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Performance of Full-Depth Asphalt Bases On San Diego County Experimental Base Project

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16. ABSTRACT

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This experiment was planned to accomplish the following objectives:

1. To determine specific thicknesses of various types of base courses required to give a desired level of performance.
2. To relate certain measured properties of the pavement and pavement components to observed performance.
3. To study deflection and strain behavior of the test pavements to provide a better theoretical basis for translating future performance results to other environments.

This paper is concerned with the first two objectives. Specifically, four Full-Depth asphalt bases are analyzed, their relative thickness requirements are determined and related to pavement performance as measured by a performance rating system and by the present serviceability index (PSI).

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PERFORMANCE OF FULL-DEPTH ASPHALT BASES ON SAN DIEGO COUNTY EXPERIMENTAL BASE PROJECT

by

J. F. Shook and J. R. Lambrechts

[Sweetwater Test Road]

Prepared for Presentation to

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Respectively, The Asphalt Institute, College Park, Md.

and The Asphalt Institute and University of Maryland,

College Park, Md., presently Purdue University

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Under conditions of the test and limitations of the analysis, it was possible to develop significant relationships between a panel rating of test section performance and the structural variables deflection and equivalent thickness for four Full-Depth asphalt base sections included in the experiment. The data did not yield significant relationships with either traffic or present serviceability index (PSI). Base type weighting factors, relative to a high-quality asphalt concrete base, were developed from the analysis for asphalt cement, cutback asphalt and emulsion asphalt treated bases using a marginal-quality sandy gravel aggregate.

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INTRODUCTION

The San Diego County Experimental Base Project is a full-scale experimental project consisting of 35 test sections designed to determine thickness requirements for five Full-Depth asphalt bases and two untreated granular bases. Testing, after seven years traffic, was discontinued in 1973.

San Diego County was the primary sponsor of the project. The Asphalt Institute was cosponsor. Cooperating agencies included the California Division of Highways, Los Angeles County, Orange County, the Chevron Asphalt Company, the Douglas Oil Company, the Shell Oil Company, and the Union Oil Company.

The basic experiment was designed by

The Asphalt Institute; San Diego County was responsible for road design and plans, contract administration and construction control. All of the cooperating organizations participated in the testing and research activities.

The experiment is located on a section of Sweetwater Road, San Diego County, as shown in Figure 1. Construction was completed July 1966. Average rainfall in San Diego is about 10 inches (254 mm) per year. Daytime temperatures range from 70°F to 90°F (21°C to 32°C) throughout the year. The project is constructed on an A-7-6 soil with poor drainage. Traffic volume in 1966 consisted of approximately 12,000 vehicles per day, of which approximately 600 were trucks.

This experiment was planned to accomplish the following objectives:

1. To determine specific thicknesses of various types of base courses required to give a desired level of performance.
2. To relate certain measured properties of the pavement and pavement components to observed performance.
3. To study deflection and strain behavior of the test pavements to provide a better theoretical basis for translating future performance results to other environments.

This paper is concerned with the first two objectives. Specifically, four Full-Depth asphalt bases are analyzed, their relative thickness requirements are determined and related to pavement performance as measured by a performance rating system and by the present serviceability index (PSI). Hopefully, also, the work presented herein will help in a small way in meeting the need to relate pavement distress to pavement performance.

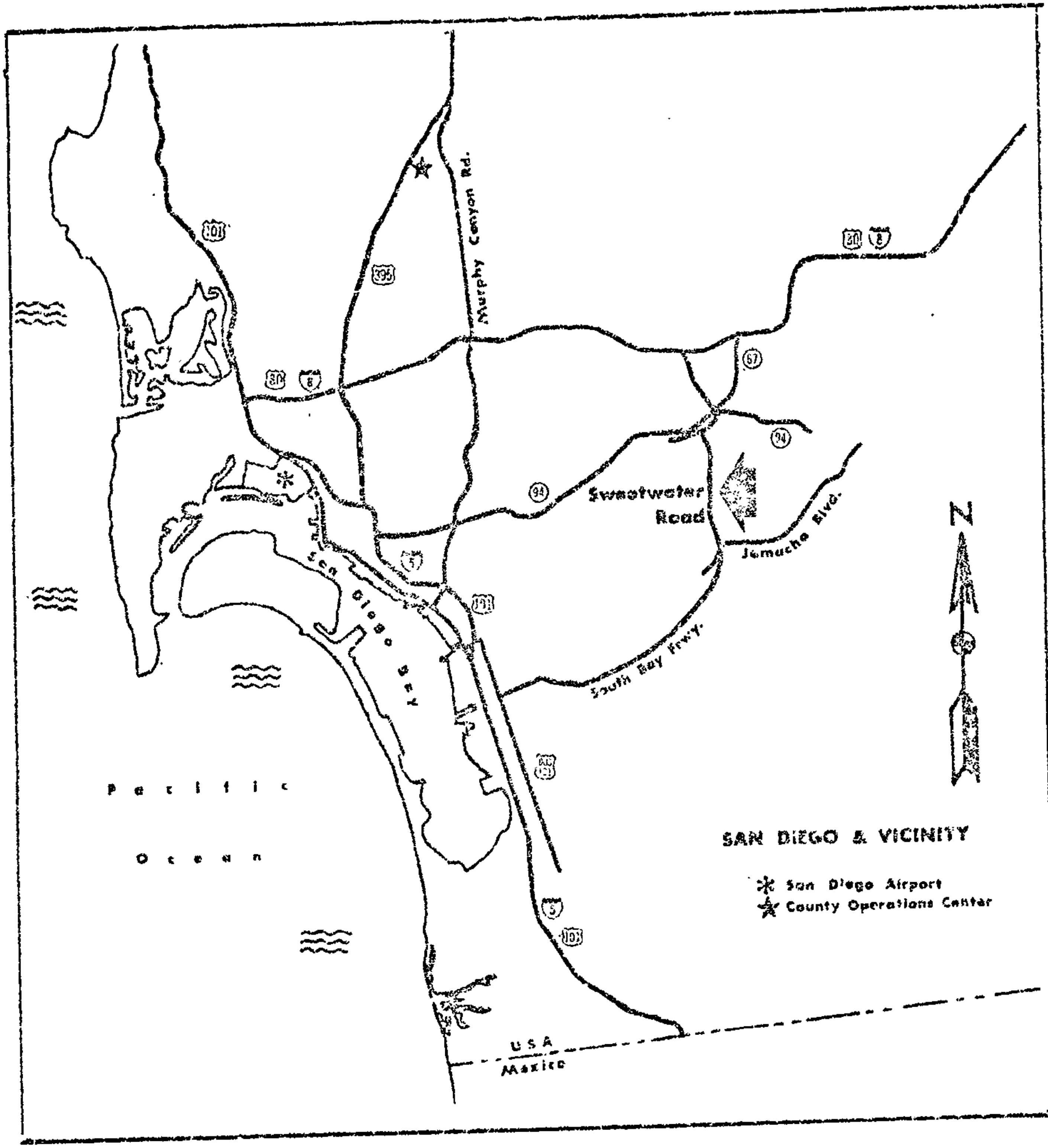

Figure 1 - Test Site Location

EXPERIMENT DESIGN

The experiment design and analysis concepts are in accord with those given in National Cooperative Highway Research Program Report 2A, Guidelines for Satellite Studies of Pavement Performance (1). The basic experiment was that of a 6 by 4 full factorial design on base type and base thickness design level. One additional base type was included at two thickness levels, and one standard design at a single thickness design level. Each base was constructed to four thickness levels, with a uniform 3-inch (76.2 mm) surface course and no subbase course. The experiment design is shown in Table 1. The test section layout is shown schematically in Figure 2.

Table 1

BASE TYPE AND THICKNESS VARIABLES

Base Type	Aggregate Quality	Base Thickness for Given Design Level[1] A	B	C	D
Asphalt Concrete	High	3.6 (91)[2]	4.8 (122)	5.8 (147)	7.7 (196)
Untreated Class 2 Aggregate	High	7.2 (183)	9.6 (244)	11.5 (292)	15.8 (401)
Asphalt Treated Special Aggregate	Medium	4.6 (117)	6.7 (170)	8.4 (213)	11.5 (292)
Cutback Treated Special Aggregate	Medium	5.4 (137)	8.2 (208)	9.7 (246)	13.9 (353)
Emulsion Treated Special Aggregate	Medium	5.4 (137)	8.2 (208)	9.7 (246)	13.9 (353)
Emulsion Treated Class 3 Aggregate	Low	5.4 (137)		9.7 (246)	
Untreated Class 3 Aggregate	Low	7.2 (183)	9.6 (244)	11.5 (292)	15.8 (401)
California Standard Design				6.0[1] (plus 10.8 in. subbase)	

[1]Uniform 3-inch (76.2 mm) surface course.

[2]Dimensions are given in inches and (millimeters).

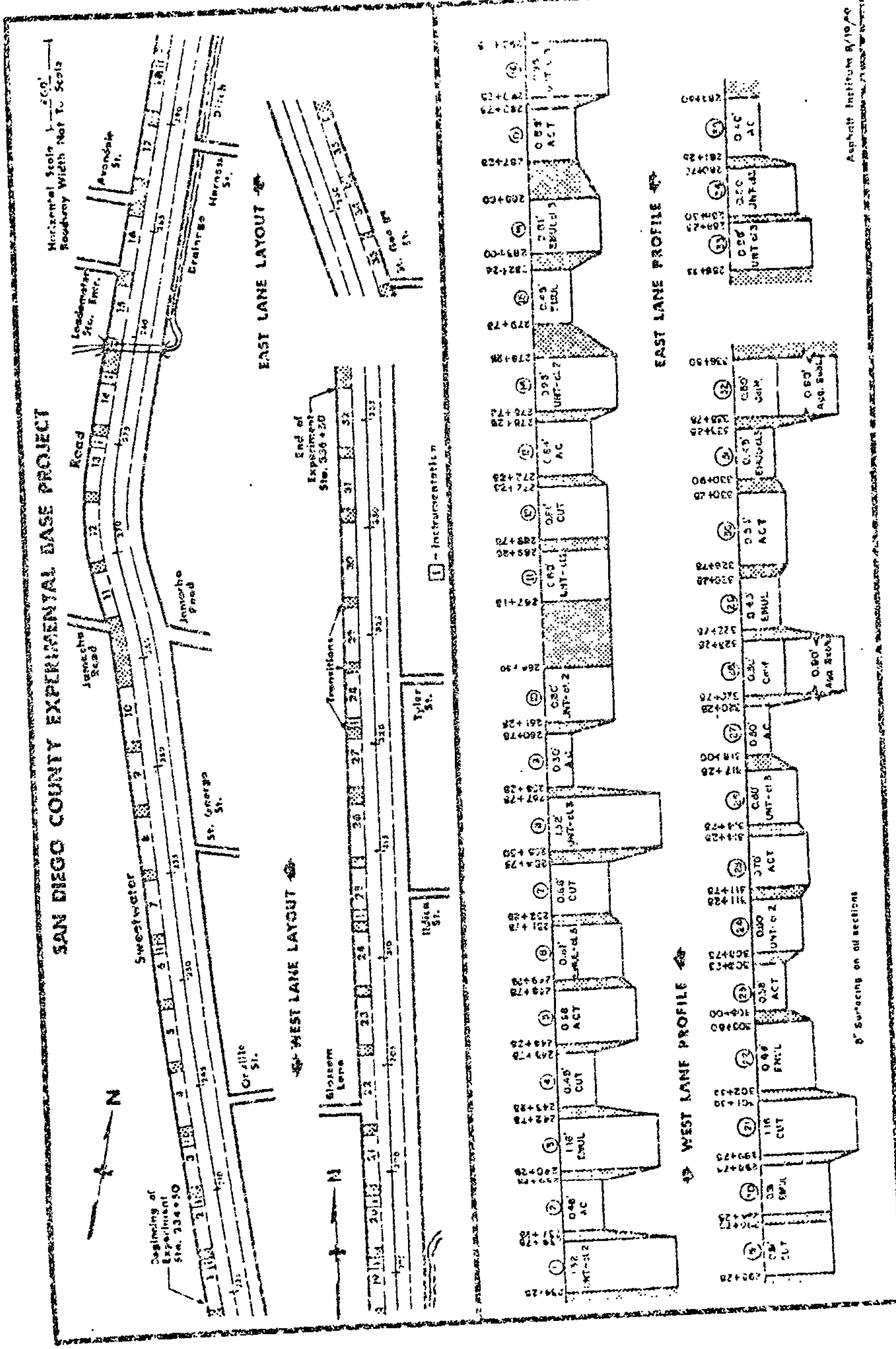
SAN DIEGO COUNTY EXPERIMENTAL BASE PROJECT
EAST LANE LAYOUT
WEST LANE LAYOUT
EAST LANE PROFILE
WEST LANE PROFILE
Horizontal Scale
Roadway Width Not To Scale
Sweetwater
Road
Transitions
Instrumentation
Beginning of Experiment Sta. 234+50
End of Experiment Sta. 336+30
Asphalt Institute

Figure 2

Thickness design level in the experiment (Table 1) is defined as a thickness needed to give a projected design life. The purpose of this design was to permit analyzing the performance data at any point in time with the expectation that there would be some thickness of each type of base having closely the same level of performance.

The following materials were included in the experiment.

1. Asphalt concrete, conforming to California standard specifications, using Type B, 3/4-inch (19 mm) maximum size, medium grading aggregate and a 60-70 penetration grade asphalt. (This is similar to an Asphalt Institute Type IV mix.) The asphalt concrete surface course mixture was similar, but with 1/2-inch (12.7 mm) maximum size aggregate.
2. Untreated aggregate base, conforming to California standard specifications for Class 2 base.
3. Cutback asphalt-treated base using medium-quality special aggregate, plant-mixed with an MC-800 cutback asphalt. The aggregate met these specifiations (special aggregate):

Sieve Size	Percent Passing
3/4 inch (19 mm)	100
No. 4	55-80
No. 30	25-55
No. 200	4-10

Sand equivalent, 25 min.

R-value, 65-75

Moisture vapor susceptibility, 60 min.

4. Emulsion asphalt-treated, medium quality special aggregate, plant-mixed with an SM-K emulsion asphalt. The special aggregate was the same as in 3 above.
5. Asphalt concrete, medium-quality special aggregate, plant-mixed with a 60-70 paving grade asphalt. The aggregate was the same as in 3 above.
6. Untreated county standard Class 3 base. This is a granite-sand aggregate base material (R = 73 min.) used by San Diego County.
7. Emulsion asphalt-treated county standard granite-sand base.
8. Combination of Class 2 untreated base and the county granite-sand used as subbase.

Typical mix design and other characteristics for the asphalt base mixes are given in Table 2. Data also have been reported in References (2), (3) and (4).

MEASUREMENTS PROGRAM

There were two purposes for the measurements program conducted after construction. The first was to document pavement performance. The second purpose was to measure pavement deflections and strains in order to develop a better understanding of fundamental pavement behavior. Theoretical concepts based on multi-layered elastic theory are being evaluated utilizing dynamic deflection and strain data collected on the project. It is the purpose of this study to look at the performance of the pavements as they can be related to thickness, base type, traffic and similar factors.

Table 2

CONSTRUCTION TEST DATA FOR ASPHALT BASE MIXES

Test	Asphalt Concrete	Asphalt Treated	Emulsion Treated	Cutback Treated	Emulsion Treated Class 3
Stabilometer					
Compaction					
Pressure, psi(kPa)	500(3400)	500(3400)	500(3400)	500(3400)	500(3400)
S-Value	42	39	35	35	33
R-Value	83	82	82	83	84
Cohesiometer Value	226	201	280	122	390
Asphalt Content, %	5.5	5.6	3.8	5.5	3.2
Density, pcf (kg/M^3)	138.7(2221)	133.9(2145)	133.9(2145)	130.9(2097)	142.8(2287)
Marshall					
Stability, lbs (kN)	3890(17.3)	4284(19.1)	1607(7.1)	901(4.0)	1540(6.8)
Flow, 0.01 in.	11	12	19	12	14
Density, pcf (kg/M^3)	139.3(2231)	129.1(2068)	122.9(1969)	132.3(2119)	132.5(2122)
Air Voids, %	4	11	15	9	7
VMA, %	18	24	28	22	23
Test Temp., °F (°C)	100(38)	100(38)	100(38)	100(38)	100(38)
Extraction & Grading					
Asphalt, %	5.8	5.8	4.2	5.1	3.1
Moisture, %	.14	0.24	1.8	.68	2.4
Grading, % Passing:					
1 in.(25.4mm)					100
3/4 in.(19mm)	100	100	100	100	-
1/2 in.(12.7mm)	92	93	96	96	100
3/8 in.(9.4mm)	76	86	90	87	95
No. 4	53	73	75	74	95
No. 8	38	67	70	68	80
No. 16	30	64	64	63	59
No. 30	23	50	52	52	44
No. 50	14	24	25	24	31
No. 100	7	10	13	11	18
No. 200	4.6	6.0	8.7	6.6	10.6
Relative Compaction, %	95	97	95	96	96

Basic measures of performance and related factors made periodically include

1. Present serviceability index (PSI) measured with the CHLOE Profilometer by the California Division of Highways.
2. Performance rating made by a panel of technologists associated with the project sponsors.
3. Cracking, surveyed regularly by San Diego County.
4. Rutting, by the rating panel.
5. Traffic and axle weight studies by San Diego County.

Measurements involving pavement deflection and strain can be divided into two categories as follows:

1. Those involving instrumentation placed in the road; and
2. Those involving instrumentation brought to the road for purposes of measuring deflections under load at the pavement surface.

In the first category are LVDT deflection measurements, strain gage measurements and temperature measurements. Deflection and strain data were recorded under a moving truck driven over the in-place instruments at known location and vehicle speed. These measurements have been used to test the validity of applying elastic theory to predictions of deflection and strain. Results of studies made to date have been reported by Finn and Hicks (5).

The Benkelman Beam and the California Deflectometer were used to measure deflections under load at the pavement surface. They have been used both to assist in theoretical studies and in studies to relate deflection to performance.

Both laboratory and field samples have been used for conventional testing and to obtain material properties for use in theoretical studies.

Present serviceability index (PSI) was calculated using the equation,

$$PSI = 5.03 - 1.91 \log (1 + SV) - 0.01 \sqrt{C + P}$$

where SV = slope variance

C + P = amount of Class 2 and Class 3 cracking plus patching,

RD = rut depth

All definitions are from the AASHO Road Test (6).

Performance ratings were made periodically by an inspection team or panel of six technologists[1] involved in the project. The panel inspected the sections, noted their "condition" on a scale graded from "excellent" to "failed" and recommended further testing or possible maintenance needs. The ratings were completely subjective. No attempt was made to relate them to PSI or other measurements.

For analysis purposes the panel ratings were given a numerical scale equivalent by the authors as follows:

Rating	Scale Value
Excellent	5
Good	4
Fair	3
Poor	2
Failed	1

Additional evaluations were made by individuals, particularly of drainage conditions, and these have been useful in making subjective evaluations of the project findings.

[1]Usually, only four or five participated in any one rating session

Deflection values given in Tables 3-A through 3-D were obtained with a Benkelman Beam using an 18,000 lb (80 kN) axle load. About 10 measurements were made in each test section. The deflection values given in Table 3 are mean values plus 2 standard deviations ($\overline{X} + 2\sigma$) corrected to a standard temperature of 70°F (21°C). The procedures for taking deflection measurements, correcting for temperature, etc. used are described in Reference (7). Typical plots of Rating and PSI versus time are shown in Figure 3.

PERFORMANCE DATA

This study is concerned with the performance of Full-Depth test sections in the experiment. Four of these, Asphalt Concrete, Asphalt Treated Special Aggregate, Emulsion Treated Special Aggregate and Cutback Treated Special Aggregate were analyzed as will be described later. Performance of the other bases were not subjected to the analysis technique.

Data collected during 1970, 1971 and 1972 are summarized in Tables 3-A through 3-D. The project was constructed in 1966. Observations and measurements were discontinued in 1973. Only the 1970, 1971 and 1972 data were used in the analysis as will be described later. This generally was a period of declining performance that seemed to hold most promise for the analytical treatment used.

In 1972, after six years of traffic, five of the 35 test sections had been removed from traffic, largely because of realignment to provide for left-turning traffic. Eleven test sections were rated "poor" or lower (rating numbers ≤2.0). All untreated class 3 aggregate base sections were rated poor or lower as were the California standard sections. The thinnest section,

Table 3-A

PERFORMANCE DATA

ASPHALT CONCRETE BASE

Section No.	Surface Thickness	Base Thickness	Year	EAL_{18} 1000	PSI	Rating	Defl.	Rut Depth	Cracking
	(1)	(1)		(2)	(3)	(4)	(1,5)	(1)	(7)
9	3.22	3.02	1966	0	3.2	5.0	33(838)	0	0
	(81.8)	(76.7)	1970	83	2.9	2.0	106(2692)		0
			1971	118	3.0	1.5	148(3759)	0.75(19)	73
			1972	152		1.0	141(3581)	0.38(9.7)	75
27	3.24	3.88	1966	0	3.7	5.0	27(686)	0	0
	(82.3)	(98.6)	1970	83	2.2	1.0	173(4394)		64
			1971	118	2.0	1.0	196(4978)		160
			1972	152		(6)			160
35	3.22	4.86	1966	0	3.8	5.0	143(3632)	0	0
	(81.8)	(123)	1970	110	2.8	5.0	68(1727)		0
			1971	141	2.4	4.5	50(1270)	0.1(2.54)	16
			1972	171		3.5	46(1168)	0	16
2	3.14	5.61	1966	0	3.4	5.0	26(660)	0	0
	(79.8)	(142)	1970	83	2.7	3.5	78(1981)		0
			1971	118	2.8	4.0	103(2616)	<0.25(6.35)	0
			1972	152		5.0	99(2515)	<0.25(6.35)	0
13	3.28	7.78	1966	0	3.1	5.0	21(533)	0	0
	(83.3)	(198)	1970	83	2.7	4.5	50(1270)		0
			1971	118	3.0	4.0	66(1676)	0.25(6.35)	0
			1972	152		4.5	79(2007)	<0.25(6.35)	0

(1) Dimensions are given in 10^{-3} inches and (millimeters).
(2) Equivalent 18,000-lb (80 kN) axle loads.
(3) Present Serviceability Index.
(4) Panel Rating, scale: 5 = Excellent, 1 = Failed.
(5) Deflection, $\bar{X} + 2\sigma$ corrected to 70°F (21°C)
(6) Section removed from test.
(7) Cracking, class 2 and 3 (Reference 6), $Ft.^2/1000\ Ft.^2$

Table 3-B

PERFORMANCE DATA

ASPHALT TREATED BASE

Section No.	Surface Thickness	Base Thickness	Year	EAL_{18} 1000	PSI	Rating	Defl.	Rut Depth	Cracking
	(1)	(1)		(2)	(3)	(4)	(1,5)	(1)	(7)
23	3.00 (76.2)	4.82 (112)	1966		3.8	5.0	26(660)	0	0
			1970	83	3.2	5.0	23(584)		0
			1971	118	3.2	5.0	33(838)	0	0
			1972	152		5.0	32(813)	0	0
30	3.44 (87.4)	6.80 (173)	1966		3.3	5.0	26(660)	0	0
			1970	83	2.7	3.5	46(1168)		0
			1971	118	2.8	4.0	49(1245)	0	0
			1972	152		3.5	61(1549)	0	0
17	3.26 (82.8)	7.04 (179)	1966		3.5	5.0	27(686)	0	0
			1970	83	2.8	5.0			0
			1971	118	3.0	5.0	66(1676)	0	0
			1972	152		3.5	55(1397)	0	0
25	3.16 (80.3)	8.56 (217)	1966		3.9	5.0	22(559)	0	0
			1970	83	3.1	4.0	36(914)		0
			1971	118	3.1	4.0	65(1651)	0	0
			1972	152		(6)	58(1473)		0
5	3.38 (85.9)	11.2 (284)	1966		3.5	5.0	28(711)	0	0
			1970	83	3.1	5.0	29(737)		0
			1971	118	3.3	4.0	41(1041)		0
			1972	152		5.0	46(1168)	0.25(6.35)	0

(1) Dimensions are given in 10^{-3} inches and (millimeters).
(2) Equivalent 18,000-lb (80 kN) axle loads.
(3) Present Serviceability Index.
(4) Panel Rating, scale: 5 = Excellent, 1 = Failed.
(5) Deflection, $\bar{X} + 2\sigma$ corrected to 70°F (21°C)
(6) Section removed from test.
(7) Cracking, class 2 and 3 (Reference 6), $Ft.^2/1000\ Ft.^2$

Table 3-C

PERFORMANCE DATA

EMULSION TREATED BASE

Section No.	Surface Thickness	Base Thickness	Year	EAL_{18} 1000	PSI	Rating	Defl.	Rut Depth	Cracking
	(1)	(1)		(2)	(3)	(4)	(1,5)	(1)	(7)
29	3.29	5.56	1966		3.7	5.0	27(686)	0	0
	(83.6)	(141)	1970	83	2.3	2.5	71(1803)		5
			1971	118	2.9	2.0	101(2565)		40
			1972	152		1.5	96(2438)	0.25(6.35)	116
15	3.26	6.04	1966		3.4	5.0	71(1803)	0	0
	(82.8)	(153)	1970	83	2.8	2.0	133(3378)		0
			1971	118	3.1	3.0	111(2819)		11
			1972	152		2.5	94(2388)	0	15
22	3.10	8.00	1966		3.3		37(940)		0
	(78.7)	(203)	1970	83	2.7				18
			1971	118	2.1				
			1972	152		(6)			
20	3.10	8.96	1966		3.5	5.0	23(584)	0	0
	(78.7)	(228)	1970	83	3.2	3.0	37(940)		15
			1971	118	4.0	3.0	46(1168)		0
			1972	152		3.0	49(1245)	0	0
3	3.12	12.42	1966		3.2	5.0	32(813)	0	0
	(79.2)	(316)	1970	83	3.2	4.0	35(889)		0
			1971	118	3.0	3.5	37(940)		0
			1972	152		3.0	45(1143)	0	0

(1) Dimensions are given in 10^{-3} inches and (millimeters).
(2) Equivalent 18,000-lb (80 kN) axle loads.
(3) Present Serviceability Index.
(4) Panel Rating, scale: 5 = Excellent, 1 = Failed.
(5) Deflection, $\bar{X} + 2\sigma$ corrected to 70°F (21°C)
(6) Section removed from test.
(7) Cracking, class 2 and 3 (Reference 6), $Ft.^2/1000\ Ft.^2$

Table 3-D

PERFORMANCE DATA

CUTBACK TREATED BASE

Section No.	Surface Thickness	Base Thickness	Year	EAL_{18} 1000	PSI	Rating	Defl.	Rut Depth	Cracking
	(1)	(1)		(2)	(3)	(4)	(1,5)	(1)	(7)
4	3.22 (81.8)	5.46 (139)	1966		3.2	5.0	34(864)	0	0
			1970	83	2.6	5.0	48(1219)		0
			1971	118	2.7	4.0	49(1245)		0
			1972	152		5.0	73(1854)	0	11
7	3.12 (79.2)	7.80 (198)	1966		3.6	5.0	29(737)	0	0
			1970	83	3.0	4.0	39(991)		0
			1971	118	2.9	3.5	50(1270)		0
			1972	152		4.5	50(1270)	0.25(6.35)	0
19	3.05 (77.5)	8.96 (228)	1966		3.7	5.0	109(2769)	0	0
			1970	83	2.8	4.0	58(1473)		3
			1971	118	2.3	2.5	78(1981)		43
			1972	152		1.5	71(1803)	0	83
12	3.26 (82.8)	10.02 (255)	1966		3.5	5.0	29(737)	0	0
			1970	83	3.2	5.0	25(635)		0
			1971	118	2.9	3.0	59(1499)		0
			1972	152		5.0	68(1727)	0	0
21	2.83 (71.9)	13.94 (354)	1966		3.4	5.0	34(864)	0	0
			1970	83	3.0	5.0			0
			1971	118	2.6	5.0	32(813)		0
			1972	152		5.0	33(838)	0	0

(1) Dimensions are given in 10^{-3} inches and (millimeters).
(2) Equivalent 18,000-lb (80 kN) axle loads.
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(4) Panel Rating, scale: 5 = Excellent, 1 = Failed
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(6) Section removed from test.
(7) Cracking, class 2 and 3 (Reference 6), $Ft.^2/1000\ Ft.^2$

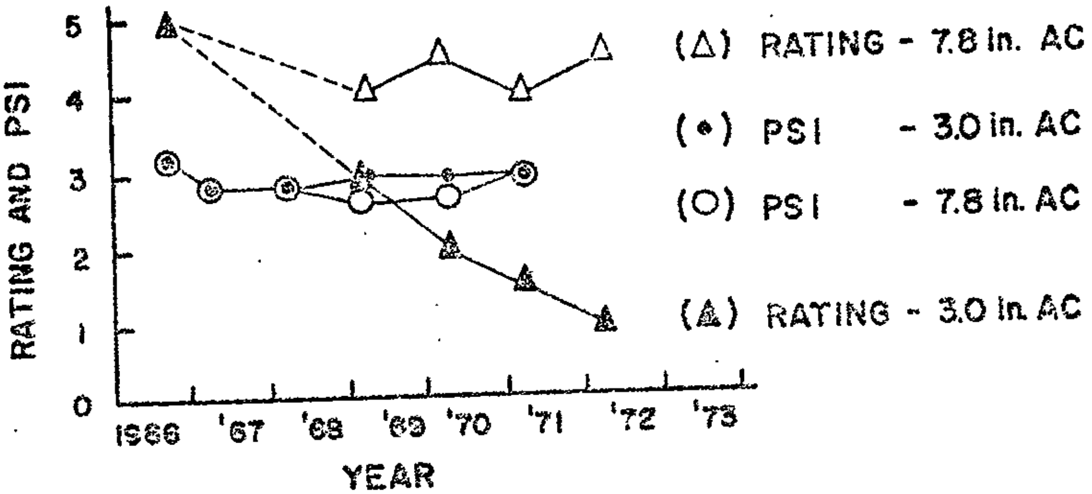

Figure 3—Performance Trends for Asphalt Concrete

Base Sections 9 and 13

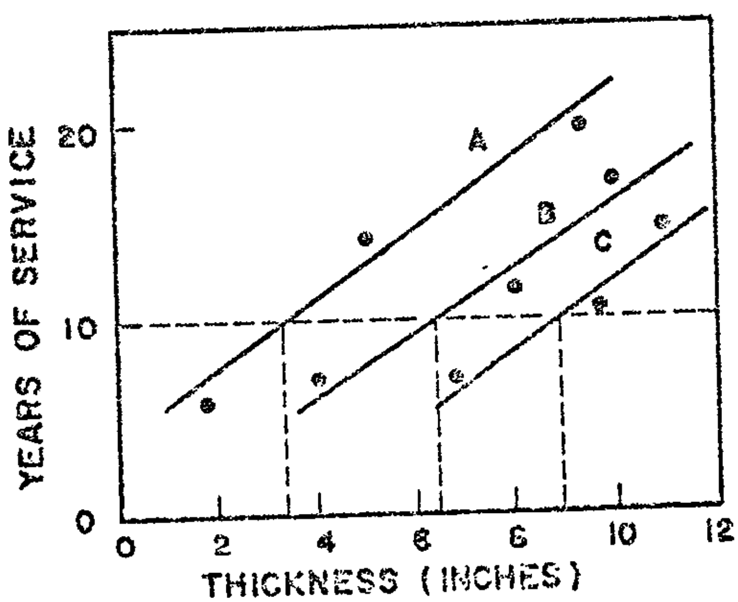

Figure 4—Hypothetical Relationships between Years

of Service and Base Thickness for

Three Materials: A, B and C

level A, of the asphalt concrete base was rated failed. The thinnest and next to thinnest sections of the emulsion treated base mix were rated poor. The level C untreated class 2 aggregate base section was also rated poor. One of two level C cutback treated base sections was also rated "poor."

The latest available PSI data is for 1971. No sections were rated as low as 2.0 but six were rated 2.5 or less. Only one section had appreciable rutting in 1972 and only two had appreciable cracking in 1970, but cracking had increased appreciably by 1972. Most cracking being observed by 1970 was believed to be load-associated. The cracking was longitudinal and began near the pavement edge and progressed inward. Tables 3-A through 3-D include only class 2 and 3 cracking, as defined in the AASHO Road Test (6).

PERFORMANCE ANALYSIS

One of the objectives of this experiment was to compare the behavior of various Full-Depth asphalt bases. In most design procedures now in use, different bases require different thicknesses described by layer equivalencies or ratios of thickness which will give equal performance. Layer equivalencies now used by some agencies were determined from AASHO Road Test data (references (8) and (9)), or are based on engineering judgment. There are many indications, for the most part from theoretical considerations, that layer equivalencies are not constant but vary with subgrade, load, temperature (for asphalt-bound materials), moisture and other factors. But they are an integral part of many design procedures, have considerable economic implications and will, no doubt, be used for some years to come. The performance analysis presented herein makes use of layer equivalencies as a weighting factor in the analysis.

As indicated earlier, the experiment was based on statistical factorial design principles in which base type and thickness were both variables in the experiment. It was postulated that layer equivalencies could be determined by comparing thicknesses required to give equal performance. Performance could be described as years (and traffic) to some level of service (PSI, performance index, performance rating, etc.) or level of service after some period of time had passed. A hypothetical relationship illustrating this principle, as given by Horner (10), is shown in Figure 4.

Horner pointed out the impracticality of using factorial designs in which each base type is built with the same thickness levels. Two designs of equal thickness but of radically different base types might take considerably different lengths of time to reach a given level of performance. For this reason, the San Diego experiment was designed using a scheme in which each base type has its own set of thickness levels:

Base Type	Base Thickness, inches, for Expected Years of Service		
	A Years	B Years	C Years
A	a	d	g
B	b	e	h
C	c	f	i

Partial replication, one replicate thickness per base type, was provided for. Also, since the objective of the experiments was to test bases, no subbases were included, and a uniform surface course thickness was used throughout.

Analysis of the data would be reasonably simple using multiple regression techniques if the performance lines proved to be parallel and the regression coefficients significant, etc. In the analyses given in this report they are assumed to be linear when log performance is plotted against log thickness. Considering the data scatter, the characteristics of AASHO Road Test performance data, References (6), (11) and (12), and the ease of analysis, this seems a reasonable assumption at this time.

The model for determining performance under this assumption would be

$$\log P = a_i + b \log T_i$$

where P = measure of performance (Rating, PSI, etc.)

T_i = thickness of base type i = A, B, C, etc.

The slopes are seen to be equal and layer equivalencies between materials A and B are determined by the relationship

$$T_B/T_A = 10^{(a_A - a_B/b)}$$

The first analysis was made using Rating (by the inspection team) as the measure of performance. However, original attempts to follow the plan outlined above were not successful because of the wide scatter in the data. For this reason attempts were made to modify the model or to pool data to provide a stronger data base.

It was observed that drainage conditions were poor and variable and that Benkelman Beam deflections also were variable. Since Benkelman Beam measurements are considered to reflect subgrade conditions to a high degree, deflection measurements were used in an attempt to improve the relationship. Data for the years 1970, 1971 and 1972 were used because they produced a reasonably balanced set of data for analysis. Since three years were involved, traffic, in terms of equivalent 18,000-lb (80 kN) axle loads (EAL_{1i}), were also added to the original model.

The first pass through the analysis procedure was based on the use of the computer program CORREL for multivariate analysis of data (13) using the model

$$Y = a_0 + a_1X_1 + a_0X_2 + a_3X_3$$

where Y = f (rating)

X_1 = f (traffic, EAL_{18})

X_2 = f (deflection)

X_3 = f (equivalent thickness of asphalt concrete base, pD_2)

D_2 = actual thickness of base

$1/p$ = weighting factor, or ratio of the thickness of a given base to the thickness of asphalt concrete base required to give equal performance.

There are two significant differences between this model and the more simple model tried originally. The first is the inclusion of deflection and traffic. The other is the use of an equivalent thickness of asphalt concrete base, rather than actual base thickness as the variable.

For the first pass through the analysis values of 1/p were assumed from analyses of the data made by F. N. Finn and the project steering committee using earlier data. Values of 1/p used were as follows:

Base Type	1/p
Asphalt Concrete	1.0
Asphalt Treated	1.2
Emulsion Treated	1.7
Cutback Treated	1.5

Four different relationships were used: one arithmetic relationship between variables and three with log transformations of the variables. In all four relationships the degree of correlation between rating and the other variables remained fairly constant regardless of the transformation used. The correlation between rating and both deflection and equivalent pavement thickness was significantly different from zero at the 99 percent level. The common assumption that rating should vary directly with pavement thickness and inversely with deflection was verified in the analysis. A significant inverse relationship between equivalent pavement thickness and deflection was also shown to exist.

The only predictor that did not show a good degree of correlation with the rating was the traffic variable, EAL_{18}. At the 80 percent level, this correlation was not significantly different from zero. While not a desirable outcome, it did permit pooling of the data for the three years, 1970, 1971 and 1972 for the next step in the analysis. It is not easy to explain the lack of significant correlation between EAL_{18} and the rating factor. When plotted, these variables show no real trend. However, if the individual pavement sections are observed separately, a very good trend or relationship may be seen (Figure 3). This seems to indicate that the poor correlation for the entire sample is due to a lack of range in the traffic variable. Also, as is evident from the data, the number of equivalent axle loads is not truly a random variable.

From the above considerations the following model was adopted in an attempt to determine analytically the values of 1/p. The model is

$$\log R = a_0 + a_1 d + a_2 \log pD_2$$

where R = rating

d = deflection in 10^{-3} inch units

p = base weighting factor, set equal to 1.0 for asphalt concrete

D_2 = actual base thickness

The multiple correlation program CORREL (13) was run on pairs of base types, each pair consisting of data for the three years for the asphalt concrete base and one of the remaining three base types. A range of p - values was chosen for each run from 1/p = .8 to 2.1. By plotting 1/p versus correlation coefficients between log rating and log pD_2 it was possible to determine the best fit 1/p value for each base type. These are given below:

Base Type	1/p
Asphalt Concrete	1.0 (assumed)
Asphalt Treated	0.85
Emulsion Treated	1.7
Cutback Treated	1.2

By using these values of 1/p to determine new equivalent thicknesses a new performance relationship was then determined. The final performance equation computed with the MULTR multiple regression computer program (13), using Rating as the dependent variable is:

$$\log R = 0.604583 - 0.0034831(d) + 0.195726 \log pD_2$$

where R = rating

d = deflection in 10^{-3} inch units

p = base weighting factor, as given above

D_2 = actual base thickness

$R^2 = 0.64$

S.E. = 0.117491

The squared multiple correlation coefficient (R^2) and standard error of estimate indicate that the regression equation does a fair job of explaining variations in the rating.

Three additional performance models were also attempted using the same technique:

$$\log PSI = a_0 - a_1 d + \log a_2 pD_2$$

$$\log R = a_0 - a_1 d + \log a_2 (D)$$

$$\log PSI = a^0 - a_1 d + \log a_2 (D)$$

where PSI, R, d and p are as defined earlier and

$D = D_1 + pD_2$

D_1 = thickness of surface course

D_2 = thickness of base course

The reason for using PSI as the dependent variable is obvious since PSI is a standard measure with a history of use and development tracing back to the AASHO Road Test.

The use of $D = D_1 + pD_2$ was made to approximate the structural number concept adopted on the AASHO Road Test and used in the AASHO Interim Guide for the Design of Flexible Pavement Structures (8).

The analyses using the PSI and D variables indicated that values of 1/p remained essentially unchanged and so they were used as originally determined. However, neither of the equations using PSI resulted in a significant correlation. None of the R^2 values were greater than 0.3 and the coefficients on the thickness variable were negative. These results were judged not acceptable and the model was rejected.

The two successful performance equations as finally determined for the four cases are summarized in Table 4. Both equations appear to be equal in their ability to represent the data, although in the equation using $D = D_1 + pD_2$ thickness effects have more weight in predicting rating.

In addition to the multiple regressions discussed above, several simple correlations were tried between rating and PSI. None resulted in a significant correlation. It was necessary to conclude, therefore, that PSI could not be used to indicate test section performance.

Table 4

SUMMARY OF PERFORMANCE EQUATIONS

Equation No.	Performance Measure	Thickness Variable	R^2	S.E.	Equation
(1)	R	pD_2	0.640	0.117491	$\log R = 0.6045828 - 0.0034831\,d + 0.1952726 \log pD_2$
(2)	R	$D = D_1 + pD_2$	0.649	0.116091	$\log R = 0.4929623 - 0.0035115\,d + 0.2789277 \log D$

R = panel rating
PSI = present serviceability index
D_1 = thickness of surface course
D_2 = thickness of base course
p = base type weighting factor
d = deflection in 10^{-3} in. (0.0254 mm) units
R^2 = squared multiple correlation coefficient
S.E. = standard error of estimate

DISCUSSION

One of the major conclusions of the HRB Workshop on Structural Design of Asphalt Concrete Pavement Systems, held in Austin in December 1970 (14), concerned the need to relate pavement distress to performance. Performance data from the San Diego Experimental Base Project should be of some help in meeting this need.

Pertinent to the study presented here is the report of the HRB Workshop Group 1, "Relating Distress to Pavement Performance." The group indicated that there are basically two methods in use for serviceability evaluation of pavements: one using a road-user related index or rating system and the other a mechanistic evaluation primarily based on deflection measurements. The group "went on record to state that a present serviceability rating or present serviceability index pavement evaluation system is the most satisfactory method currently available for evaluating pavement performance." The group also stated that major needs include (1) a better relationship among service, performance, time and traffic; (2) a study of the effects of maintenance on serviceability trends; (3) a data feedback system; and (4) quantitative distress information. Although these factors are not all discussed specifically, some effort is made to relate findings from the San Diego project to these needs.

The project measurements program included five measures which possibly could be used to evaluate pavement performance: (1) present serviceability index, (2) a panel rating, (3) cracking, (4) rut depth and (5) deflection. In this study deflection has been used only to remove subgrade variability influences. Cracking was used only as it influenced PSI measurements. No direct use was made of rut depth, which in most cases was small.

The panel ratings are in many respects indicators of maintenance needs and reflect subjective evaluations of the pavement condition using only visual "data." Present serviceability index was based on a mechanical evaluation of the pavement surface condition, except for the limited influence of cracking. A relationship between the two would indicate to some extent how well PSI might reflect a visual maintenance need-related rating.

Comparisons between PSI and ratings, Tables 3-A through 3-D and Figure 3, indicate that the two measures do not reflect pavement performance in the same way. The correlation between the two was extremely poor, as explained earlier.

If deflection and equivalent thickness (pD_1 or $D = D_1 + pD_2$) are considered structural variables, it is concluded on the basis of the analyses presented here that rating was a reasonably good indicator of pavement performance but that PSI was not.

The two final equations relating deflection and thickness to the rating performance indicator are given in Table 4. The relationship between rating, deflection and $D = D_1 + pD_2$ are shown in Figure 5.

The base type weighting factors (1/p) determined in the performance analysis also have significance in that they are related to layer coefficients or layer equivalency values used in many pavement design methods, such as the <u>AASHO Interim Guide for the Design of Flexible Pavement Structures</u> (8) and The Asphalt Institute manual, <u>Thickness Design—Full-Depth Asphalt Pavement Structures for Highways and Streets</u> (9).

The base type weighting factors are summarized in Table 5, along with the original values assumed in designing the experiment. Even though a discussion of equivalency factors is beyond the scope of this paper, it is encouraging to note that the three treated bases performed as well or better

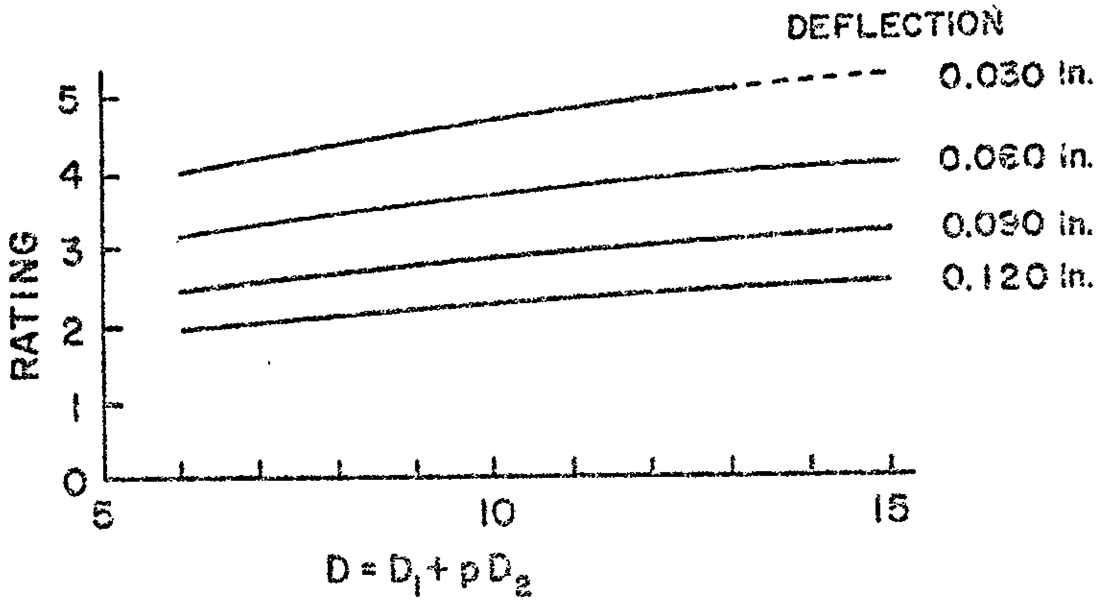

Figure 5—Rating versus D

Table 5

SUMMARY OF BASE WEIGHTING FACTORS

Base Type	Design	Analysis
Asphalt Concrete	1.0	1.0 (assumed)
Asphalt Treated	1.2	0.85
Emulsion Treated	1.7	1.7
Cutback Treated	1.5	1.2

than expected relative to the high-type asphalt concrete base. These three mixes were designed and constructed using a marginal-quality sandy gravel similar to many available in larger quantity elsewhere, and the results could have wide applicability provided proper account is given to different environmental conditions, etc.

CONCLUSIONS

Under conditions of the test and limitations of the analysis, the following conclusions may be drawn from performance data from the San Diego Experimental Base Project. The conclusions apply only to the four Full-Depth base sections incorporated in the experiment at all thickness levels.

It was possible to develop significant relationships between a panel rating of test section performance and the structural variables deflection and equivalent thickness. The data did not yield significant relationships with either traffic or present serviceability index (PSI).

Base type weighting factors were developed from the analysis. The analysis indicated that the relative performance of the Full-Depth asphalt treated bases using a marginal-quality sandy gravel aggregate, compared to the high quality asphalt concrete base, was as good or better than assumed in the original design of the experiment. Their relevance to other conditions and environments remain to be determined.

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