESIGN IN COLUMN NEW OF THE ARRAY POLICY.
  265 POLICY(1,NEW)=1.0
      POLICY(2,NEW)=USERCT(1)
      POLICY (3,NEW) = BPOCCT
      POLICY (4,NEW) = BPTUC
      POLICY (5,NEW) = BPWSCC
      POLICY (6,NEW) = BPRM
      POLICY (7,NEW) = BSAL
      POLICY (8,NEW) = AMINCT
      POLICY(9,NEW)=FLU
      POLICY(10,NEW)=OCCT(1)
      POLICY(11,NEW)=DOVER(2)
      POLICY(20,NEW) = IBT
      KK = IBT
      IF( KK .GT. 10 )  KK = 10
      DO 275 I=1,KK
  275 POLICY(I+20,NEW)=BTT(I)
      IBTM=IBT
      DO 283 I=1,IBTM
  280 POLICY(I+30,NEW)=BDEXT(I)
  283 CONTINUE
  285 POLICY(40,NEW) = NBSC
      IF (NBSC .EQ. 0) GO TO 300
      KK = NBSC
      IF( KK .GT. 8 )  KK = 8
      DO 290I=1,KK
  290 POLICY (I+40,NEW) = BTSC(I)
  300 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE USER(ADT,T,TPRIM,PWTSY,ITIME,DELD,FLU1)
      COMMON COST1,COST2,FLU,TT(20),ALPHA,P1,P2,XNC,RO,RC,CL,NM,P2P,BONE
     1,CMAX,DOVER(5),XTBO,ACPR,ACCD,PROP,HPD,ITYPE,RATE,OVMIN,OVMAX,PPO2
     2,PPN2,DDO2,DDN2,AAS,ASO,ASN,C1,C2,MODEL,XLSO,XLSN,XLW,SCC,TTSC,
     3TBSC,CM1,CM2,SC,SCIB1,PSVGE1,PSVGE2,NLRC,NLRN,ITEST,NMB,AN1(32),
     4DATE(2),DIST,HWY(3),CONT,SECT,PIE,CCN(6),SCIB(20),DIP,IIIK,XLSD,
     5SIGMAB(20),T2,SIGMB1
      DIMENSION CCSR(6,7), CCSU(6,7), CURS(6,2), CCD(1,2), TRAFIO(4,3)
C
C**********************************************************************
C   THIS SUBROUTINE DETERMINES THE USER COST DURING CONSTRUCTION OF AN
C    OVERLAY.
C**********************************************************************
C
C THE FOLLOWING ARE TABLES CONTAINING THE USER COSTS.
C   COST OF SLOWING DOWN IN A RURAL AREA
      DATA CCSR/8.473,18.2,31.55,50.36,77.932,120.546,0.,9.413,21.491,
     1  39.609,66.233,106.979,2*0.,11.354,28.422,53.917,92.482,3*0.,
     2  15.795,39.941,76.022,4*0.,22.612,56.405,5*0.,32.485,6*0./
C   COST OF SLOWING DOWN IN AN URBAN AREA
      DATA CCSU/5.869, 11.769, 19.5, 30.03, 45.002, 67.868, 0., 5.602,
     1  12.857, 22.933, 37.338, 58.992, 2*0., 6.501, 15.976, 29.61,
     2  49.114, 3*0., 8.607, 21.448, 40.242, 4*0., 11.856, 29.36,
     3  5*0., 16.432,6*0./
C   COST OF OPERATING AT A REDUCED SPEED
      DATA CURS/393.47, 214.53, 156.05, 129.03, 115.51,110.16, 362.43,
     1  197.06, 142.57, 116.84, 103.24, 96.73/
C   COST OF DELAY
      DATA COD/3499.76,3263.11/
      DATA TRAFIO/1350.,3000.,1400.,3000.,2700.,4500.,2800.,4700.,
     1  4350.,6200.,4500.,6400./
C
C   HPSY-PRODUCTION RATE IN HOURS PER SQ. YARD OF OVERLAY.
      HPSY=ACCD*(DELD+FLU1)/(36.*ACPR)
      LO =(ASO/10.0) + 0.5
      LN =(ASN/10.0) + 0.5
      K =(AAS/10.0) + 0.5
      IF( LO .GT. 6 )  LO = 6
      IF( LN .GT. 6 )  LN = 6
      IF( K .GT. 6 )  K = 6
      TIPH = ADT * PROP / 100.
C
C   MODEL 1
C
      PO1 = 0.
      PN1 = 0.
      DO1 = 0.
      DN1 = 0.
```

```
      PO2 = PPO2/100.
      PN2 = PPN2/100.
      DO2 = DDO2
      DN2 = DDN2
      D = 1. / 12.
      GO TO (60,20,30,40,50),MODEL
C
C  MODEL 2
C
   20 AQ = XLSO* TIPH / ASO
      PO1 = 0.5*(1. - EXP(-AQ) )**2
      PN1 = PO1
      DO1 = (1. + EXP(2.*AQ) )*(EXP(AQ) - AQ - 1. ) /
     1 (2.*TIPH*PO1*(EXP(2.*AQ) - EXP(AQ) + 1. ) )
      DN1 = DO1
      GO TO 60
C
C  MODEL 3
C
   30 OUTRAT = TRAFIO(2*ITYPE-1,NLRO)
      RECOVY = TRAFIO(2*ITYPE,NLRO)
      IF( TIPH .LE. OUTRAT )  GO TO 60
      PO1 = HPD*(TIPH - OUTRAT)/(2.*TIPH*D)
      IF( PO1 .GT. 1. )  PO1 = 1.
      DO1 = HPD*(TIPH - OUTRAT) * (RECOVY - OUTRAT) /
     1  (2.*TIPH*PO1*(RECOVY - TIPH) )
      GO TO 60
C
C  MODEL 4
C
   40 OUTRAT = TRAFIO(2*ITYPE-1,NLRO)
      RECOVY = TRAFIO(2*ITYPE,NLRO)
      IF( TIPH .LE. OUTRAT )  GO TO 44
      PO1 = HPD*(TIPH - OUTRAT)/(2.*TIPH*D)
      IF( PO1 .GT. 1. )  PO1 = 1.
      DO1 = HPD*(TIPH - OUTRAT) * (RECOVY - OUTRAT) /
     1  (2.*TIPH*PO1*(RECOVY - TIPH) )
   44 OUTRAT = TRAFIO(2*ITYPE -1,NLRN)
      IF( TIPH .LE. OUTRAT )  GO TO 60
      PN1 = HPD*(TIPH - OUTRAT)/(2.*TIPH*D)
      IF( PN1 .GT. 1. )  PN1 = 1.
      DN1 = HPD*(TIPH - OUTRAT) * (RECOVY - OUTRAT) /
     1  (2.*TIPH*PN1*(RECOVY - TIPH) )
      GO TO 60
C
C  MODEL 5
C
   50 OUTRAT = TRAFIO(2*ITYPE-1,NLRO)
```

```
      RECOVY = TRAFIO(2*ITYPE,NLRO)
      IF( TIPH .LE. OUTRAT )  GO TO 60
      PO1 = HPD*(TIPH - OUTRAT)/(2.*TIPH*D)
      IF( PO1 .GT. 1. )  PO1 = 1.
      DO1 = HPD*(TIPH - OUTRAT) * (RECOVY - OUTRAT) /
     1   (2.*TIPH*PO1*(RECOVY - TIPH) )
   60 CONTINUE
C
C  NOW COLLECT ALL PERTINENT INFORMATION SO THAT THE USER COST
C  FOR THE OVERLAY CAN BE COMPUTED.
C
      GO TO (65,68),ITYPE
C  COST OF STOPPING FROM APPROACH SPEED IN A RURAL AREA.
   65 CO1 = CCSR(K,1)/1000.
      CN1 = CO1
C COST OF SLOWING TO THRU SPEED IN A RURAL AREA.
      CO4 = CCSR(K,LO+1)/1000.
      CN4 = CCSR(K,LN+1)/1000.
      GO TO 70
C  COST OF STOPPING FROM APPROACH SPEED IN AN URBAN AREA.
   68 CO1 = CCSU(K,1) / 1000.
      CN1 = CO1
C COST OF SLOWING TO THRU SPEED IN AN URBAN AREA.
      CO4 = CCSU(K,LO+1)/1000.
      CN4 = CCSU(K,LN+1)/1000.
C COST OF DELAY DUE TO CONGESTION OUTSIDE THE RESTRICTED AREA.
   70 CO2 = DO1 * COD(1,ITYPE) / 1000.
      CN2 = DN1 * COD(1,ITYPE) / 1000.
C COST OF DRIVING AT A REDUCED SPEED.
      IF ( MODEL .EQ. 5 )  GO TO 74
      CO3 = (CURS(LO,ITYPE) - CURS(K,ITYPE) )*XLSO / 1000.
      CN3 = (CURS(LN,ITYPE) - CURS(K,ITYPE) )*XLSN / 1000.
      GO TO 77
   74 CO3 = (CURS(LO,ITYPE)*XLSD-CURS(K,ITYPE)*XLSC) / 1000.
      CN3 = (CURS(LN,ITYPE) - CURS(K,ITYPE) ) * XLSN / 1000.
C EXCESS COST OF STOPPING FROM THRU SPEED + COST OF IDLE TIME,ALL
C WITHIN THE RESTRICTED AREA.
   77 GO TO (80,90),ITYPE
   80 CO5 = CCSR(LO,1)/1000. + DO2*COD(1,ITYPE)/1000.
      CN5 = CCSR(LN,1)/1000. + DN2*COD(1,ITYPE)/1000.
      GO TO 100
   90 CO5 = CCSU(LO,1)/1000. + DO2*COD(1,ITYPE)/1000.
      CN5 = CCSU(LN,1)/1000. + DN2*COD(1,ITYPE)/1000.
  100 TUCH=TIPH*( PO1*(CO1+CO2+CO3) + (1.-PO1)*(CO3+CO4) + PO2*CO5 ) +
     1     TIPH*( PN1*(CN1+CN2+CN3) + (1.-PN1)*(CN3+CN4) + PN2*CN5 )
      TUCSY = HPSY * TUCH
      ITIME = TPRIM + 0.5
C DETERMINE THE PRESENT WORTH OF THE USER COSTS.
```

```
      PWTSY = TUCSY/(1. + RATE ) ** ITIME                                 00116000
      RETURN                                                              00116100
      END                                                                 00116200
```

```
      SUBROUTINE TIME(I,T,SS,XN,TPRIM,XNPRIM,ISW,BI,BIP,P)
      COMMON COST1,COST2,FLU,TT(20),ALPHA,P1,P2,XNC,RO,RC,CL,NM,P2P,BONE
     1,CMAX,DOVER(5),XTBO,ACPR,ACCD,PROP,HPD,ITYPE,RATE,OVMIN,OVMAX,PPO2
     2,PPN2,DDO2,DDN2,AAS,ASO,ASN,C1,C2,MODEL,XLSO,XLSN,XLW,SCC,TTSC,
     3TBSC,CM1,CM2,SC,SCIB1,PSVGE1,PSVGE2,NLRO,NLRN,ITEST,NMB,AN1(32),
     4DATE(2),DIST,HWY(3),CONT,SECT,PIE,CCM(6),SCIB(20),DIP,IIIK,XLSD,
     5SIGMAB(20),T2,SIGMB1
C***********************************************************************
C FOR ANY SCI, THIS SUBROUTINE IS AN ITERATIVE PROCESS WHICH USES THE
C SERVICEABILITY LOSS EQUATION AND THE TRAFFIC EQUATION TO DETERMINE
C THE NUMBER OF EQUIVALENT 18-KIP APPLICATIONS AND THE LENGTH OF TIME
C (IN YEARS) BEFORE THE SERVICEABILITY INDEX HAS BEEN REDUCED TO ITS
C  MINIMUM ACCEPTABLE VALUE OF P2.
C  THE SWITCH ISW IS INCLUDED SO THAT THE ITERATION PROCEDURE FOR
C  DETERMINING TIME MAY BE TRUNCATED WHEN THE LIFE OF AN INITIAL
C  CONSTRUCTION OR AN OVERLAY WILL BE LESS THAN MTTO OR MBTO,RESPECTIVEL
C  THESE DESIGNS ARE NOT ALLOWED AND WILL NOT BE CONSIDERED.
C***********************************************************************
      ISW = 1
      TEST = 0.05
      TBOT = TPRIM
      DELT = XTBO
      GO TO 3
    2 TBOT = T
      ISW = 0
    3 T = TBOT + DELT
      XN = (XNC/(CL * (RC+RO) )) * (2.*RO*T + ((RC-RO)/CL) * T**2)
      XN = XN / 10.**6
      XXN = XN - XNPRIM
      ERROR = -SQRT(5.0-P2) + SQRT(5.0-P ) + (53.6*XXN*SS**2)/ALPHA +
     1              (SQRT(5.-P2P)-SQRT(5.-P ))*(1.-EXP(-BI*(T-TPRIM)))
      IF( ERROR )  2, 6, 5
    4 XN = (XNC/(CL * (RC+RO) )) * (2.*RO*T + ((RC-RO)/CL) * T**2)
      XN = XN / 10.**6
      XXN = XN - XNPRIM
      ERROR = -SQRT(5.0-P2) + SQRT(5.0-P ) + (53.6*XXN*SS**2)/ALPHA +
     1              (SQRT(5.-P2P)-SQRT(5.-P ))*(1.-EXP(-BI*(T-TPRIM)))
      IF( ABS(ERROR) .LT. 0.001  )  GO TO 6
      IF( ERROR )  7, 6 , 5
    5 IF( ISW .EQ. 1 )  GO TO 6
      TTOP = T
      DELT = DELT/2.0
      T = TTOP - DELT
      IF( DELT .LT. TEST )  GO TO 6
      GO TO 4
    7 TBOT = T
      DELT = DELT/ 2.0
      T = TBOT + DELT
```

```
      IF( DELT .LT. TEST )  GO TO 6                                      00121300
      GO TO 4                                                            00121400
    6 BIP= BI*EXP(-BI*(T-TPRIM) )                                        00121500
      RETURN                                                             00121600
      END                                                                00121700
```

```
      SUBROUTINE PWRM(RMAINT,RATE,T,TPRIM,C1,C2,CL)
C***********************************************************************
C THIS SUBROUTINE DETERMINES THE PRESENT WORTH PER SQ. YD. OF ROUTINE
C MAINTENANCE(WHICH INCREASES LINEARLY) WHICH IS PERFORMED DURING THE
C I TH OVERLAY PERIOD.
C***********************************************************************
      IT = T + 0.5
      IF( T .GT. CL )  IT = CL
      ITIME = TPRIM + 0.5
      N = IT - ITIME
      RMAINT = 0.
      IF( N .EQ. 0 )  GO TO 20
      IF( RATE .GT. 0. )  GO TO 15
      DO 10 J=1,N
   10 RMAINT = RMAINT + C1 + (J-1)*C2
      GO TO 20
   15 AN = N
      RP1 = 1.0 + RATE
      CONCT = C1*(RP1**N-1.)/(RATE*RP1**(N-1) )
      AINCT = C2*(RP1**N-RATE*AN-1.)/(RATE**2*RP1**(N-1) )
      RMAINT =(CONCT + AINCT)/(1. + RATE)**ITIME
   20 RETURN
      END
```

```
      SUBROUTINE SEAL(TTSC,TBSC,TT,SCC,I,CL,RATE,PWSCC,NSC,TSC)          00123900
C*************************************************************************
C THIS SUBROUTINE DETERMINES THE PRESENT WORTH PER SQ. YD. OF ALL SEAL  00124000
C COATS WHICH WILL BE PERFORMED DURING THE ANALYSIS PERIOD.             00124100
C*************************************************************************
      DIMENSION TT(20),NUM(20),TSC(20)                                   00124300
C  NSC WILL BE THE NUMBER OF SEAL COATS PERFORMED.
      NSC = 0                                                            00124400
      DO 2 K=1,I                                                         00124500
    2 NUM(K) = 0                                                         00124600
      J = 1                                                              00124700
      YEARS = TT(1)                                                      00124800
      IF( YEARS .GT. CL )  YEARS = CL                                    00124900
C A SEAL COAT WILL NOT BE APPLIED IF OVERLAY WILL TAKE PLACE WITHIN ONE 00125000
    3 IF( (YEARS-TTSC) .LE. 0.0 )  GO TO 10                              00125100
      REMAIN = YEARS - TTSC                                              00125200
C THE NUMBER OF SEAL COATS THAT WILL BE APPLIED DURING THE ITH OVERLAY P00125300
      NUM(J) = 1.0 + (REMAIN/TBSC)                                       00125400
C  THE 1 IN THE NEXT RELATIONSHIP IS FOR THE SEAL COAT
C  APPLIED AFTER TTSC YEARS.
      XNUM = NUM(J) - 1                                                  00125700
C  AGAIN NO SEAL COAT WITHIN 1 YEAR PRIOR TO OVERLAY.
      IF( (REMAIN-XNUM*TBSC) .LT. 0.0 )  NUM(J)=NUM(J)-1                 00125900
   10 IF( (TT(J) + TTSC) .GE. CL )  GO TO 15                             00126000
      J = J + 1                                                          00126100
      YEARS = TT(J) - TT(J-1)                                            00126200
      IF( TT(J) .GT. CL )  YEARS = CL-TT(J-1)                            00126300
      GO TO 3                                                            00126400
C NOW DETERMINE THE PRESENT WORTH OF ALL SEAL COATS DURING THE ANALYSIS 00126500
   15 PWSCC= 0.0                                                         00126600
      PT = 0.0                                                           00126700
      DO 25 K=1,J                                                        00126800
      IF( NUM(K) .EQ. 0 )  GO TO 25                                      00126900
      POWER = TTSC + PT                                                  00127000
      KK = NUM(K)                                                        00127100
      DO 20 L=1,KK                                                       00127200
      NSC = NSC + 1                                                      00127300
C  TSC(NSC) CONTAINS THE TIME AT WHICH THE NSC TH SEAL COAT IS APPLIED.
C  KK IS THE NUMBER OF SEAL COATS IN THE K TH PERF. PERIOD.
      TSC(NSC) = POWER                                                   00127600
      IPT = POWER + 0.5                                                 001277000
      PWSCC = PWSCC + SCC/(1.0+RATE)**IPT                                00127800
      POWER = POWER + TBSC                                               00127900
   20 CONTINUE                                                           00128000
   25 PT = TT(K)                                                         00128100
      RETURN                                                             00128200
      END                                                                00128300
```

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