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16. Abstract

A number of States are beginning to use roughness measurements from the California and Rainhart profilographs for construction control of rigid pavements. A recent Texas study, Research Study 8-10-87-56, provided correlations between Present Serviceability Index (PSI) as obtained from profile measured by the Surface Dynamics Profilometer (SDP), and profile index (PI) obtained between these profilographs for rigid pavements. The PI was computed using the 0.1 and 0.2 inch blanking bands, which are the ones most commonly used for computing PI. This current report provides details on similar study which investigates correlations of PSI with Rainhart and California profilograph PI measurements for asphalt pavements and concrete pavements with asphalt overlays. Two-tenths mile sections in six different areas of Texas were measured with these devices for the study. Additionally, as in the first study, the 0.1 and 0.2 blanking bands were used to compute the PI. In addition to the correlations with PSI, correlations are also provided between each profilograph with one another.

17. Key Words	18. Distribution Statement
Rainhart Profilograph, California Profilograph, Surface Dynamics Profilometer (SDP), SIometer, Walker Roughness Device (WRD), Present Serviceability Index (PSI), Profile Index (PI), Blanking Bands	

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PROFILOGRAPH CORRELATION

WITH PRESENT SERVICEABILITY INDEX

ASPHALT PAVEMENTS

by

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The University of Texas at Arlington

Report 579-1F

Automated Pavement Data
Collection Equipment

Project 8-10-88-579

conducted for

Texas State Department of Highways
and Public Transportation

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

JUNE 1989

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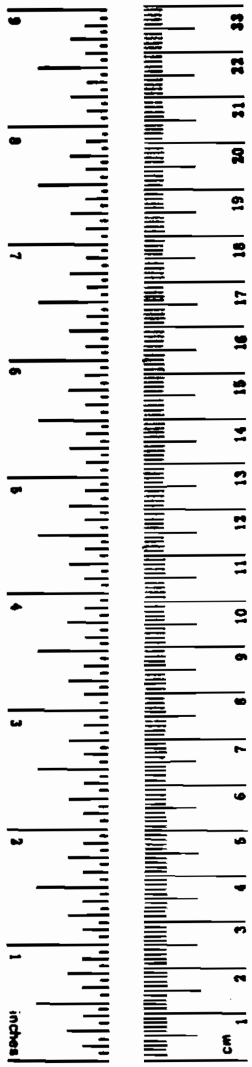
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

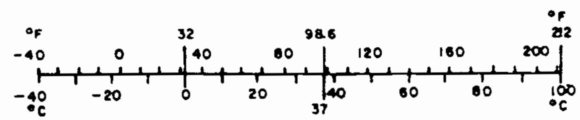
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report presents the results of the Texas State Department of Highways and Public Transportation (SDHPT) Project 8-10-87-579. The Project was initiated to determine the correlation between the profile index (PI) produced by the California and Rainhart Profilographs with Present Serviceability Index (PSI) for asphalt pavements and asphalt overlays of portland cement concrete pavements. The PI was computed using the 0.1 and 0.2 inch blanking bands. The PSI measurements are obtained from profile measured by the Surface Dynamics Profilometer (SDP). The correlation between PSI and PI for concrete pavements was investigated during an earlier SDHPT Study, 8-10-97-56. This current study was initiated to continue this investigation by including asphalt pavements and concrete pavements with asphalt overlays.

The project implementation was not possible without the close cooperation of the Department personnel. Special recognition should also be given to Mr. Randy McDonald of the Federal Highway Administration, who was instrumental in the initialization of the study effort.

Roger S. Walker

June 1989

ABSTRACT

A number of States are beginning to use roughness measurements from the California and Rainhart profilographs for construction control of rigid pavements. A recent Texas study, Research Study 8-10-87-56, provided correlations between Present Serviceability Index (PSI) as obtained from profile measured by the Surface Dynamics Profilometer (SDP), and profile index (PI) obtained between these profilographs for rigid pavements. PI was computed using the 0.1 and 0.2 inch blanking bands, which are the ones most commonly used for computing PI. This current report provides details on a similar study which investigates correlations of PSI with Rainhart and California profilograph PI measurements for asphalt pavements and concrete pavements with asphalt overlays. Two-tenths mile sections in six different areas of Texas were measured with these devices for the study. Additionally, as in the first study, the 0.1 and 0.2 inch blanking bands were used to compute the PI. In addition to the correlations with PSI, correlations are also provided between each profilograph with one another.

KEY WORDS: Rainhart Profilograph, California Profilograph, Surface Dynamics Profilometer (SDP), SIometer, Walker Roughness Device (WRD), Present Serviceability Index (PSI), Profile Index (PI), Blanking Bands

SUMMARY

This report provides correlation results between profile index (PI) as measured by the California and Rainhart Profilographs and Present Serviceability Index (PSI) as obtained from the Surface Dynamics Profilometer for asphalt pavements and concrete pavements with asphalt overlays. The study was initiated to only consider the two blanking bands, 0.1 and 0.2 inches for computing PI, as these are the two bands currently most often used by states with these two types of profilographs. Two-tenths mile sections in six different areas of Texas were measured with these devices for the study. In addition to the correlations with PSI, correlations are also provided between each profilograph with one another.

The study reported herein, is similar to a previous study, Texas Project, 8-10-87-56, which investigated correlations between these devices for concrete pavements. Similar to what was found in this first study for concrete pavements, a high correlation was found between PSI and PI for the asphalt pavements. A much lower correlation was noted for concrete pavements with asphalt overlays.

IMPLEMENTATION STATEMENT

Correlation data between PI determined from California and Rainhart Profilographs with PSI will aid highway design and construction personnel to better define current and future rideability specifications for construction projects. This information in conjunction with the results found in a similar study for rigid pavements, Texas State Department of Highways and Public Transportation Project 8-10-87-56, is useful for investigating differences between roughness measuring equipment currently in use by the State for such pavement types.

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CHAPTER 1

INTRODUCTION

Background

The Surface Dynamics Profilometer (SDP) has been used by the Texas State Department of Highways and Public Transportation (TSDHPT) for a number of years for obtaining road profile measurements. These measurements are used for obtaining present serviceability index (PSI). The PSI obtained from the SDP has been found to provide consistent, objective, and reliable results, and as such, is currently used in the State as the standard for roughness measurements.

The profilograph has been used for measuring smoothness of pavements for construction projects in Texas and other states. The relationship between the Rainhart and California profilograph roughness measurements, profile index (PI), and Present Serviceability Index obtained from the Surface Dynamics Profilometer was recently investigated for rigid pavements during Project 8-10-87-569, " Correlation of California and Rainhart Profilographs with PSI" [WAL88]. The study provided correlations between PSI, as obtained from the SDP, and Profile Index from the California and Rainhart Profilographs. For the first study, two-tenths mile sections in three areas of Texas of new and old rigid pavements were measured with these devices.

In addition to the correlations with PSI, the study also provided correlations between each profilograph with one another for the two blanking bands, 0.1 and 0.2 inches and between roughness data from the Walker Roughness Device (WRD) or Siometer. A mathematical model of the two profilographs was developed and the measuring capabilities of the two profilographs to various road profile frequencies or wavelength components investigated. The study was initiated to specifically consider the two blanking bands, 0.1 and 0.2 inches for computing PI, as these were the two bands most often used by states with these two types of profilographs for computing PI. At the conclusion of the project, it was recommended that additional studies be performed which included asphalt pavements and asphalt overlays of concrete pavements. This current project was initiated to correlate PI with PSI for these pavement types.

Study Plan and Report Scope

The main objective of this project was to investigate the relationships between measurements obtained from the Rainhart and California profilographs and PSI as obtained from the SDP for flexible pavements and for concrete pavements that had received an asphalt overlay. The relationships between the two profilographs themselves, as well as an indication of measurement errors, were investigated.

The major objective and study plan for the project was as follows:

1. Select fifteen to twenty (15-20) flexible and 15-20 rigid or concrete pavement sections with asphalt overlays of 0.2 mile length as preliminary test sites for the correlation study. The sections are to have PSI values of about 3.5 and higher. Final section selection are based on the PSI measurements as established by the SDP.

2. Obtain the profile using the SDP and compute the corresponding PSI. Measure the sections using the California and Rainhart Profilographs and determine the profile index for both devices for 0.1 and 0.2 inch blanking bands. Make repeat data runs, to obtain an estimate of the measurement error.

3. Provide correlations between each device and PSI.

The following chapter (Chapter 2) provides details on the data sections selected and provides the measurement values. The Rainhart profilograph, SDP and WRD owned by D-10 were used in the study. The California profilograph was obtained from the Beaumont office. A brief description of each device is provided in the Appendix.

Chapter 3 discusses the correlations performed. These correlations include correlations between the two profilographs for the two blanking bands and correlations between the profilographs and PSI. Additionally, a discussion of the measurement error between repeat data runs is provided.

Chapter 4 provides the summary and conclusions of the study.

CHAPTER 2

DATA COLLECTION

Introduction

The devices used for the study were the California Profilograph, manufactured by McCracken Co., the Rainhart Profilograph, manufactured by Rainhart Co. and the the 690D Profilometer, built by K.J.Law. The WRD, (R680 built by Micro-sher Inc.) was primarily used to help select the preliminary sections, and the SI values are also included.

For the project, over forty sections in six different areas of the State were run. Multiple runs were made on most sections by each device. As noted earlier, fifteen to 20 sections were to be selected with a PSI's of 3.5 and better. When the SDP was run and the PSI determined, 15 asphalt and 18 concrete sections with asphalt overlays were found with a PSI above 3.5. Three additional asphalt and two concrete with asphalt overlays are also included which were below 3.5 but above 3.0.

Tables 2.1a and 2.1b provide the locations and names assigned to each section. In the figures and tables which follow, the asphalt pavement sections will always be given first, (denoted by "a") followed by the concrete pavements with asphalt overlays (denoted by "b"). The sections were selected from six different areas in the State. The asphalt pavements were selected in the Austin and Dallas areas, and the concrete with asphalt overlays were selected near Beaumont, Bryan, Lufkin, and Alvarado.

Data Collection Procedures

As indicated above over forty pavements sections of 0.2 mile length were selected from roads in six different areas of the State. The section locations and run values are listed in the following tables. Each section was run by all four roughness measuring devices. Some of the sections are in close proximity to one another, e.g., opposite lane, very next

0.2 mile section, or within a few hundred feet.

The time and effort required to assemble and disassemble each profilograph, as well as, in their operations (e.g., traffic control, multiple data runs, etc.) played a major role in selecting the sections. Additionally, attempts were made to select sections which had various levels of roughness, in the desired range of 3.5 and above. The measurements were made by the State Department of Highways and Public Transportation D-10 personnel.

Tables 2.2a and 2.2b provide the results from the SDP for each pavement type. Table 2.3 provides similar results for the WRD. Because the WRD was used primarily for initial section selection, and because some of the sections were only run once, just the single run or section average is given.

The California profilograph results are provided in Tables 2.4a and 2.4b, while the Rainhart results provided in Tables 2.5a and 2.5b. The profile index for both devices are given using the 0.1 and 0.2 blanking bands. Most of the profilograph runs were made twice over each section. Three runs were made on the Beaumont sections BCA3-BCA6, Tables 2.4b and 2.5b. All repeat runs were made as close as possible to the same wheel paths. Only one run was made on the Austin sections AUA6-AUA8 in Tables 2.4a and 2.5a. Initially five sections in this area were included, however it was later discovered that the PSI readings on the last two sections were invalid. This was because the profilometer was giving incorrect sample distances for these sections. Thus these data were not appropriate for use and therefore were not used for developing correlations in the revised preliminary report. The profile measurements made with the SDP were done at 20 MPH. Those with the WRD were made at 50 MPH.

Table 2.1a
Pavement Sections
Asphalt

SECTION	LOCATION
AUA1	About 2 miles East Cedar Park, East Bound on FM 1431
AUA2	next section on FM 1431
AUA3	next section on FM 1431
AUA4	next section on FM 1431
AUA5	next section on FM 1431
AUA6	FM 685 - about 3 miles East of Pflugervile East bound outside Lane
AUA7	next section on FM 685
AUA8	next section on FM 685
DA1	US 183 about 2 mile West Ennis West bound outside lane
DA2	next section on US 183
DA3	next section on US 183
DA4	next section on US 183
DA5	Across from DA4 East bound outside lane
DA6	next section on US 183
DA7	next section on US 183
DA8	next section on US 183
DA9	FM 342 just North Red Oak South bound
DA10	next section on FM 342

Table 2.1b
Pavement Sections
Asphalt - Concrete

SECTION	LOCATION
AVCA1	I35W South-bound about 2 miles South Alvarado
AVCA2	next section on I35W
AVCA3	next section on I35W
BCA1	US 105 North bound just North of I10, Vidor
BCA2	across from BCA1 South bound
BCA3	US 105 North bound about 2 miles North BCA1
BCA4	next section on US 105
BCA5	across from BCA4 South bound
BCA6	next section on US 105
BYCA1	US 190 East bound about 8 miles East of Bryan
BYCA2	skip 0.2 mile east - next section on US 190
BYCA3	next section on US 190
BYCA4	across from BYCA2 West bound on US 190
BYCA6	next section on US 190
BYCA7	skip 0.2 mile west - next section on US 190
BYCA9	next section on US 190
BYCA11	Texas 21 West bound, inside lane, 1 mile East of Caldwell
BYCA12	next section on Texas 21
LUCA2	US 59 North bound outside lane, North of Dibolt
LUCA3	next section on US 59

Table 2.2a
SDP-PSI Results
Asphalt

SECTION	SDP-AVG	SDP-1	SDP-2	SDP-3
AUA1	4.60	4.60	4.55	4.69
AUA2	4.65	4.67	4.62	4.65
AUA3	4.72	4.75	4.67	4.75
AUA4	4.76	4.74	4.75	4.79
AUA5	4.63	4.64	4.58	4.66
AUA6	3.91	3.86	3.95	
AUA7	3.84	3.81	3.86	
AUA8	3.17	3.17	3.17	
DA1	3.96	3.90	3.98	3.99
DA10	4.22	4.26	4.22	4.19
DA2	3.23	3.41	3.15	3.12
DA3	3.81	3.89	3.83	3.70
DA4	3.37	3.36	3.34	3.40
DA5	4.49	4.48	4.51	4.47
DA6	4.53	4.51	4.53	4.54
DA7	4.38	4.42	4.36	4.37
DA8	4.48	4.47	4.42	4.56
DA9	4.48	4.47	4.53	4.43

Table 2.2b
SDP - PSI Results
Asphalt - Concrete

SECTION	SDP-AVG	SDP-1	SDP-2	SDP-3
AVCA1	4.64	4.58	4.67	4.69
AVCA2	4.74	4.74	4.74	4.75
AVCA3	4.72	4.66	4.75	4.75
BCA1	4.41	4.38	4.40	4.44
BCA2	4.16	4.13	4.25	4.09
BCA3	4.08	4.07	4.13	4.05
BCA4	4.05	4.03	4.06	4.06
BCA5	4.11	4.14	4.07	4.11
BCA6	4.13	4.14	4.14	4.12
BYCA1	3.96	3.85	4.06	3.98
BYCA11	4.38	4.36	4.40	4.38
BYCA12	4.25	4.31	4.20	4.24
BYCA2	4.25	4.15	4.34	4.27
BYCA3	4.28	4.22	4.28	4.35
BYCA4	4.41	4.39	4.42	4.42
BYCA6	3.02	3.01	3.00	3.06
BYCA7	3.38	3.64	3.30	3.20
BYCA9	3.10	3.13	2.99	3.18
LUCA2	3.50	3.46	3.55	3.48
LUCA3	3.10	3.05	3.11	3.13

Table 2.3
WRD-SI Results

SECTION	WRD-SI	SECTION	WRD-SI
Asphalt		Asphalt - Concrete	
AUA1	4.7	AVCA1	4.6
AUA2	4.6	AVCA2	4.7
AUA3	4.6	AVCA3	4.7
AUA4	4.8	BCA1	4.4
AUA5	4.9	BCA2	4.1
AUA6	3.7	BCA3	4.1
AUA7	4.0	BCA4	4.1
AUA8	3.2	BCA5	4.1
DA1	3.9	BCA6	4.1
DA10	4.2	BYCA1	4.0
DA2	3.4	BYCA11	4.4
DA3	3.9	BYCA12	4.3
DA4	3.3	BYCA2	4.3
DA5	4.6	BYCA3	4.3
DA6	4.5	BYCA4	4.4
DA7	4.1	BYCA6	3.0
DA8	4.2	BYCA7	3.4
DA9	4.5	BYCA9	3.0
		LUCA2	3.5
		LUCA3	3.1

Table 2.4a
California Profilograph
Asphalt

SECTION	0.1 Blanking RUN 1	RUN2	AVERAGE	0.2 Blanking RUN 1	RUN 2	AVERAGE
AUA1	8.75	7.5	8.13	3	1.25	2.13
AUA2	6.5	10.5	8.5	2	1.25	1.63
AUA3	12.5	9	10.75	0.75	1	0.88
AUA4	6.5	9.25	7.88	1.25	1	1.13
AUA5	12.5	5.75	9.13	2	1	1.5
AUA6	14.25		14.25	0.75		0.75
AUA7	28.5		28.55	15		15
AUA8	49.75		49.75	33.5		33.5
DA1	24	23.75	23.88	16	14.25	15.13
DA2	61.25	55.75	58.5	48.25	46	47.13
DA3	30.75	29.75	30.25	20.5	19.75	20.13
DA4	54.75	55.25	55	44.5	43.5	44
DA5	13.25	14.25	13.75	6.75	8.25	7.5
DA6	9.25	10.75	10	6	1.75	3.88
DA7	13.75	12	12.88	4.75	6	5.38
DA8	10	10.25	10.13	4.5	5.25	4.88
DA9	11.75	12	11.88	4.75	4.25	4.5
DA10	12.5	18.75	15.63	6.25	6.5	6.38

Table 2.4b
California Profilograph
Asphalt - Concrete

	0.1 Blanking				0.2 Blanking			
	RUN1	RUN2	RUN3	AVERAGE	RUN1	RUN2	RUN3	AVERAGE
AVCA1	10.5	9.75		10.13	0.75	1		0.88
AVCA2	7.25	8.75		8	0.75	1.25		1
AVCA3	9	8.5		8.75	2.75	2		2.38
BCA1	22	20.75		21.38	15	8.25		11.63
BCA2	20.5	17.75		19.13	9	10		9.5
BCA3	13	17.25	18.5	16.25	6	4.25	6.75	5.67
BCA4	17.25	18.5	15.75	17.17	7.75	12.25	10.5	10.17
BCA5	19.75	13.5	26.5	19.92	6.25	5.25	4.75	5.42
BCA6	12	21.5	27.25	20.25	2.25	3.25	3	2.83
BYCA1	16	12		14	4.25	4.75		4.5
BYCA11	13.25	10.25		11.75	3.5	3.5		3.5
BYCA12	18.25	24		21.13	17.75	13.25		15.5
BYCA2	12	11		11.5	5.5	1.5		3.5
BYCA3	17	12.75		14.88	6	6		6
BYCA4	7.25	16.5		11.88	3.5	2.75		3.13
BYCA6	50.75	43.5		47.13	26.5	23.5		25
BYCA7	35	31.25		33.13	26.5	29.25		27.88
BYCA9	49.25	47.5		48.38	34	35.75		34.88
LUCA2	43.75	52		47.88	34.5	35		34.75
LUCA3	20.5	29.5		25	8	12.5		10.25

Table 2.5a
Rainhart Profilograph
Asphalt

	0.1 Blanking			0.2 Blanking		
	RUN1	RUN2	AVERAGE	RUN1	RUN2	AVERAGE
AUA1	2.5	2.25	2.38	0	0	0
AUA2	1.75	1.25	1.5	0	0	0
AUA3	1.25	0.75	1	0	0	0
AUA4	2.5	1.5	2	0	0	0
AUA5	2.75	1.75	2.25	0	0	0
AUA6	8.75		8.75	4		4
AUA7	15.5		15.5	9.5		9.5
AUA8	27.5		27.55	20.75		20.75
DA1	9	10.75	9.88	0.75	0.5	0.63
DA2	24.75	25.75	25.25	12.75	9.75	11.25
DA3	11.75	15.5	13.63	4.75	4.5	4.63
DA4	25	26.5	25.75	12.25	12	12.13
DA5	4.75	6.75	5.75	0.75	0.5	0.63
DA6	3.75	5.25	4.5	0	0	0
DA7	2.75	4	3.38	1.25	0.5	0.88
DA8	2.5	6.5	4.5	0.25	0	0.13
DA9	3.5	1.25	2.38	0	0.5	0.25
DA10	4.25	2.25	3.25	0.25	2	1.13

Table 2.5b
Rainhart Profilograph
Asphalt - Concrete

	0.1 Blanking				0.2 Blanking			
	RUN 1	RUN 2	RUN 3	AVERAGE	RUN 1	RUN 2	RUN3	AVERAGE
AVCA1	2	0.75		1.38	0.25	0.25		0.25
AVCA2	0.5	0.75		0.63	0	0		0
AVCA3	0.25	1.75		1	0	0		0
BCA1	10.75	4.25		7.5	0	1.25		0.63
BCA2	9.75	4.5		7.13	1.5	2		1.75
BCA3	5.5	2.75	4.75	4.33	0.75	1.25	1.25	1.08
BCA4	6.5	4.5	2.5	4.5	0.5	0.75	1.25	0.83
BCA5	5	3.5	4.25	4.25	1	2	2	1.67
BCA6	3.25	2.75	8.5	4.83	0.25	1.75	1	1
BYCA1	3	2.5		2.75	2	1.5		1.75
BYCA11	3.25	5		4.13	2.5	1.5		2
BYCA12	3.5	2		2.75	0.5	0		0.25
BYCA2	3.75	4.5		4.13	1.25	1.25		1.25
BYCA3	2.5	2.5		2.5	1.25	2		1.63
BYCA4	1.5	3		2.25	0.5	2.5		1.5
BYCA6	25.25	21		23.13	6.75	10		8.38
BYCA7	17.5	13		15.25	4.25	5.5		4.88
BYCA9	32	31.75		31.88	11.75	9.5		10.63
LUCA2	15.25	18		16.63	5.75	8.75		7.25
LUCA3	12.25	11.5		11.88	4	5.5		4.75

CHAPTER 3

DATA ANALYSIS

In this chapter the data collected is correlated and presented. First, a comparison between the Rainhart and California profilographs is shown. This comparison included the Rainhart vs. California units using 0.1 inch and 0.2 inch blanking bands. Also, each profilograph was compared to one another for each of these two bands. The profilograph indices were then plotted against PSI from the SDP. Separate plots for all the above combinations are given for asphalt pavements and concrete pavements with asphalt overlays. Tables 3.1a and 3.1b provide the equations for the linear regressions used. Because of the large number of figures, they are placed at the end of the Chapter. Table 3.2 provides the average and variance of the repeat data runs.

California vs. Rainhart Profilographs

The profile index determined from the selected sections were computed for both classes of pavement types, for both profilographs, and for both the 0.1 and 0.2 inch blanking bands. The results of these different combinations are presented in Figures 3.1a and 3.1b through 3.6a and 3.6b. The correlation is expressed in terms of a simple linear regression. The regression was computed for each combination and presented in these figures. The regression coefficients are given in Tables 3.1a and 3.1b. The correlation coefficient and standard error of regression are given on each figure. The independent variable used for each case is the variable along the x axis, although no particular reason was used in selecting one variable over the other as the independent or dependent variable. Finally, for this first set of plots, the profile index used for each case is the average of the two or three data runs. The plots depict all data runs with PSI of 3.0 and greater.

Figures 3.1a and 3.1b illustrate the relationships between the California profilograph using 0.1 inch blanking to 0.2 inch blanking. Currently, the most often used procedure for computing PI has been to use a 0.2 inch blanking band when computing the profile index for the California profilograph, and 0.1 inch when using the Rainhart device. As expected, and similar to what was found for this case for rigid pavements [WAL88], there is a good correlation between these two plots for asphalt pavements.

The PI correlations for data on the overlaid concrete pavements, Fig 3.1b, are not as good as those for asphalt pavements. The correlation between overlaid concrete pavements for the California profilograph using both blanking bands provided an R squared of 0.90.

Figures 3.2a and 3.2b depict the relationship between the 0.1 and 0.2 inch blanking band PI values for the Rainhart profilographs for asphalt pavements, and concrete pavements overlaid with asphalt. As can be noted, the correlation and standard error of regression are not as good for the asphalt pavement case (Figure 3.2a) as for the overlaid concrete pavements (Figure 3.2b). The 0.2 inch blanking band is typically not used for the Rainhart profilograph as it exceeds a considerable amount of roughness. The profile indices for asphalt pavements were typically lower than those for overlaid concrete pavements. This lack of resolution probably explains the different levels of correlation.

Figures 3.3a and 3.3b through 3.6a and 3.6b show the correlations between the two devices for each blanking band. Figures 3.3a and 3.3b illustrate the differences between the California and Rainhart devices for a 0.1 inch blanking band and Figures 3.4a and 3.4b for the 0.2 inch blanking band. Figures 3.5a and 3.5b illustrate the 0.1 inch blanking band for the California vs. the 0.2 inch blanking band for the Rainhart and Figures 3.6a and 3.6b, the reverse. Notice that the California 0.2 inch blanking band vs. the Rainhart 0.1 inch blanking band provides the best correlations for asphalt pavements, the normally used blanking band selections. However, the California 0.1 inch blanking band vs. the Rainhart 0.1 inch and the California 0.1 inch vs. Rainhart 0.2 inch blanking band give the best correlation for the case of concrete pavements with asphalt overlays. The results using the Rainhart 0.2 inch blanking band, however, might be questionable because of resolution (or lack of detail) characteristics of this blanking band. These results could also reflect problems or inconsistencies in the asphalt overlays like the rutting for example, which was noted in several of the concrete pavements with asphalt overlays or the reflective cracking.

California and Rainhart Profilograph vs. PSI

Figures 3.7a and 3.7b through 3.10a and 3.10b provide plots of PSI from the SDP and PI from the profilographs. For these plots all sections are used, and for both profilographs and blanking bands. As in the earlier figures (Figs 1-6), the values plotted are the average of the repeat runs. As can be noted, the rougher the profile index readings, the lower the PSI. However, as also can be noted, there is a lot of variation in the concrete pavements with asphalt overlays. As can be seen from the figures, the asphalt runs included slightly more sections below a PSI of 4.0 than for the concrete with asphalt overlay. A linear regression or correlation was not done for these cases as the primary interest was in the smoother pavements. However, it is noted that the data does suggest a quadratic relationship. Although not illustrated, a regression was also performed for the California 0.2 and Rainhart 0.1 blanking bands for the asphalt pavements. For this regression a square root transformation was used on the PI values to make a better fit. A 0.94 and 0.93 R square was obtained for the California and Rainhart profilographs respectively. Thus for this greater range of roughness, a quadratic relationship should probably be used.

A correlation is indicated in Figures 3.11a and 3.11b through 3.14a and 3.14b which provide relationships between PSI and profile index for the individual data runs. In the previous plots, the average of the repeat runs were used. Also, only the pavements with a PSI above 3.5 were selected so the smoother sections could be investigated more carefully. In these figures, a linear regression was performed between PSI and profile index. The regression line is given along with the 90% confidence bands for this regression. As can be noted from both the figures and in Tables 3.1a and 3.1b, the R square for the regression is good for the asphalt pavement correlations but lacking for the asphalt overlays over concrete. Recall that the R square is a measure of the percent of variation explained by the regression. A better R square occurs when average data are used. When the average values between repeat runs are used to develop the regression, the California profilograph R square for the 0.2 blanking band data increases from 0.89 to 0.92. This occurs because where the averages are used, the variations about the regression line are less, which is what the R square statistic indicates. Most current profilograph specifications are for single runs. Because of the variations noted in this study, perhaps multiple runs should be considered.

Variations Between Repeat Data Runs

The average and variations between data runs are provided in Table 3.2. The table provides the average values of the profilograph runs for both blanking bands, both profilograph, and both pavement types. Also indicated is the variance between the repeat data runs, i.e., this is not the overall variance. The values in the table are for the PSI values, 3.5 and greater, the same range used in Figures 3.11 through 3.14. As can be noted from table 3.2, the concrete pavements with asphalt overlays exhibit over a two to one greater variation than the asphalt pavements in all but one case. With the 20 and 13 degrees of freedom respectfully, these results would be statistically significant for three of the four cases shown in the table. In the one case the variations were not as significant as was for the Rainhart using the 0.1 blanking band. However, the same trend exists. The results appear consistent with the previous correlations provided in this report. The variations include both run to run variations, as well as, obtaining the profilograph readings. From the previous study [WAL88], it was noted that an average variation of 0.75 to 1 profile index reading could occur between different people reading the profilograph records, depending on the roughness. An estimate of the number of multiple runs needed for an allowable error can be made if the true population variance is known. An estimate of the number of multiple runs needed for an allowable error and a desired confidence can be made if the true or at least a close estimate of the population variance is known. However, an experiment specifically designed for this purpose would need to be conducted which would consider additional profilographs, more repeat runs, and other such variations as different wheel paths, etc.

Also of interest are the results between the two profilograph types. The California profilograph data had somewhat less variation between the 0.2 California blanking band and the 0.1 Rainhart blanking band data. However, it would not be statistically correct to assume that Rainhart data, in general had greater variation than the California profilograph data without additional studies, since only one of each profilograph type was used. Also, one would have to assume that the two profilographs gave similar results for this blanking band combination.

Because of the different results found between the asphalt pavements and the concrete pavements with asphalt overlays, the spectral density between the two class of pavements was computed. Figure 4.15 illustrates the average power spectral density of the two pavements types for all pavements with a PSI of 4.0 and greater. As noted from this figure, the concrete pavements with the asphalt overlays had a greater overall average power level than the other pavement type. No attempt was made to analyze this further because the analysis would have to be very detailed and probably consider such things as the design for the overlay, the time of the overlay, the condition of the existing concrete pavement and the roughness wavelengths, the initial pavement design including type of base, overlay thickness, traffic loading, etc.

SDP vs WRD

As noted in Chapter 2, the WRD was used primarily for initial section selection and some sections were only run once. The WRD roughness statistics are correlated to PSI from the SDP using the Austin test sections and this correlated value is the SI value provided by the WRD. Figures 3.16a and 3.16b illustrate the plot of the recorded SI values from the WRD vs the PSI values from the SDP. The R square of the asphalt and concrete with asphalt overlays were 0.93 and 0.90 respectively. Several different WRD units and vehicles were used for these recordings.

Table 3.1a Coefficients of Regression Models
PSI 3.5 and Greater - Asphalt

Dependent Variable	Independent Variable	Regression Coeff. Constant	Linear	Standard Err.	R Squared
CPI_0.2"	CPI_0.1"	-5.60	0.86	2.14	0.98
RPI_0.2"	RPI_0.1"	-1.81	0.62	2.08	0.88
CPI_0.1"	RPI_0.1"	4.91	1.82	3.83	0.95
CPI_0.2"	RPI_0.2"	4.87	2.09	8.04	0.71
CPI_0.1"	RPI_0.2"	11.8	2.52	8.01	0.79
CPI_0.2"	RPI_0.1"	-1.35	1.57	4.02	0.93
PSI	CPI_0.1"	4.94	-0.04	0.14	0.80
PSI	CPI_0.2"	4.71	-0.05	0.11	0.89
PSI	RPI_0.1"	4.72	-0.06	0.15	0.78
PSI	RPI_0.2"	4.52	-0.11	0.20	0.57

Note:

CPI: California Profile Index
RPI: Rainhart Profile Index
PSI: SDP Profile Service Index

Table 3.1b Coefficients of Regression Models
PSI 3.5 and Greater - Asphalt - Concrete

Dependent Variable	Independent Variable	Regression Coeff. Constant	Linear	Standard Err.	R Squared
CPI_0.2"	CPI_0.1"	-6.368	0.81	3.59	0.90
RPI_0.2"	RPI_0.1"	-0.130	0.35	0.79	0.93
CPI_0.1"	RPI_0.1"	10.236	1.46	4.75	0.87
CPI_0.2"	RPI_0.2"	2.809	3.15	5.64	0.75
CPI_0.1"	RPI_0.2"	11.220	3.95	5.02	0.86
CPI_0.2"	RPI_0.1"	1.888	1.18	5.21	0.79
PSI	CPI_0.1"	4.647	-0.02	0.20	0.56
PSI	CPI_0.2"	4.424	-0.03	0.22	0.47
PSI	RPI_0.1"	4.473	-0.05	0.21	0.48
PSI	RPI_0.2"	4.412	-0.13	0.21	0.51

Note:

CPI: California Profile Index
RPI: Rainhart Profile Index
PSI: SDP Profile Service Index

Table 3.2 Measurement Errors Between Repeat Runs
PSI 3.5 and Greater

ASPHALT

	ca(bb=.1)	ca(bb=.2)	ra(bb=.1)	ra(bb=.2")
AVERAGE(Repeat runs)	16.21	8.675	6.125	1.683
VARIANCE	4.98	1.197	2.022	0.159
STD ERROR	2.23	1.094	1.422	0.398
Degrees of Freedom 13				

ASPHALT OVER CONCRETE

	ca(bb=.1)	ca(bb=.2)	ra(bb=.1)	ra(bb=.2")
AVERAGE(Repeat runs)	17.26	7.354	4.424	1.396
VARIANCE	17.25	2.883	3.914	0.534
STD ERROR	4.15	1.698	1.978	0.731
Degrees of Freedom 20				
V(CPAO)/V(A)	3.46**	2.41*	1.93	3.36**

Hypothesis: Variance of asphalt = Variance of concrete with asphalt
F(.95,20,13) = 2.26
F(.99,20,13) = 3.2
* Significant at 95%
** Significant at 99%

Fig 3.1a

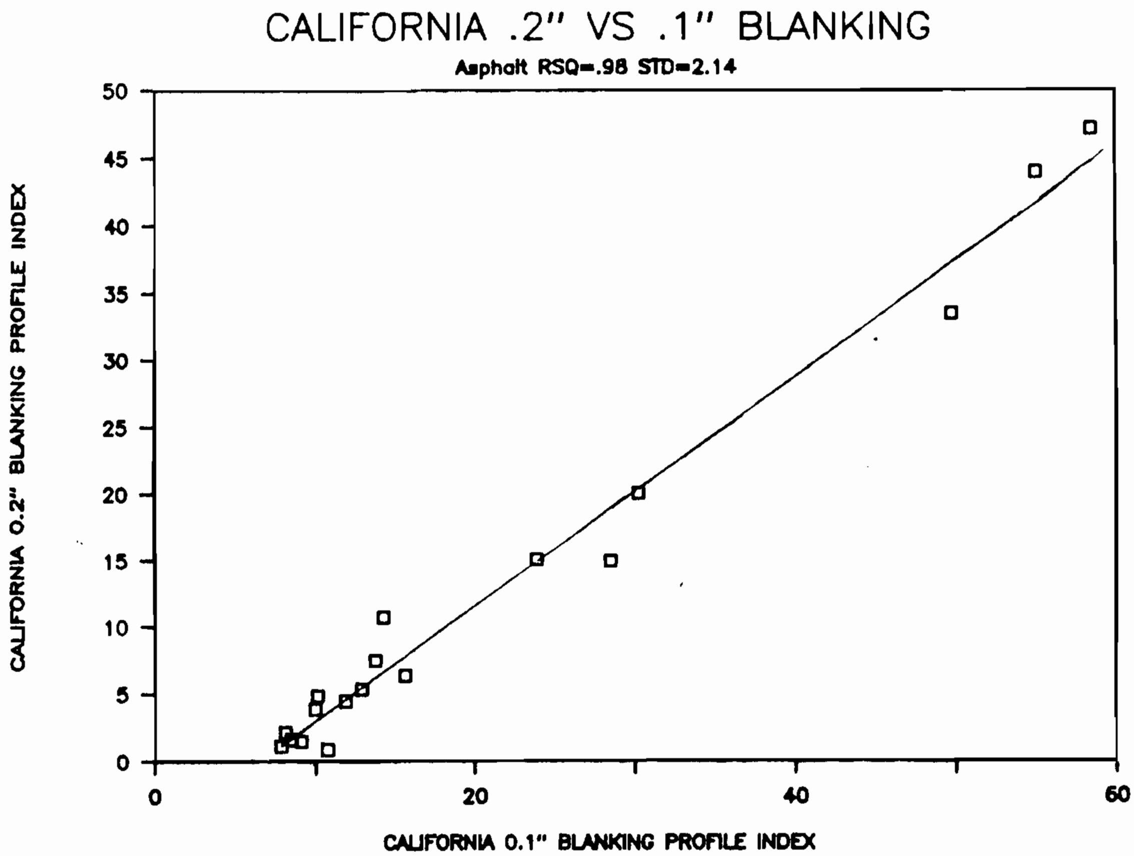


Fig 3.1b

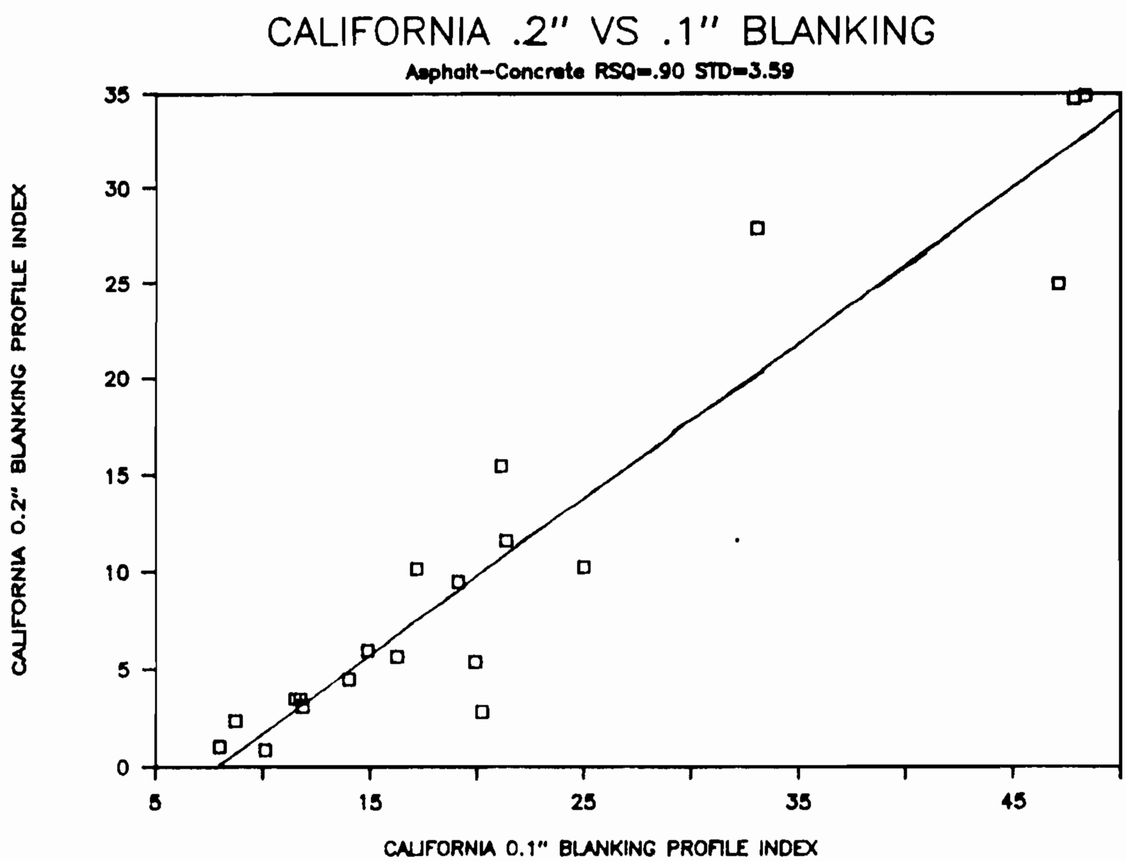


Fig 3.2a

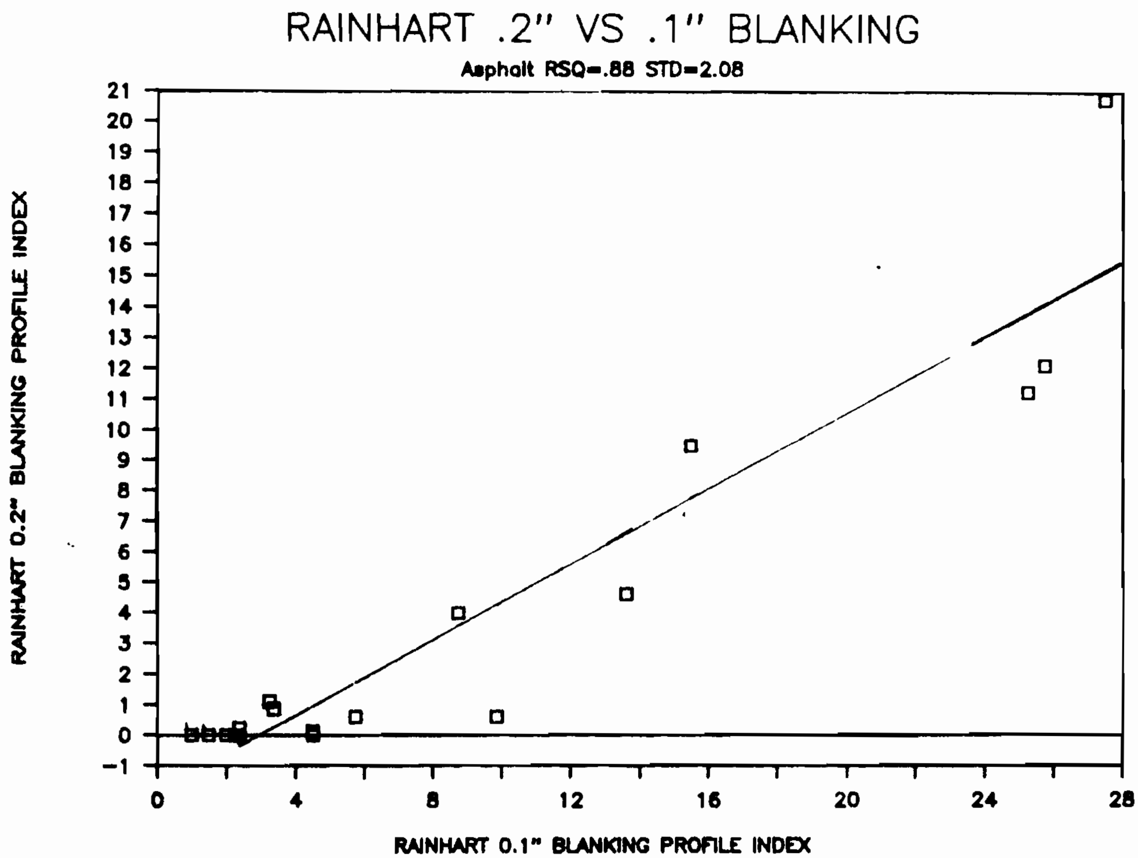


Fig 3.2b

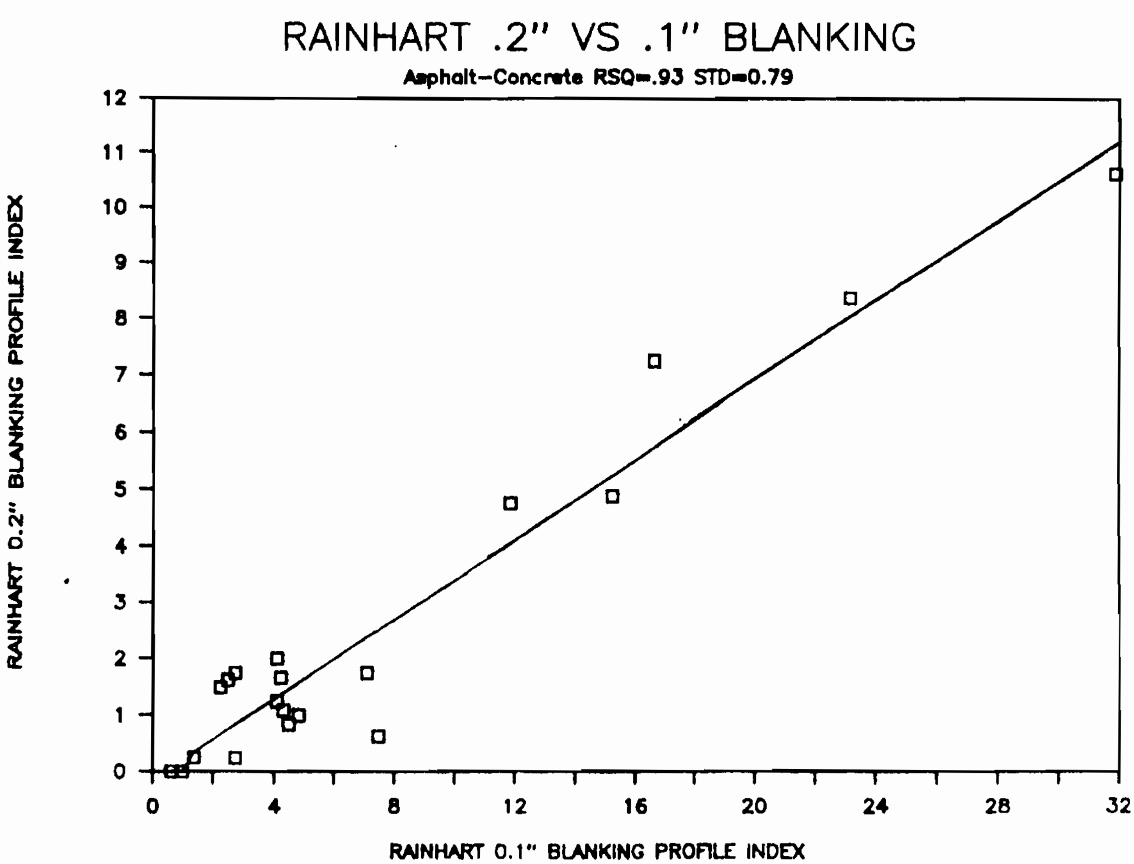


Fig 3.3a

CALIFORNIA .1" VS RAINHART .1"

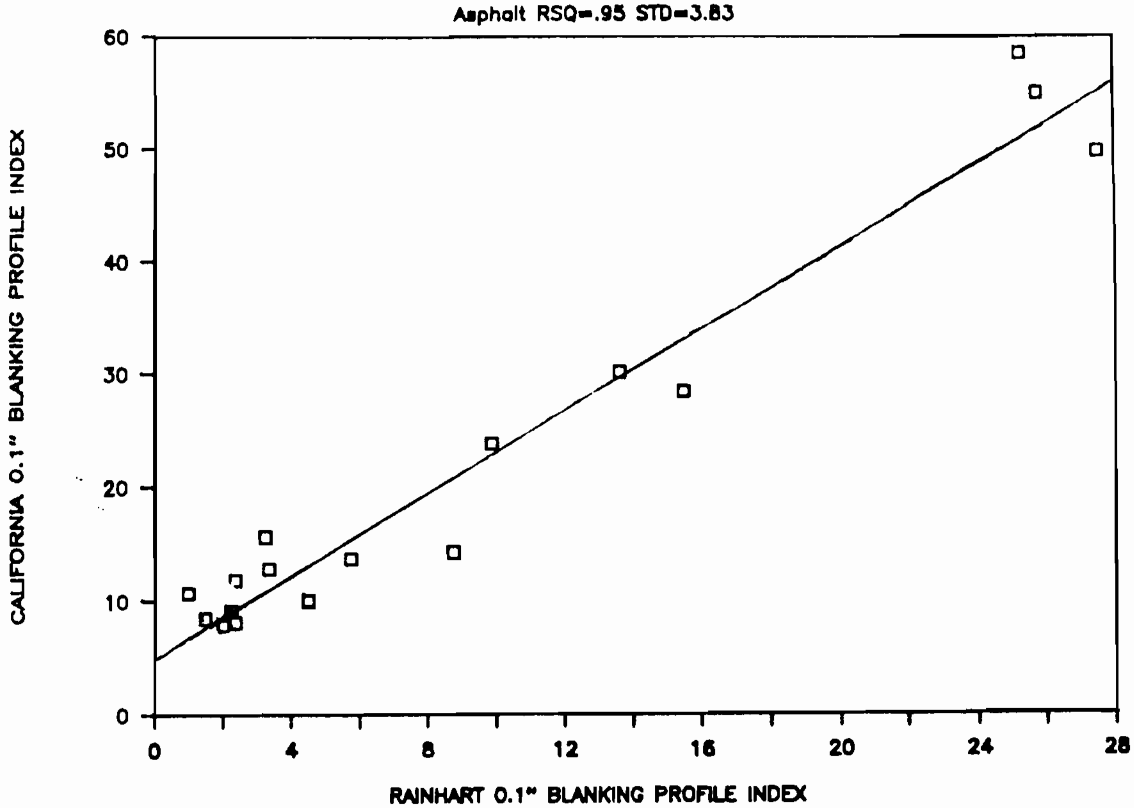


Fig 3.3b

CALIFORNIA .1" VS RAINHART .1" BLANKING

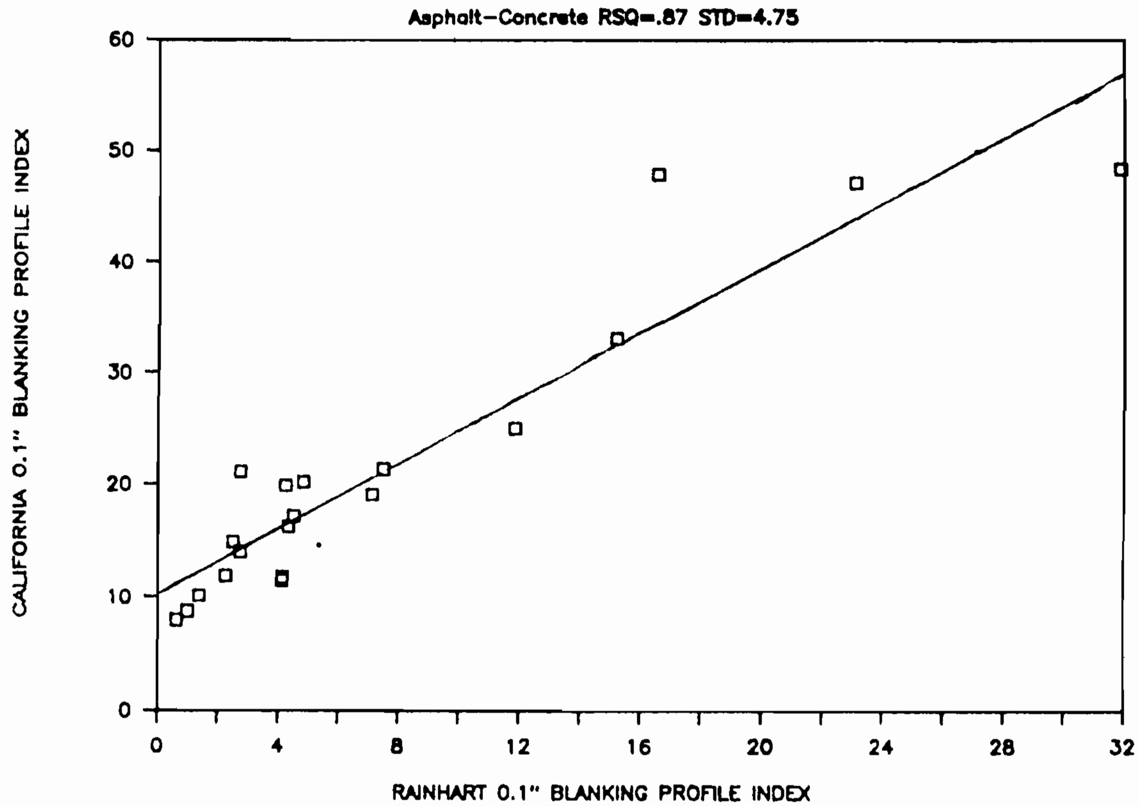


Fig 3.4a

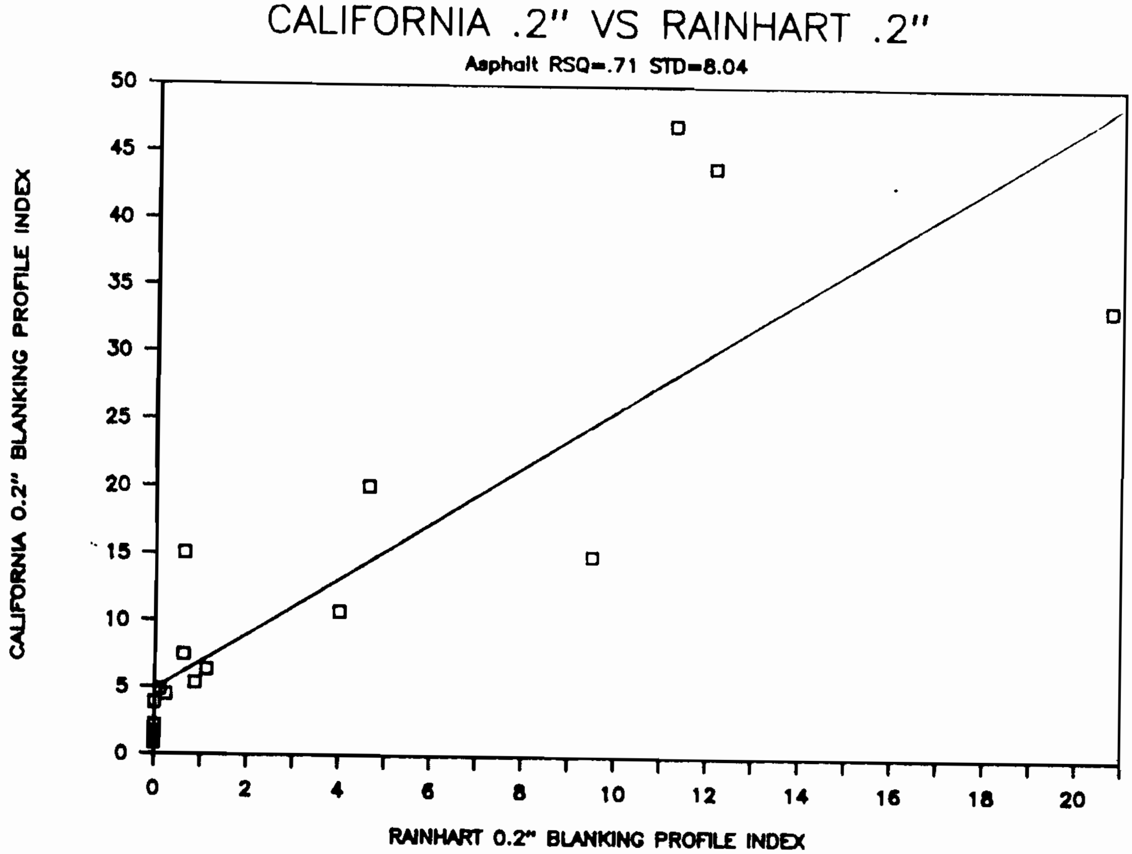


Fig 3.4b

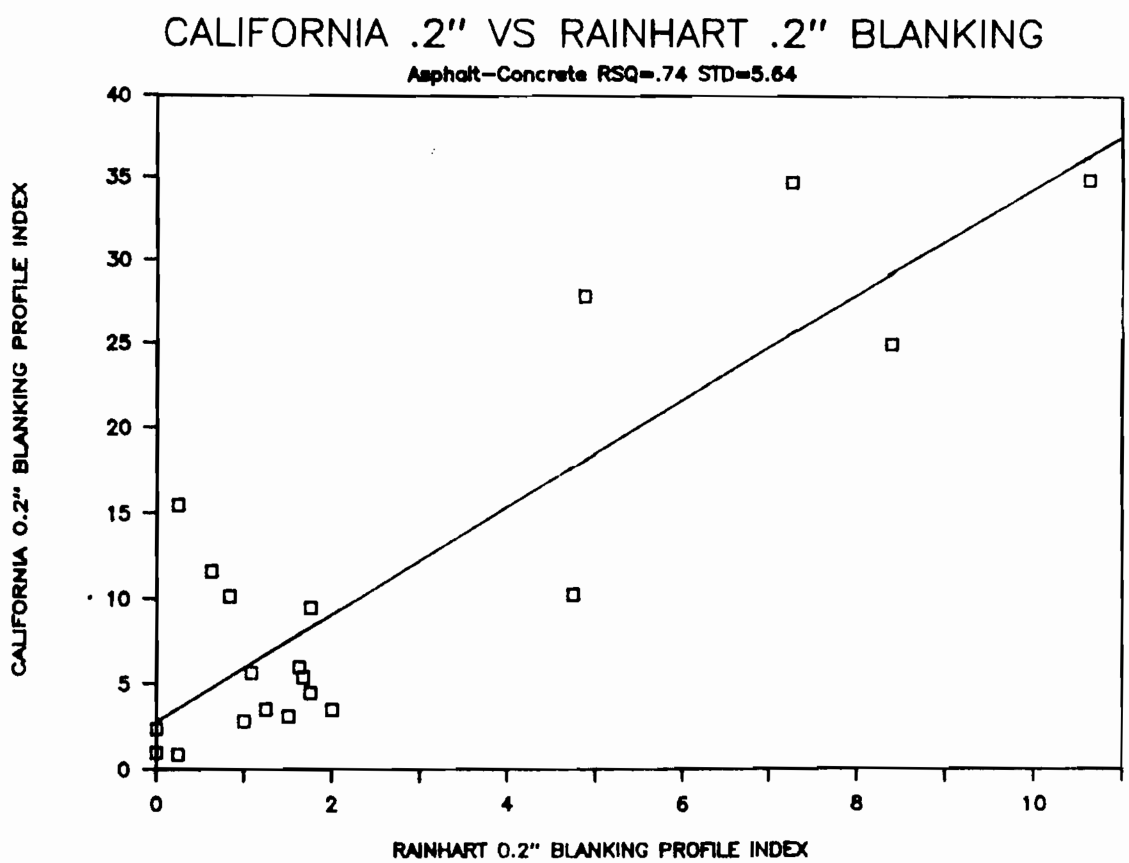


Fig 3.5a

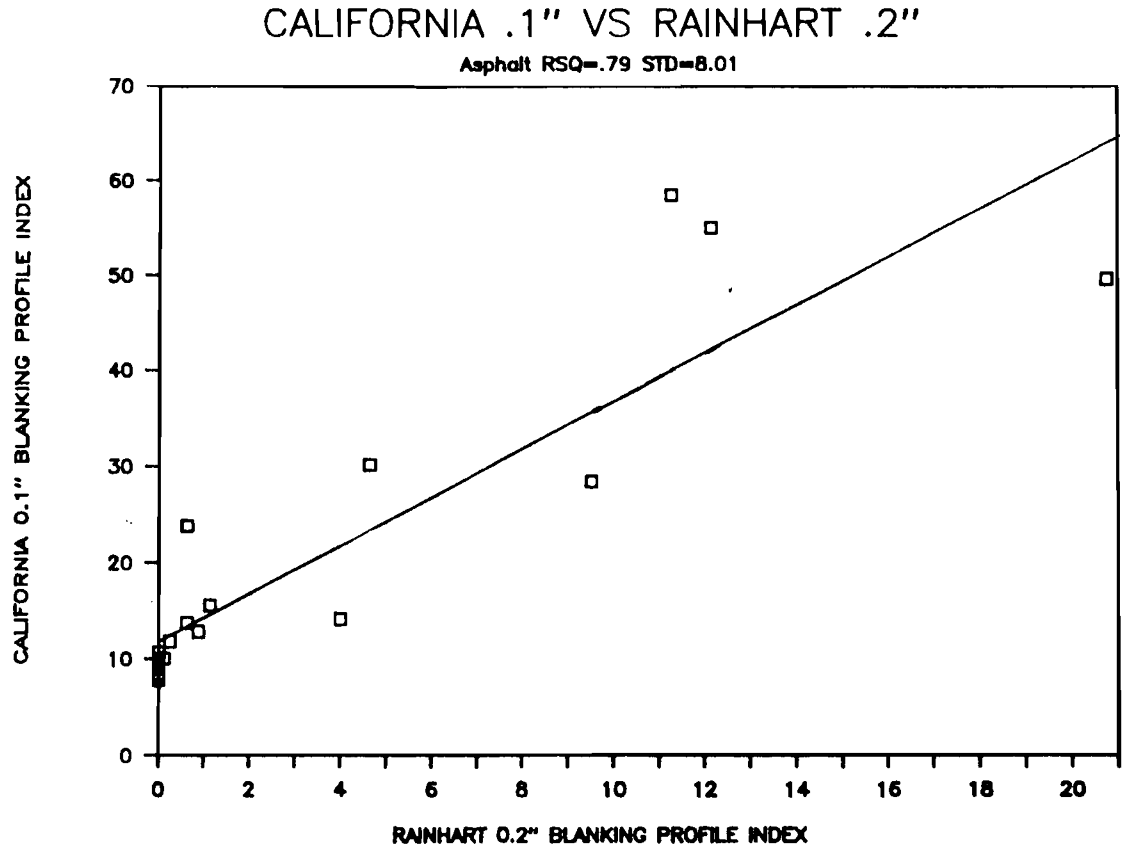


Fig 3.5b

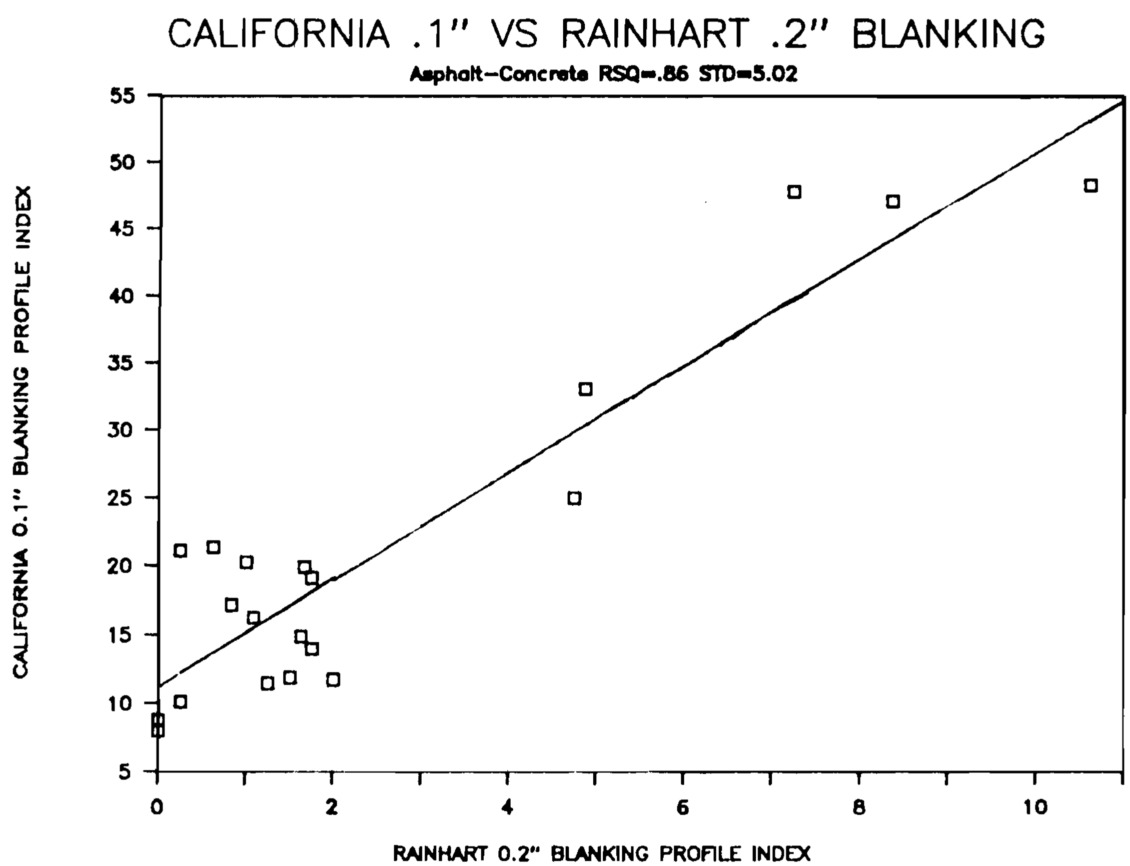


Fig 3.6a

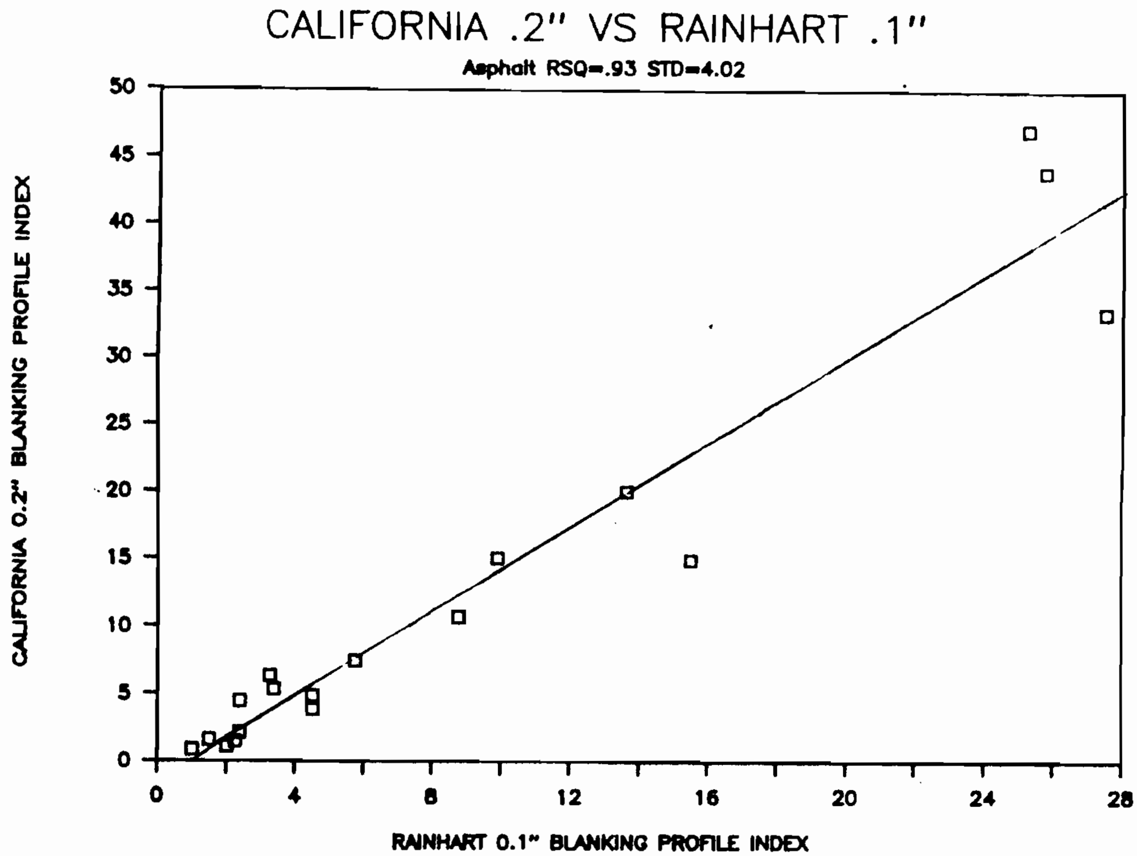


Fig 3.6b

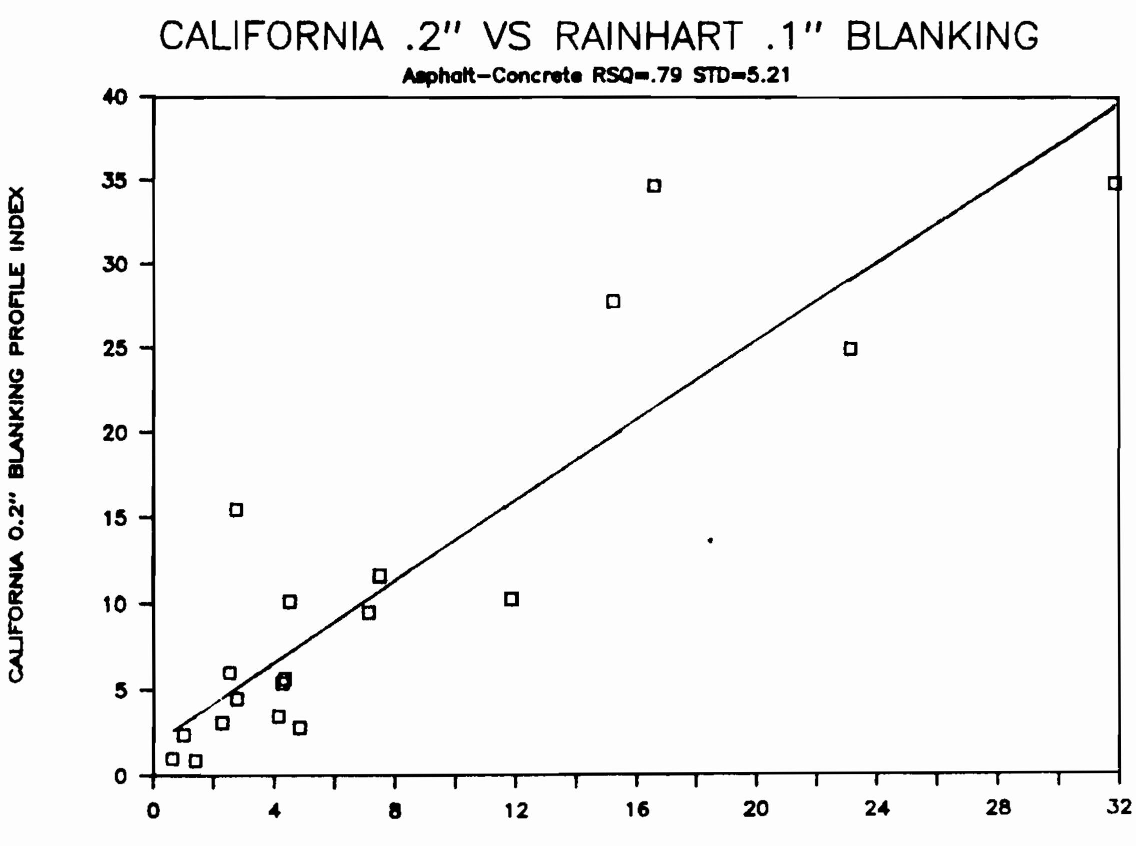


Fig 3.7a

PSI VS CALIFORNIA .1 BLANKING

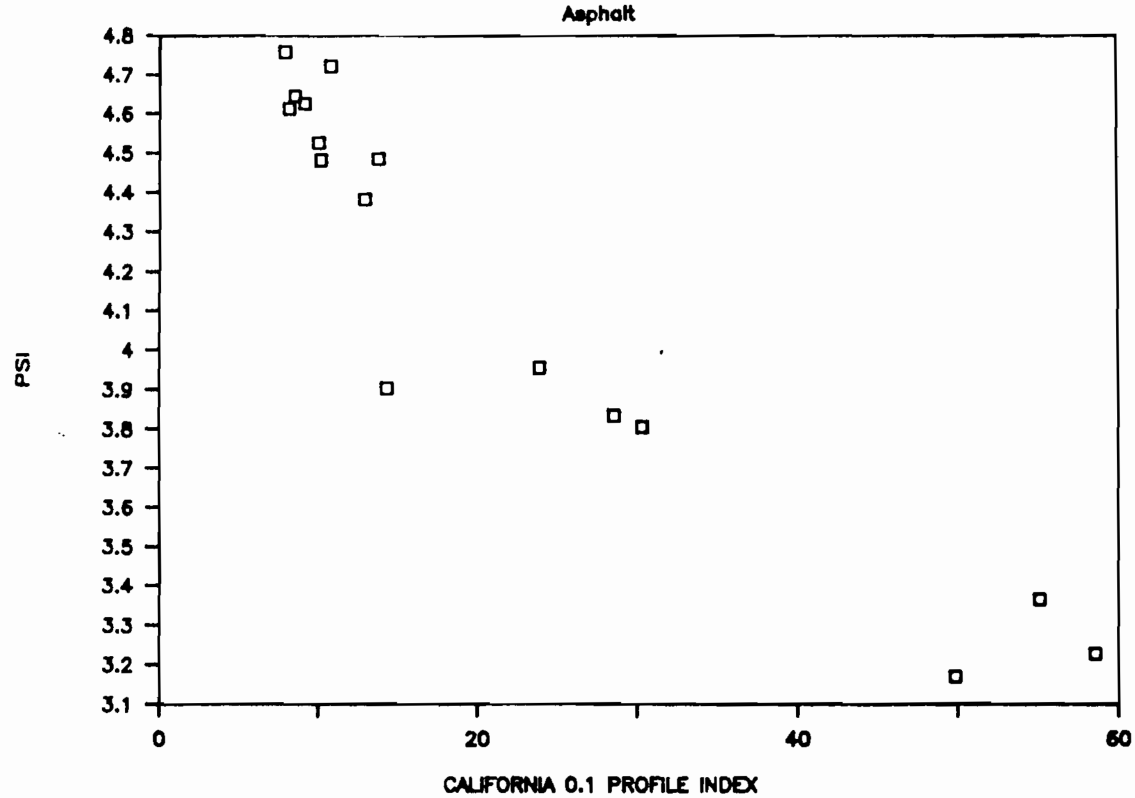


Fig 3.7b

PSI VS CALIFORNIA .1 BLANKING

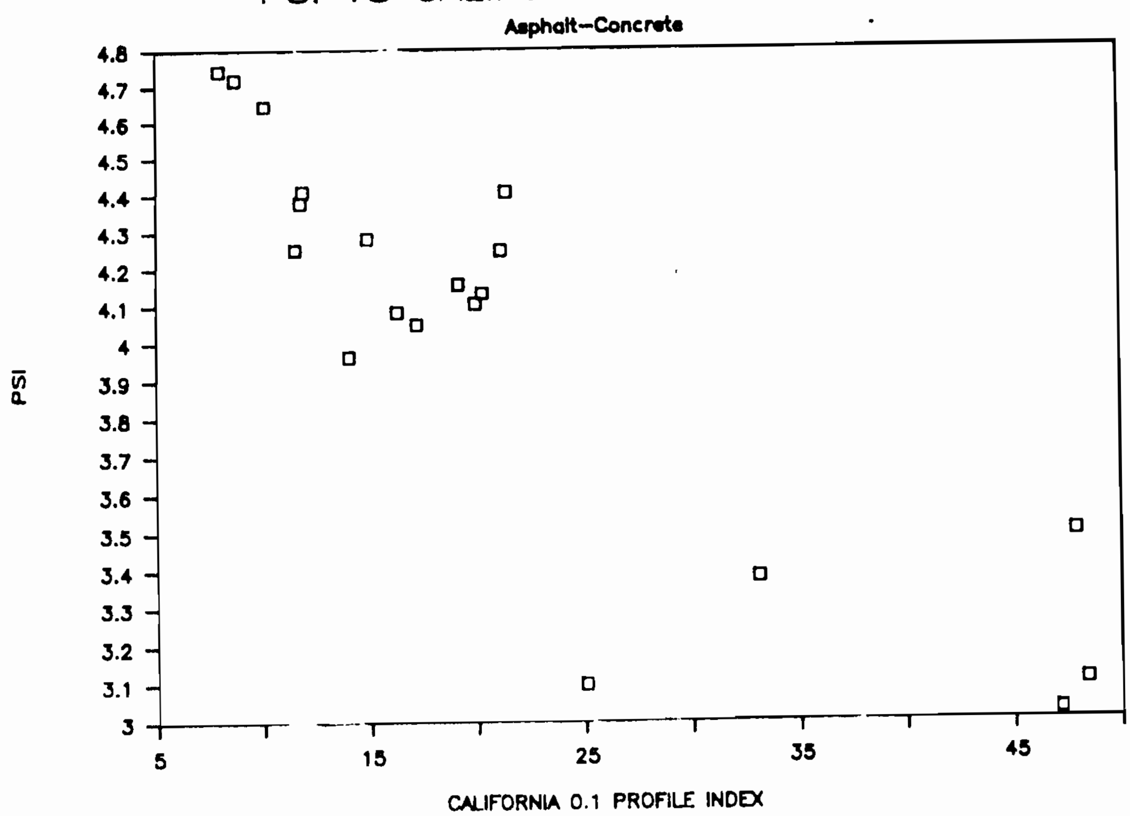


Fig 3.8a

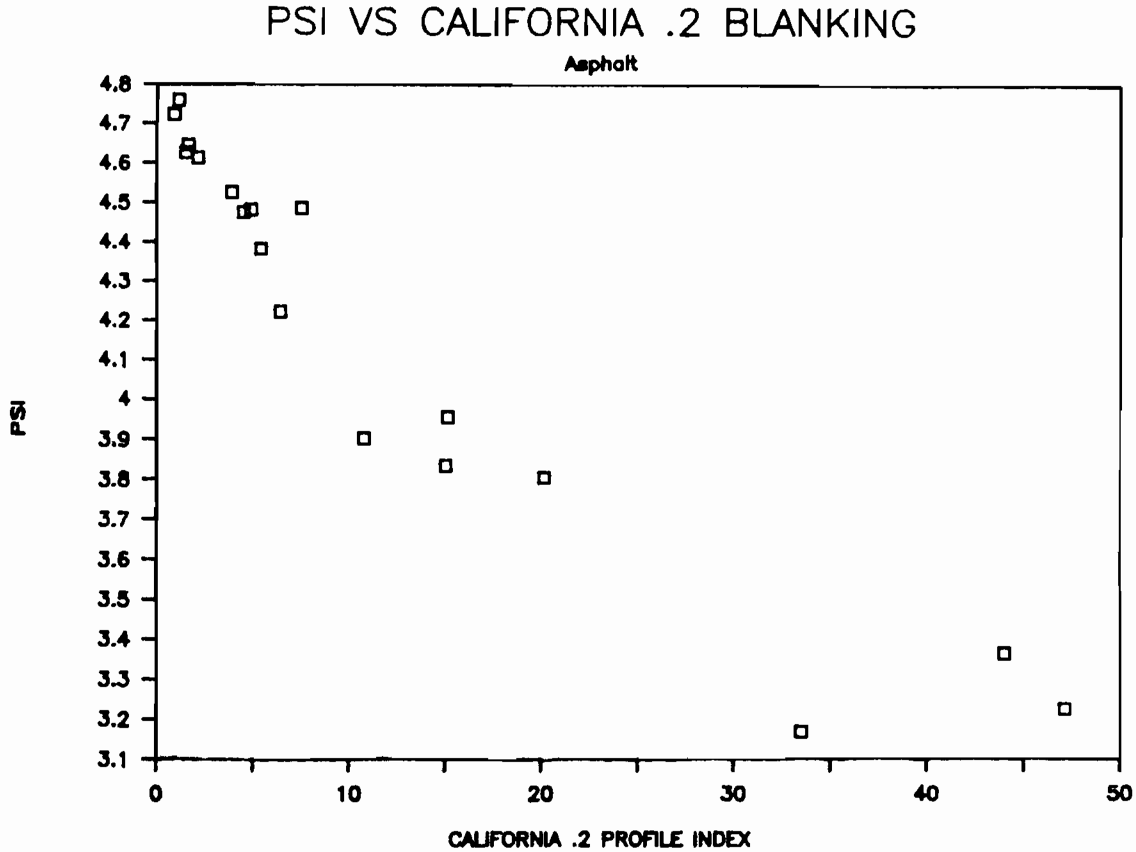


Fig 3.8b

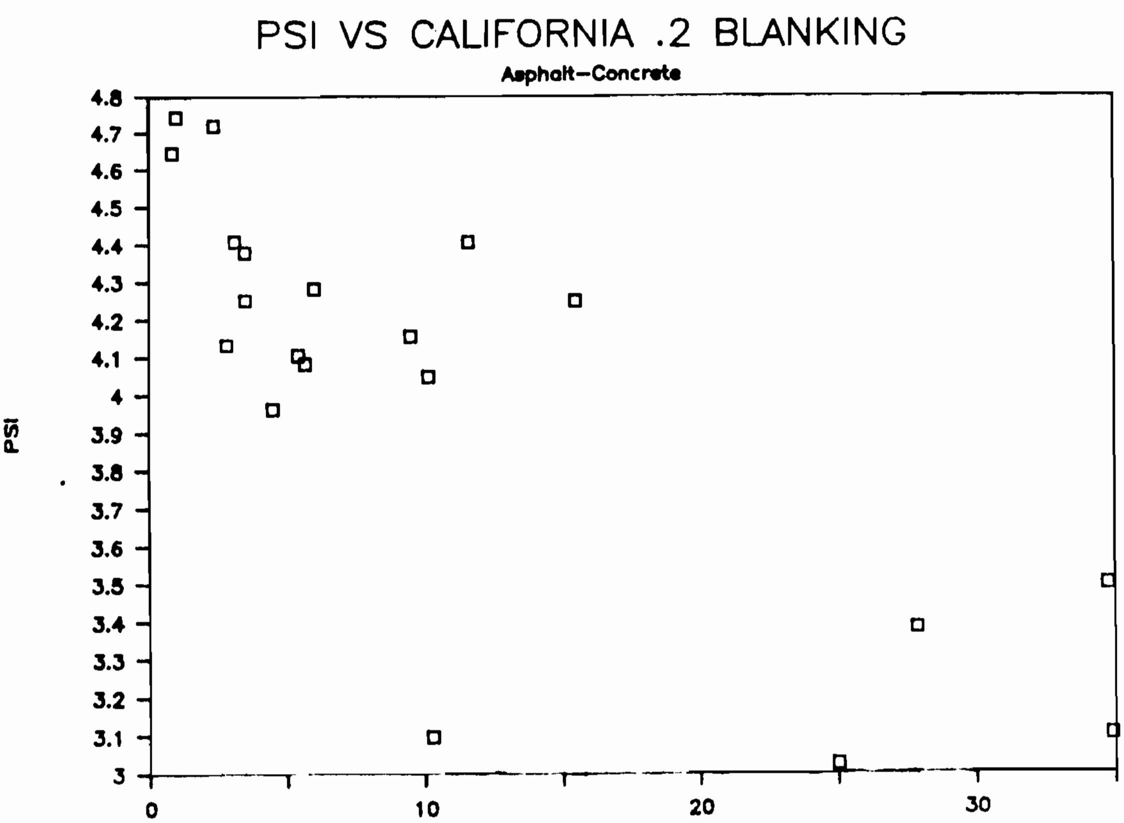


Fig 3.9a

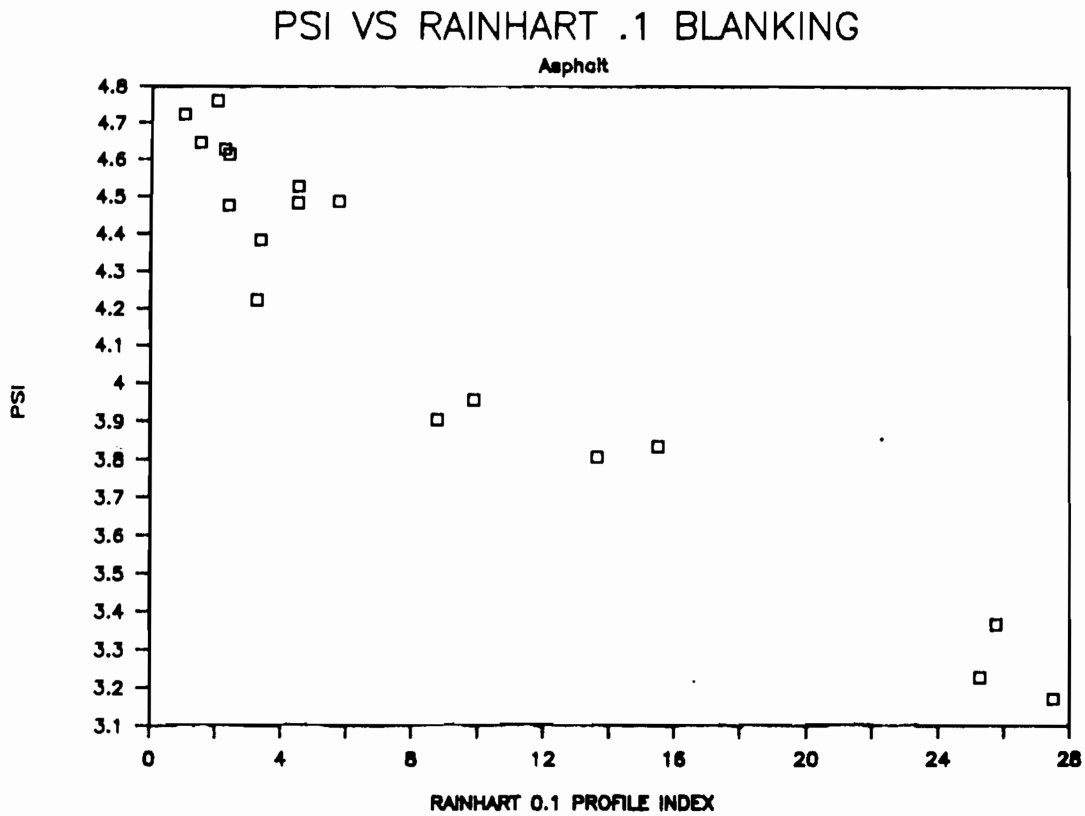


Fig 3.9b

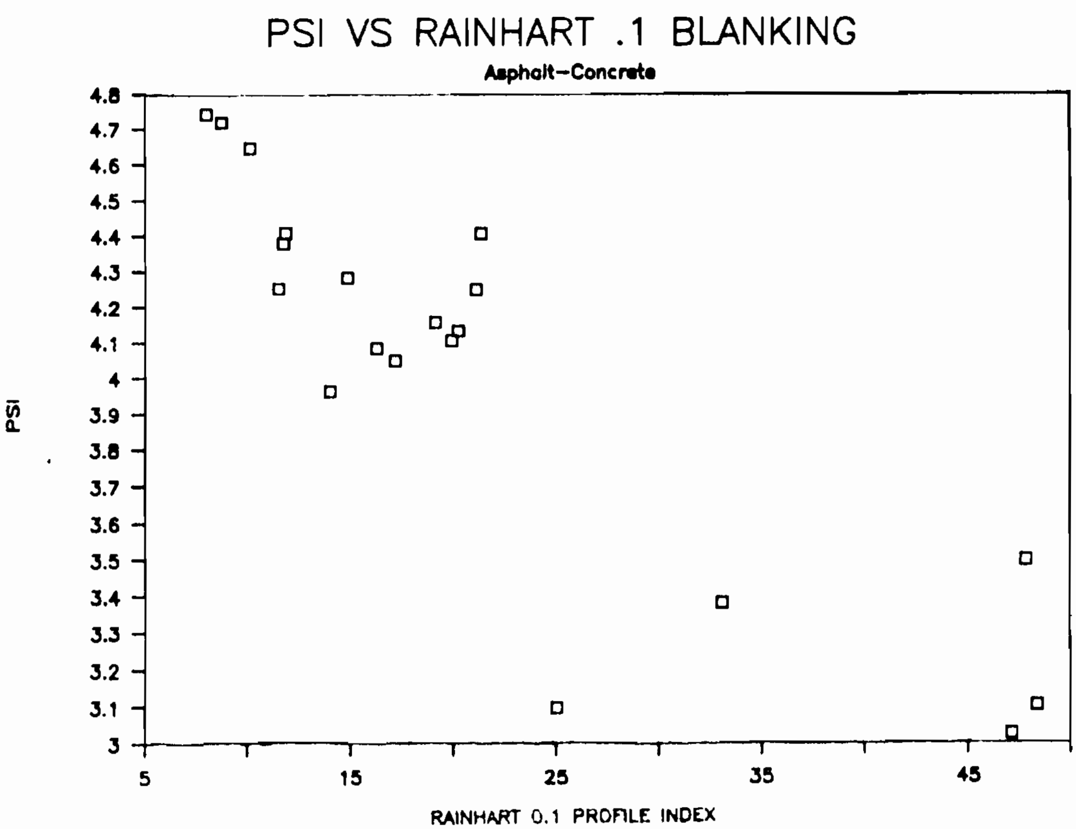


Fig 3.10a

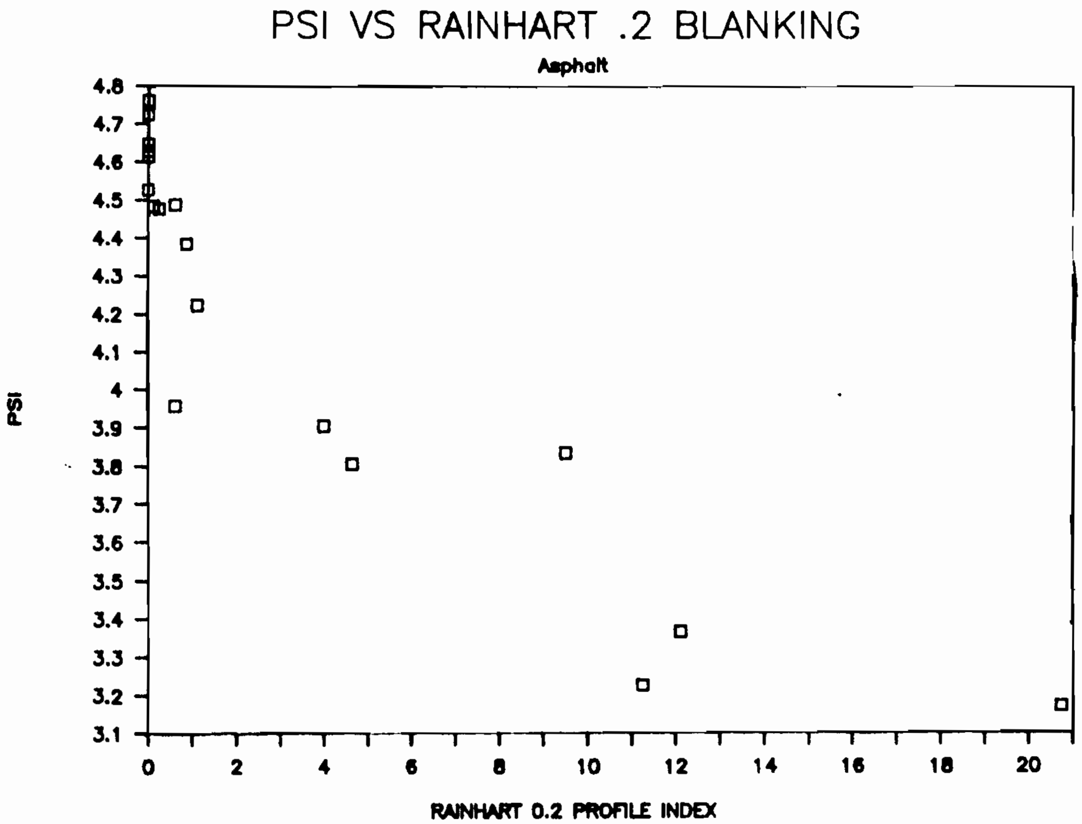


Fig 3.10b

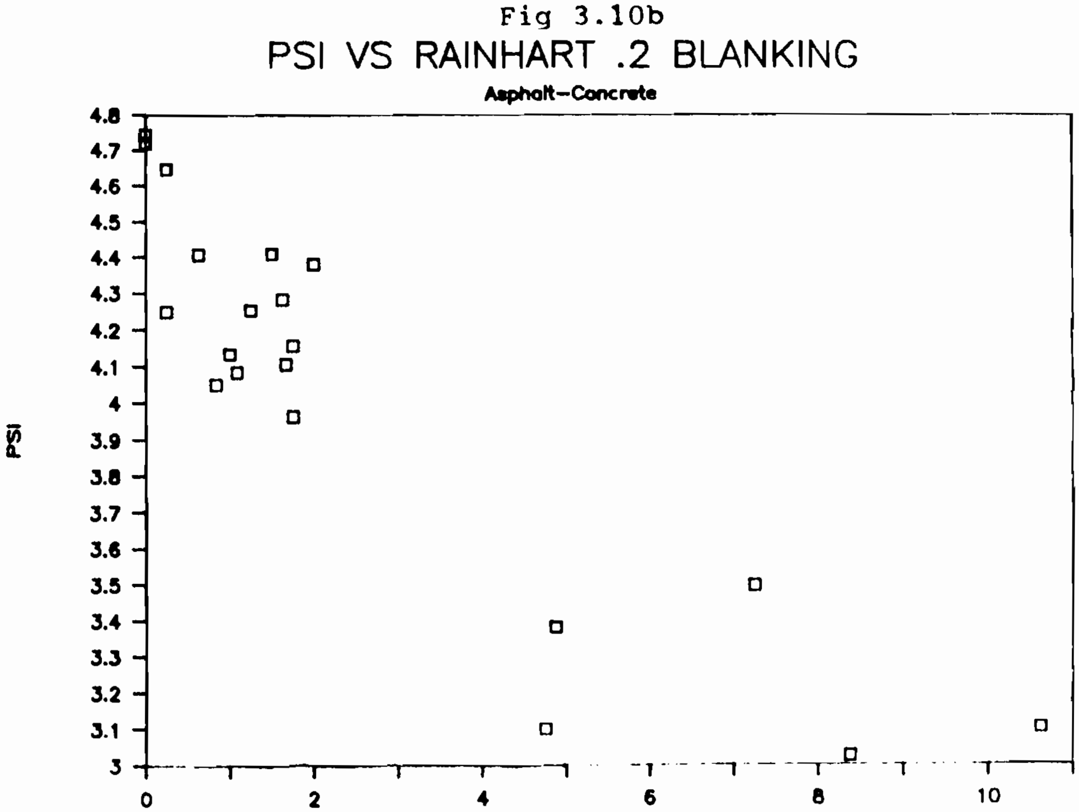


Fig 3.11a

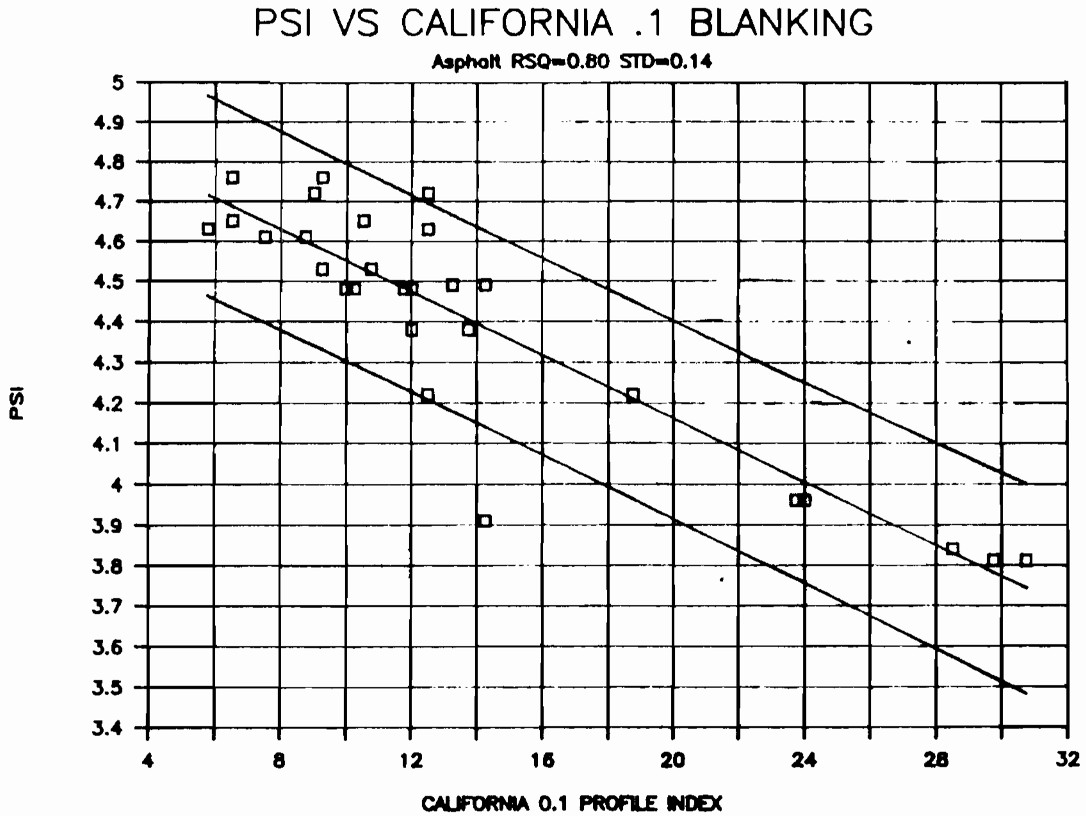


Fig 3.11b

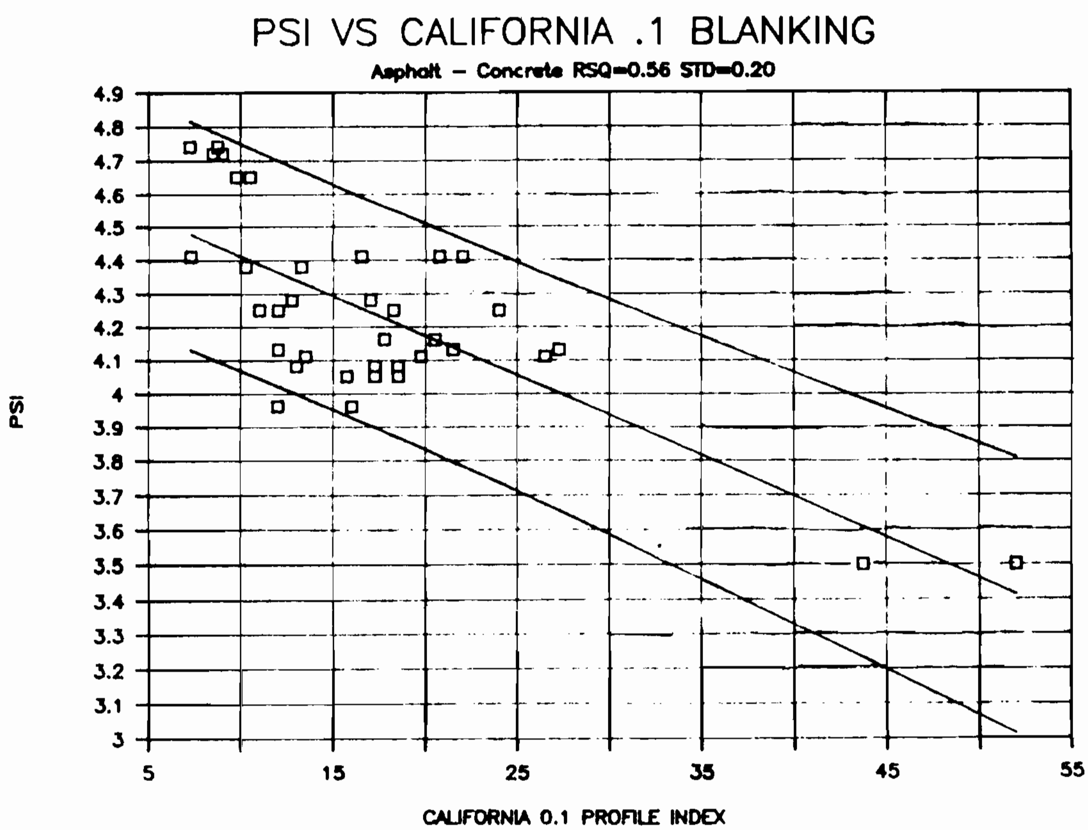


Fig 3.12a

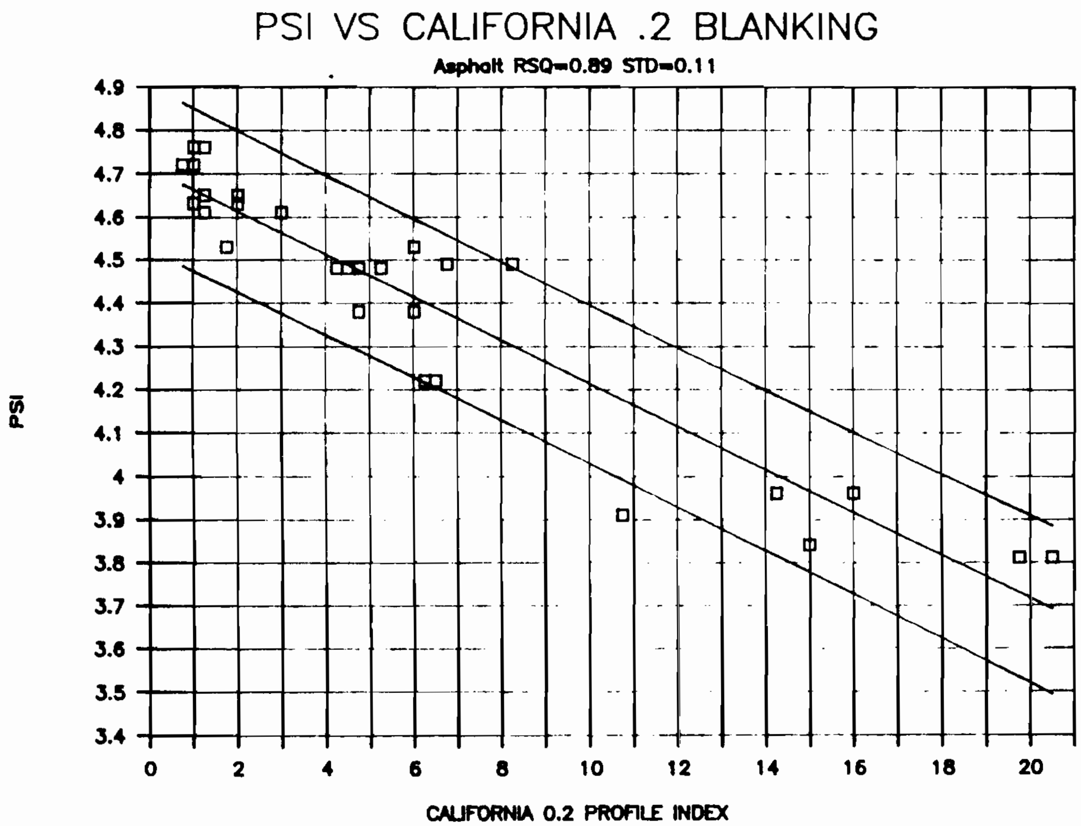


Fig 3.12b

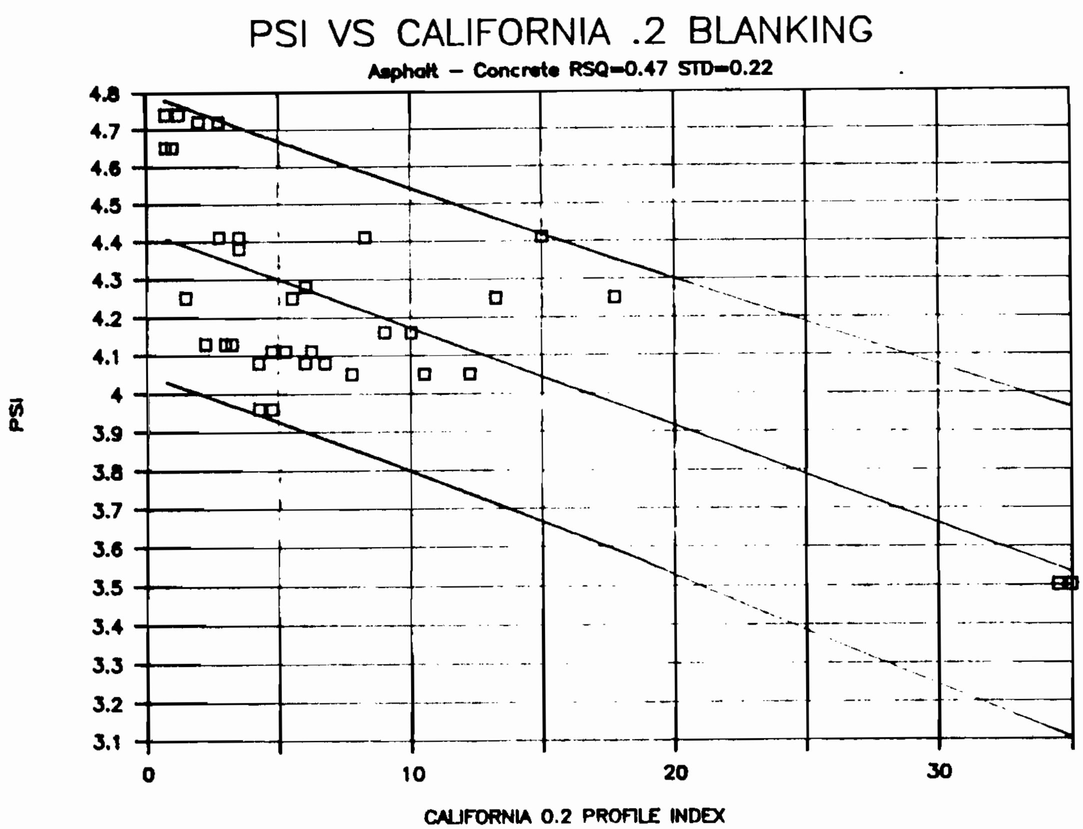


Fig 3.13a

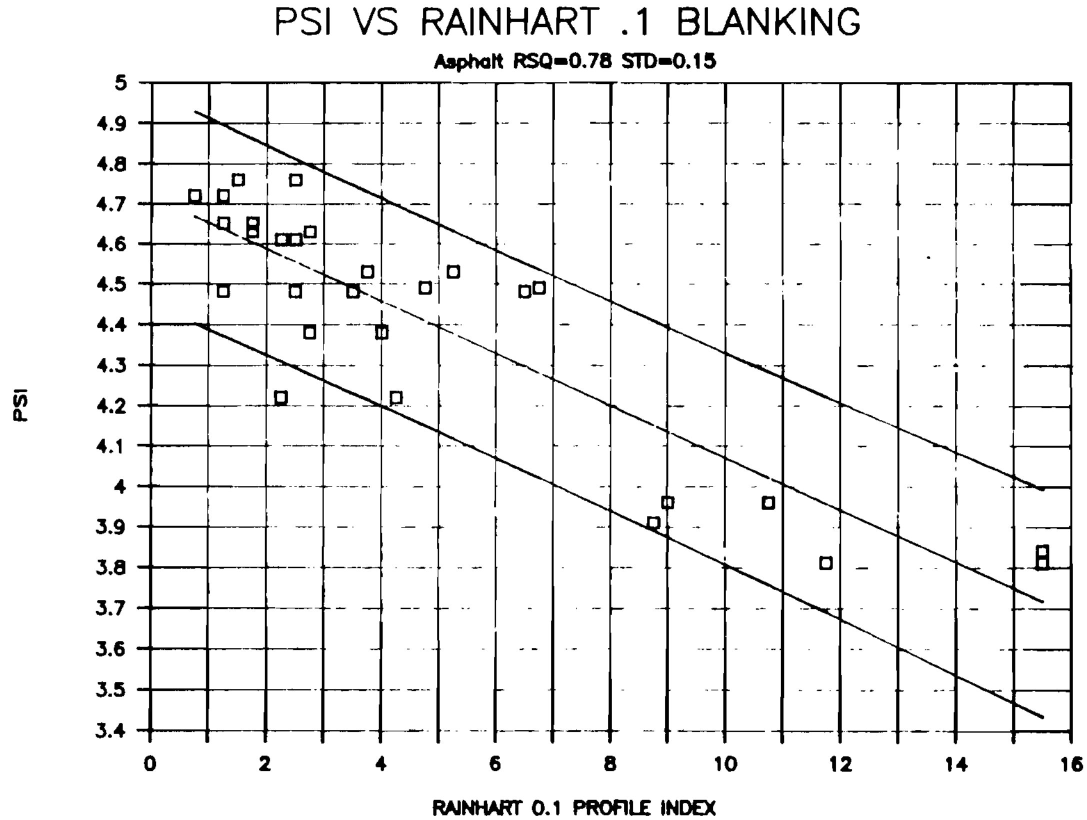


Fig 3.13b

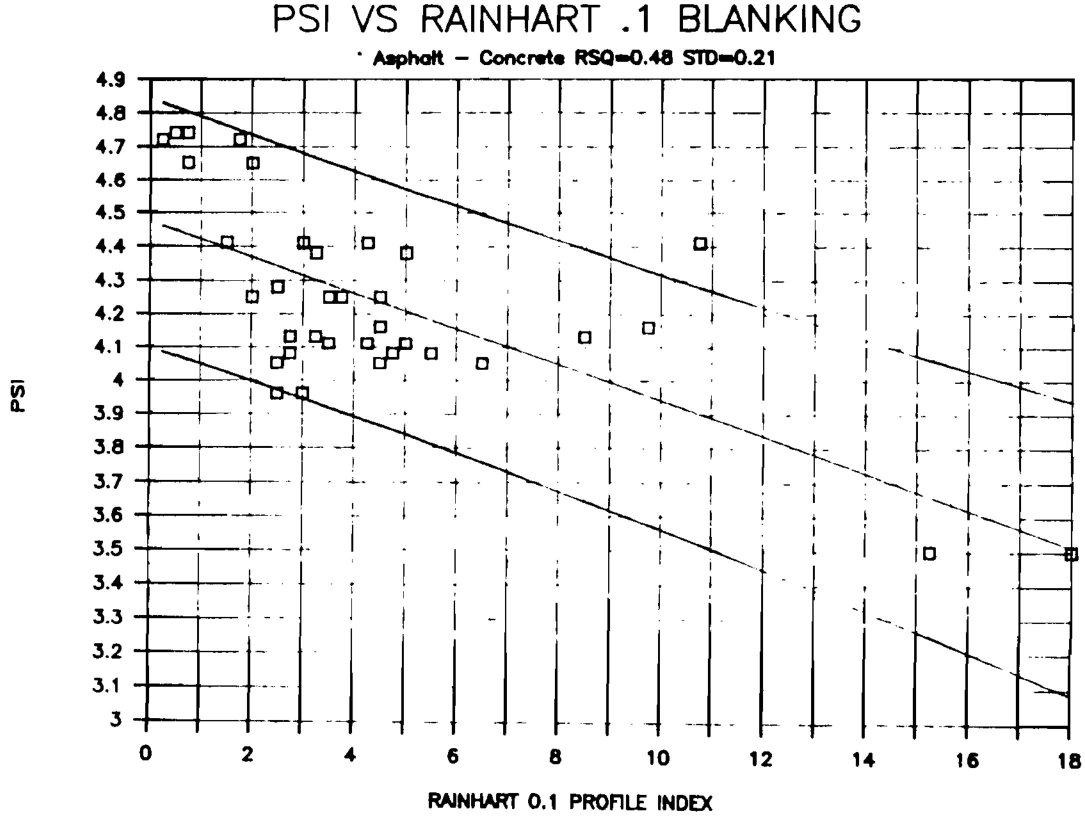


Fig 3.14a

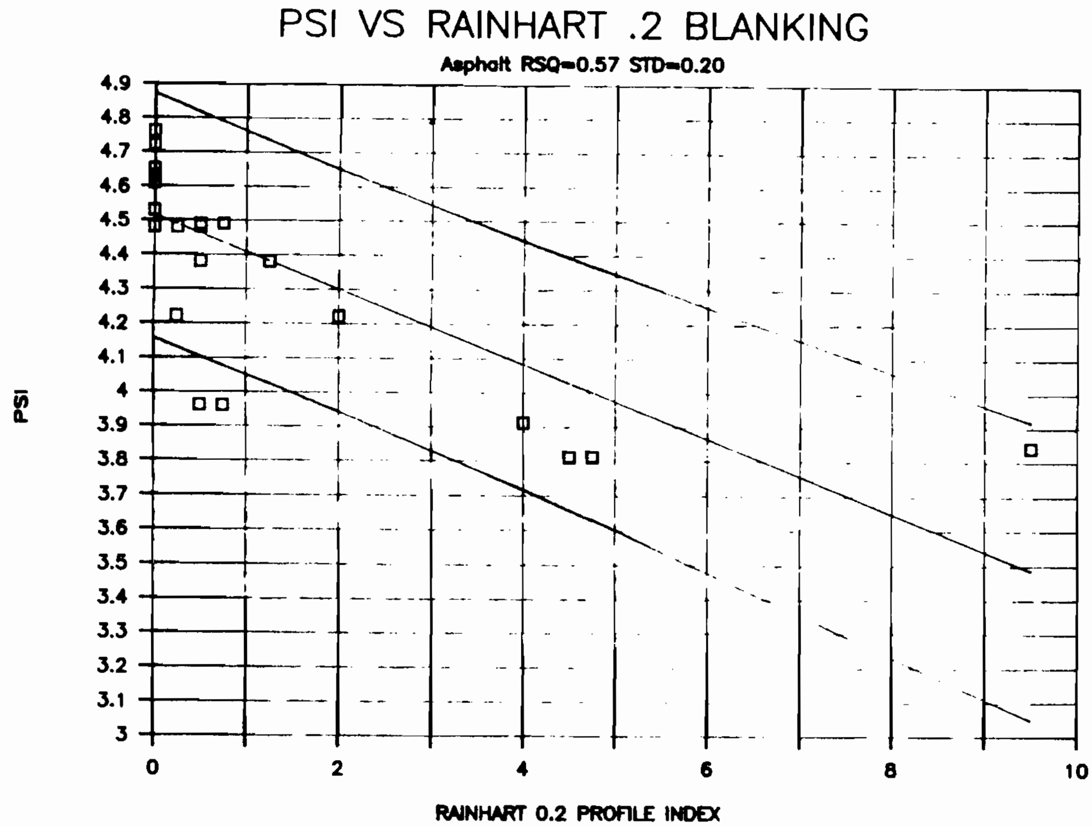


Fig 3.14b

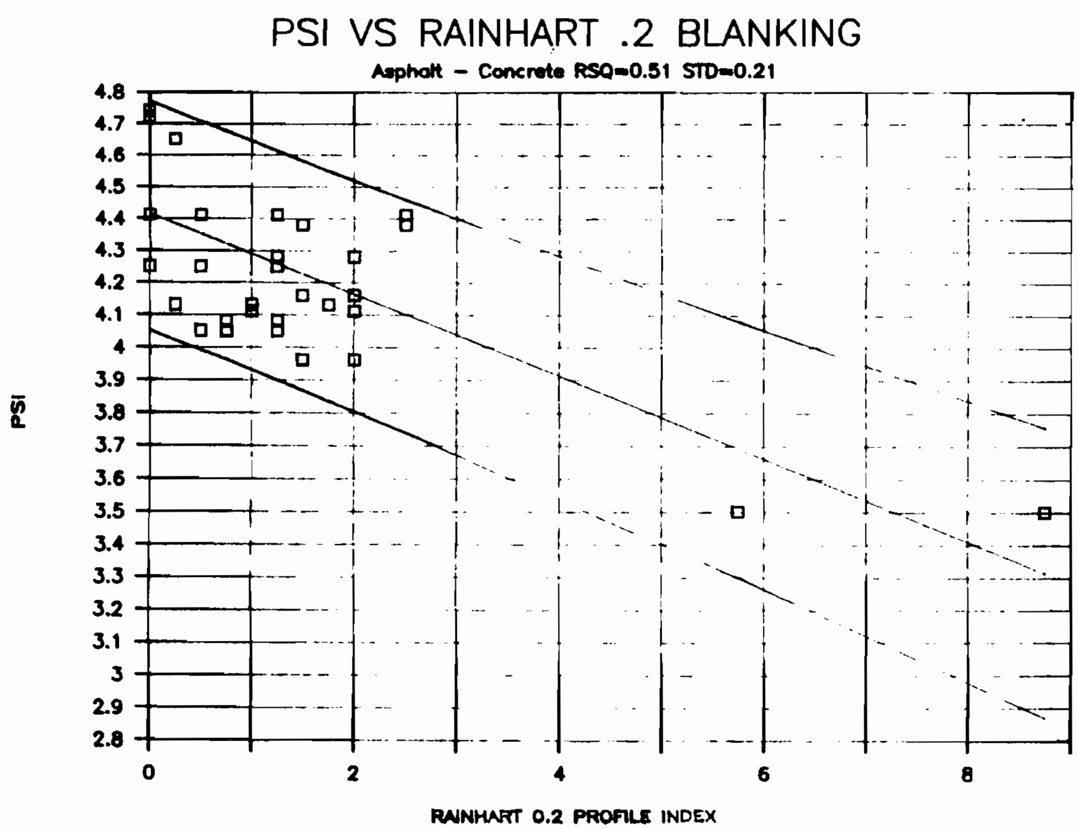


Fig 3.15

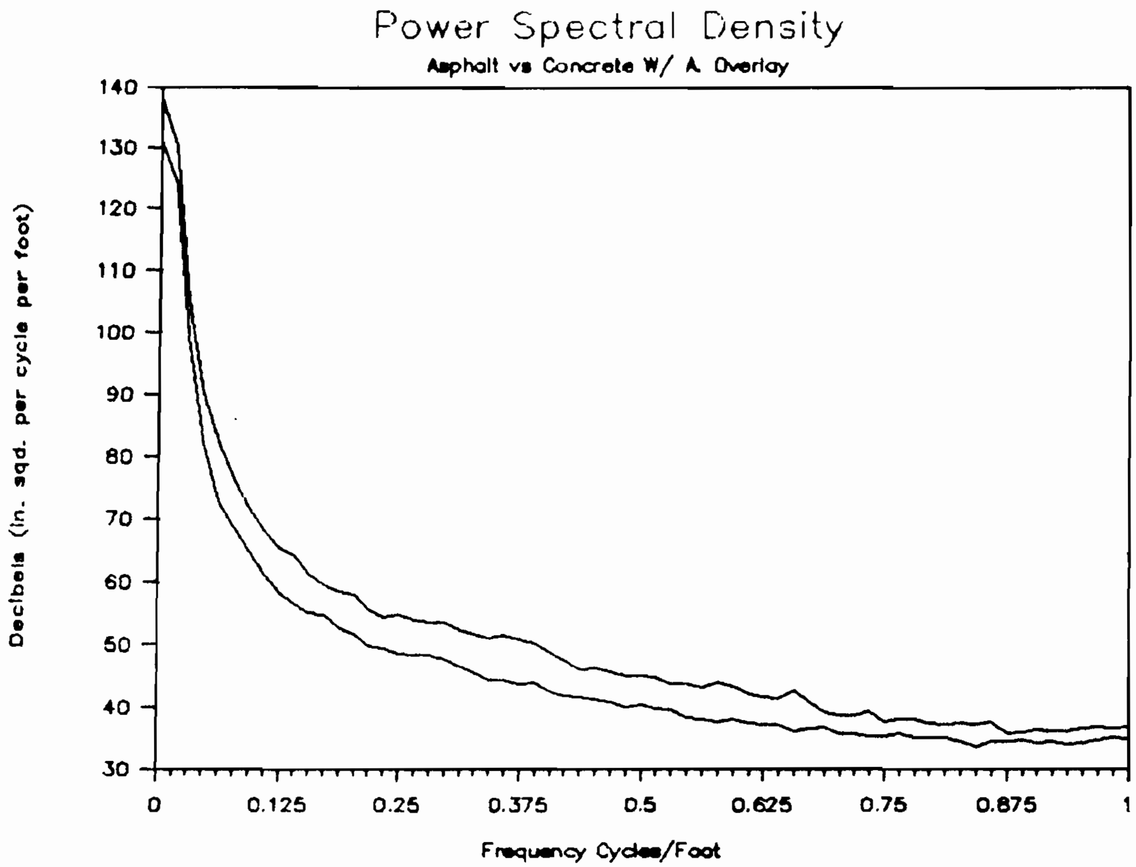

Power Spectral Density
Asphalt vs Concrete W/ A. Overlay
Decibels (in. sqd. per cycle per foot)
140
130
120
110
100
90
80
70
60
50
40
30
0
0.125
0.25
0.375
0.5
0.625
0.75
0.875
1
Frequency Cycles/Foot

Fig 3.16a

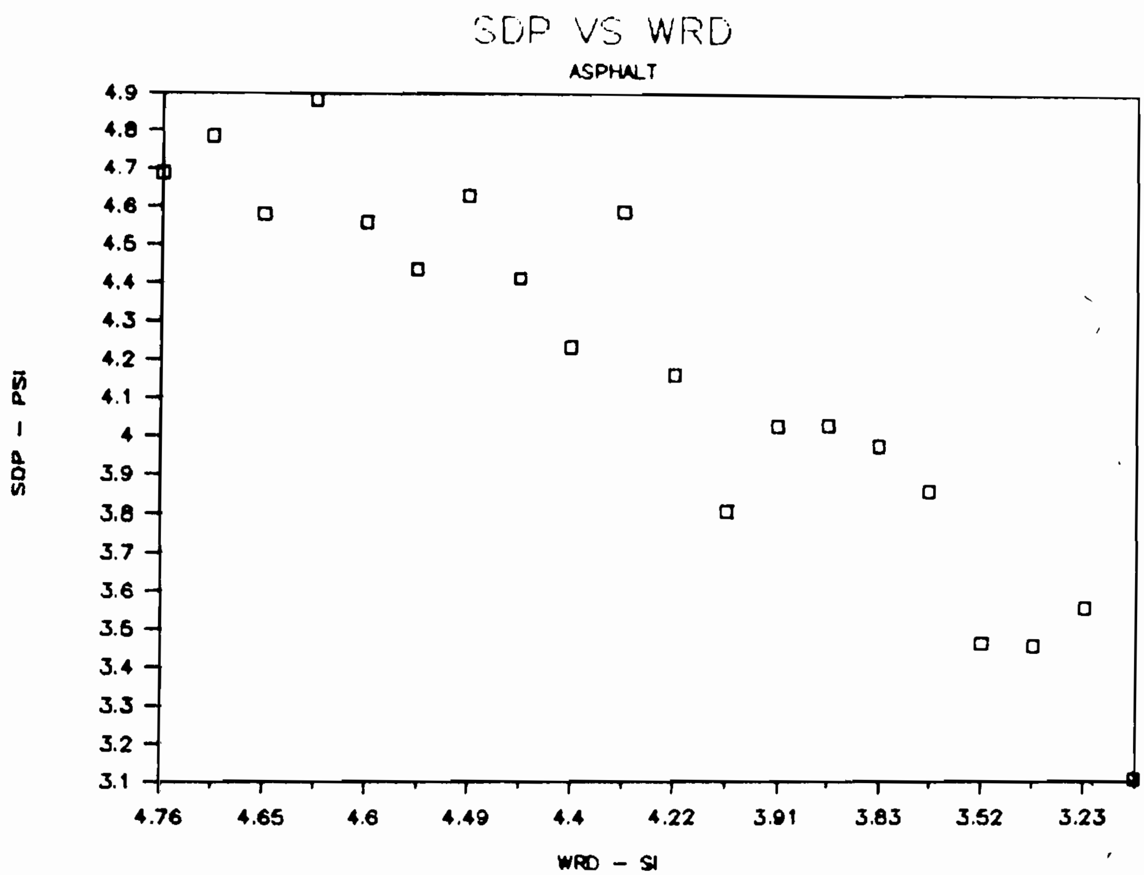
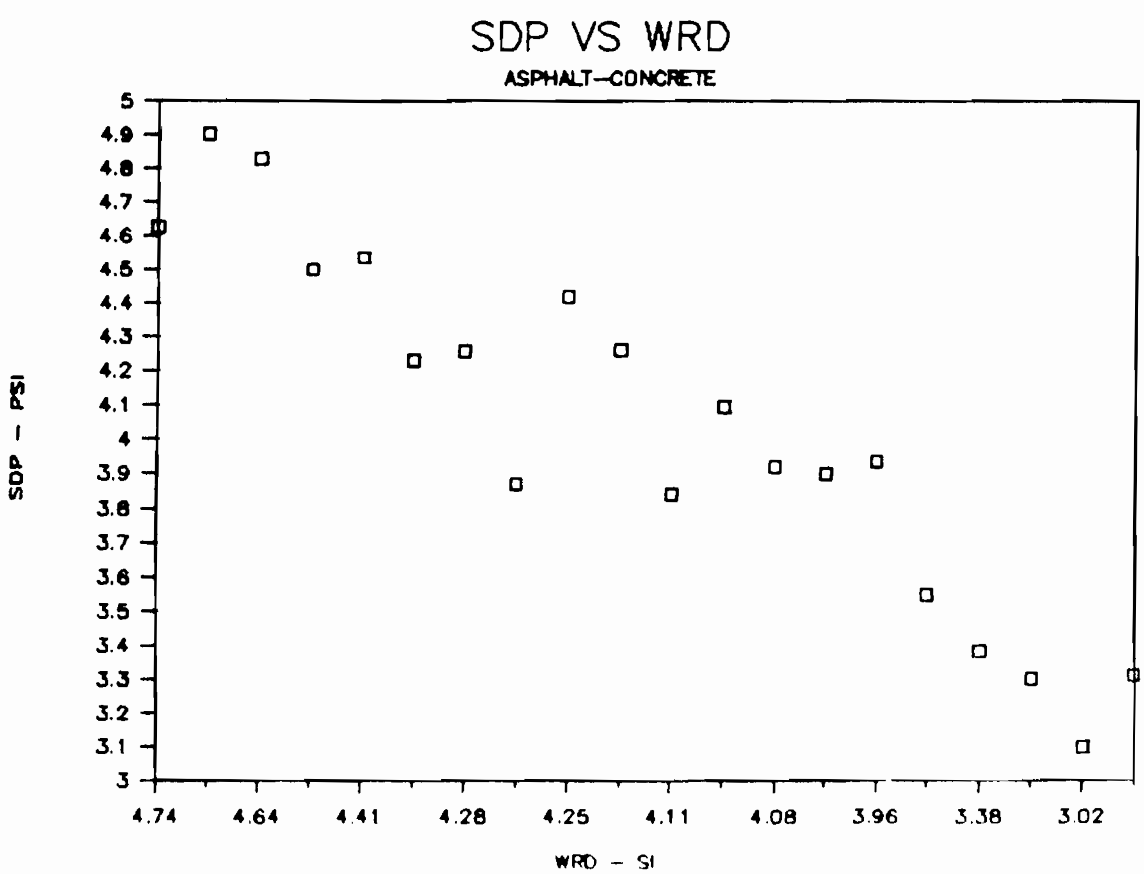


Fig 3.16b



CHAPTER 4

SUMMARY AND CONCLUSIONS

This study was initiated to determine relationships between roughness measurements from the California and Rainhart profilographs and PSI for asphalt pavements and concrete pavements with asphalt overlays. The 0.1 and 0.2 blanking bands were used for computing the PI values. These two bands were selected as they are the ones currently used most for these two profilographs types. It is of course possible to use others, or none at all. However, it was not the purpose of the project to investigate these other cases.

In this study a high correlation was found between the Rainhart and California profilographs, and between profilograph readings and PSI from the SDP for Asphalt pavements. However, lower correlation were found for concrete pavements with asphalt overlays. This was noted in all comparisons made. Also, greater replication errors were found between runs for overlaid concrete pavements.

The best correlation found between the two devices for asphalt pavements was when a 0.1 inch blanking band is used for the Rainhart device and a 0.2 inch blanking band is used for the California device. The most common practice has been to use this combination. However this was not the case for concrete pavements with an asphalt overlay. For these cases, the California instrument with a 0.1 inch blanking band vs. the Rainhart instrument using 0.1 inch data, and the California 0.1 inch vs. Rainhart 0.2 inch blanking band data gave the best correlation. Several of the concrete pavements with asphalt overlays had rutting. Also, some were rough where concrete joints had reflected through the overlay. These distresses probably rendered different roughness levels in the two wheel paths used by the SDP for measuring PSI. It also probably assured that the profilographs experienced a greatly different profile in the paths in which they were run than the average profile measured by the SDP. Thus it is not surprising to find the poor correlation for these pavements. The rutting and reflective cracking was not found on all of the overlaid concrete pavements. Because of the high traffic volumes, these distresses were not noticed until actual measurements were made. The extent of the erratic behavior and its affect on PI determination was not readily apparent until data processing.

The linear correlation was not performed for the average of each section. However, the average data points were plotted. From these plots, a quadratic relationship was indicated. The square root of the average profilograph readings were compared to the average PSI for the California 0.2 and Rainhart 0.1 blanking band data. A 0.94 and 0.93 R square, respectively, was obtained. The individual runs with a PSI of 3.5 and greater were correlated to PSI. For this regression, the 90 percent confidence limits were also computed. The R square for the cases are provided in Table 3.1. The R square indicated a good correlation for the asphalt pavements. Once again, the concrete pavements with asphalt overlays did not correlate as well, and indicated that a more through study would be required for such pavements.

As in the similar study for rigid pavements, this research effort is useful for investigating PSI relations with profile index and in comparing data from the two profilograph types. Similar to what was found for rigid pavements, the use of the profilograph on asphalt pavements, provide a good correlation to PSI.

It should be noted that the comparisons for asphalt overlays over concrete might not be valid. This is because the PSI equations were developed for either asphalt or concrete pavements. The PSI model used for this current study was for asphalt pavements. In the original model development effort for obtaining PSI using the SDP, no attempt was made to consider only concrete pavements with asphalt overlays, or overlayed pavements in general.

Additional studies would be desirable to try to develop sufficient correlations of PSI and profilograph indices for asphalt overlays over concrete pavements. Such studies might find sufficient correlations to render profilographs suitable for construction control of these composite pavements. The studies might also consider multiple profilograph types. To do this, it would be necessary to develop a separate PSI model for the SDP for concrete pavements which have been overlaid with asphalt.

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APPENDIX

Surface Dynamics Profilometer

The Surface Dynamics Profilometer was originally designed by General Motors and built by K. J. Law Engineers in 1967. The device has, as primary sensors, two accelerometers and two measuring laser probes. The accelerometers determine the amount and direction of vertical acceleration undergone by the vehicle while the laser probes measure the distance from the vehicle body to the road surface. A profile measurement is calculated by summing the double integral of the accelerometer signal and the displacement signal. The Texas State Department of Highways and Public Transportation purchased one of the first units built by Law Engineers in 1968. A second unit was purchased in the mid 1970's.

The SDP measures profile data with considerable accuracy and consistency and is independent of the vehicle suspension. It has been used as a standard reference device for performance evaluation of less accurate and expensive road roughness measurement devices [MCK82].

The principal statistic currently used by the TSDHPT in analyzing profile data from the SDP is root-mean-square vertical acceleration (RMSVA). This statistic is discussed in [MCK82]. RMSVA is the basis for the mathematical model to compute present serviceability index for a section of a road. The implementation of this model is a program called VERTAC (VERTical ACceleration). The two RMSVA statistics used in the PSI model are for four and 16 foot base lengths. Initially this program could only be run on a large mainframe computer system. The current version is run on the portable Compaq, located in the SDP [WAL87].

California Profilograph

The California style profilograph used is a 32'6" long mechanical pavement roughness measuring device with 12 wheels. The profilograph can be quickly assembled or dissembled so that it can be easily transported from location to location. When used to collect roughness information, it is pushed by an operator at walking speeds. It records roughness traces through a recording wheel at the center of the device. As the profilograph travels, a tracing pen connected to the recording wheel picks up the upward and downward motions of the wheel. The recorded trace (profilogram) usually has a 1" = 25' ratio in the horizontal direction and actual variation in the vertical direction.

The profile trace (roughness trace - not actual profile) or profilogram of a road section is used to compute a Profile Index (PI). The PI can be calculated by counting all scallops which extend outside a blanking band placed on the profilogram. The standard practice is to use a blanking band of 0.2 inches [SCD72]. A special ruler 21.12 inches long (one-tenth of a mile on 1"/25' scale) can be purchased which has a blanking band along the center line and which facilitates the PI determination. Lines, 0.1 inch apart and parallel to the center line of the ruler, are used to denote the 0.2 inch blanking band. The heights of all scallops extending outside the blanking band are accumulated and Profile Index is calculated in "inches per miles in excess of the blanking band". In counting the scallops, the accuracy is measured to the nearest 0.05 inch. Scallops must extend outside the blanking band for 0.03 inch or more and continue such for at least two feet (0.08" on 1"/25' profilogram), before they are counted.

Rainhart Profilograph

The Rainhart Profilograph, operates on a similar principle as the California Profilograph. The major difference between these two devices is in the reference plane on which the recording device is supported. The Rainhart Profilograph also has 12 wheels; however, each wheel travels on a different profile path as compared with California profilograph which travels only on three profile paths (the left right wheels on one path, the right four wheels on another, and the third under the recording wheel). The Rainhart Profilograph, with a length of 26'10", is composed of a major body frame and four rigid tripods, each being a rigid frame and wheels at each apex. These four tripods are then connected to the major body of the profilograph through a ball joint support located on the geometric center of the tripods. The recording wheel travels on the center path of the profilograph and records the vertical movement of the recording wheels relative to the body frame.

The profilogram recorded by Rainhart profilograph is processed in the same manner as the California profilogram in order to obtain the Profile Index [GHD78]. However, a blanking band of 0.1 inch is typically used for Rainhart profilogram in calculation of PI. A similar ruler with 0.1 inch blanking band can be used to count the scallops and to compute the index.

Although a 0.2 blanking band is typically used when comparing with the California profilograph, for the research effort, both a 0.1" and 0.2" blanking band were used and compared.

Walker Roughness Device

The SDP has been found to provide accurate profile measurements from which various roughness statistics can be computed. It is used in the state for providing a standard for roughness measurements. However, it is rather expensive to obtain and operate. Because of this the Mays Ride Meter and, more recently, the WRD (also known as the SIometer) are used in Texas for large scale roughness measurements. The WRD provides an estimate of the road profile. From these measurements the slope variance of the predicted profile for a four inch base length is then calculated. The WRD uses this value, which has been correlated to PSI, to determine the serviceability index (SI) of the road.

The WRD consists of three components: a sensor unit, main control module and, optionally, a computer for storing the results. The device uses an accelerometer as its primary sensor. Before using the device for measurements it is driven over a short road section which is used by the WRD to perform a statistical model of the vehicle's response. The model parameters determined in this dynamic calibration procedure is then later used during the measuring process for removing the vehicle's characteristics. The process of identifying and modeling the current or dynamic vehicle characteristics is referred to as the self-calibrating process.

The WRD provides SI, or serviceability index as output, as well as, the predicted profile, when interfaced with an optional storage, unit such as a Zenith lap-top computer.

The WRD, in general, is a compact device which can be installed and operated in virtually any vehicle. It is simple to use and can be operated by only one person. Its cost is inexpensive compared to the SDP's and is not much more than the cost of the MRM with trailer.