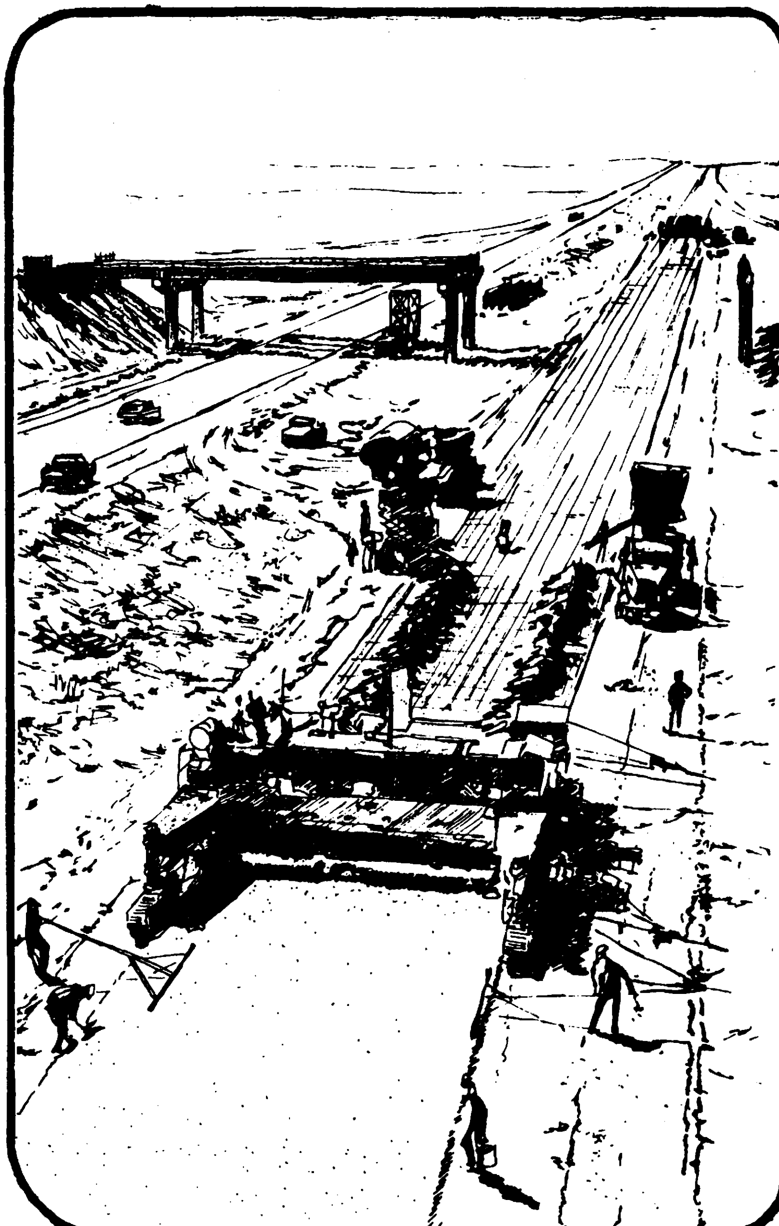
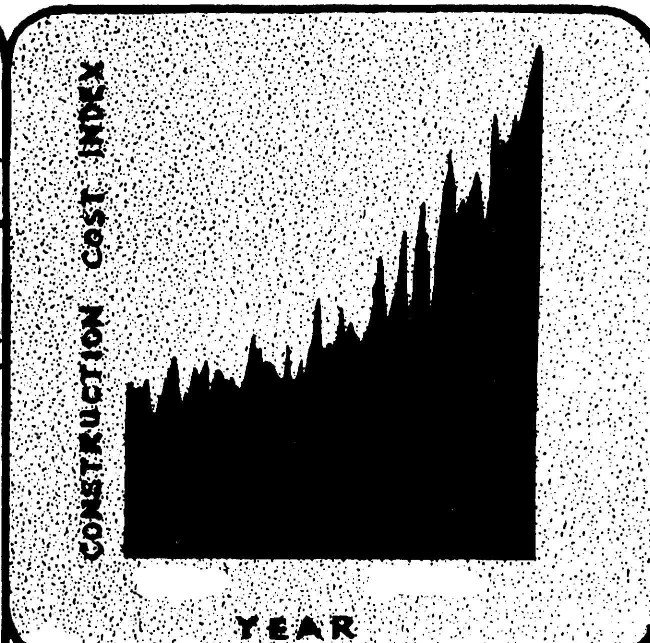
ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

PERFORMANCE OF SURFACE COURSES CONSTRUCTED WITH LIMESTONE ROCK ASPHALT MATERIALS -- VOLUME I

RESEARCH REPORT 214-14
NOVEMBER 1979





COOPERATIVE RESEARCH PROJECT
2-9-74-214

"ENGINEERING, ECONOMY AND ENERGY CONSIDERATIONS IN DESIGN, CONSTRUCTION AND MATERIALS"

TEXAS STATE DEPARTMENT
OF HIGHWAYS
AND PUBLIC TRANSPORTATION
AND
TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

TASK FORCE ON ENGINEERING, ECONOMY AND ENERGY CONSIDERATIONS

Larry G. Walker, Task Force Chairman and Materials and Tests Engineer

Charles H. Hughes, Sr., Study Contact Representative and Assistant Materials and Tests Engineer

A.H. Pearson, Jr., Assistant State Engineer-Director

Wayne Henneberger, Bridge Engineer

Robert L. Lewis, Chief Engineer, Highway Design

Byron C. Blaschke, Chief Engineer, Maintenance Operations

J.R. Stone, District Engineer

William V. Ward, Urban Project Engineer-Manager

Phillip L. Wilson, State Planning Engineer

Franklin C. Young, District Engineer

Theodore E. Ziller, Construction Engineer

PERFORMANCE OF SURFACE COURSES CONSTRUCTED WITH LIMESTONE ROCK ASPHALT MATERIALS

VOLUME I

by

J. A. Epps, J. P. Mahoney and C. H. Hughes, Sr.

Research Report 214-14

Engineering, Economy and Energy Considerations in Design, Construction and Materials

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Sponsored by

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Texas Transportation Institute
Texas A&M University
College Station, Texas 77843

EXECUTIVE SUMMARY

Limestone rock asphalt products have been utilized as surface course materials on Texas streets and highways since the 1890's. This valuable resource is presently produced for road building purposes by Uvalde Rock Asphalt Company and White's Mines in Uvalde County, Texas. Cold mixes utilizing flux oils and coverstone for surface treatments and seal coats are the products currently utilized as surface courses by the Texas State Department of Highways and Public Transportation. Production of these products for Texas State Department of Highways and Public Transportation use in both construction and maintenance approached 1,000,000 tons in 1978.

From the above discussion it is apparent that limestone rock asphalt is one of the most frequently utilized materials in the state and that its performance on highway pavements is of particular interest to the Texas State Department of Highways and Public Transportation. As a result, the state has undertaken several studies to investigate the properties of limestone rock asphalt cold mixtures and to study the performance of these mixes on the roadway. Since the completion of many of these older studies, new tools and techniques have been developed to define the properties of materials and the performance of pavements. Because of the development of these new tools and techniques, a research study was undertaken to define the performance of limestone rock asphalt pavements. Specifically, the study is concerned with defining the traffic and environmental conditions where limestone rock asphalt materials can be expected to provide a satisfactory performance from a skid and structural adequacy standpoint on the state highway system. It should therefore be noted that all collected data were

obtained from the state highway system. Therefore the conclusions and recommendations advanced by the report may not necessarily apply to city or county roadway systems where traffic speeds, traffic volumes, and the percent truck traffic are often different.

The study method utilized included both field and laboratory data collection as well as an extensive evaluation phase. The field phase of this project was established to provide skid numbers at specific locations on the pavement sections selected for study. This technique allowed the engineers to evaluate the pavement section at the location of skid testing and to make other measurements that could be used for correlation studies with skid numbers.

The types of field data collected included a general history of the section under study, a visual condition survey, photographs, deflection testing, surface texture measurements, core samples, traffic information and skid measurements. The field study team consisted of personnel from Texas State Department of Highways and Public Transportation Districts and central office Divisions and the Texas Transportation Institute. Laboratory data collected included: specific gravity, percent air voids, resilient modulus, Marshall stability, Hveem stability, and indirect tensile properties of the field cores. Additionally, the specification item, type and grade together with percent flux oil, percent water, average bitumen, bitumen in the passing No. 10 fraction, percent white rock, average bitumen in white rock, average stability and gradation were obtained from the Materials and Tests Division (Division 9), Plant Inspection Reports.

Data collected in the field and laboratory were coded on computer cards for analysis purposes. Photographs for each section can be found in Volume II of this report while data summary sheets can be found in Volume III. A brief summary of properties measured in the field and laboratory is shown in Table A. These data form the basis of the conclusions and recommendations which follow.

CONCLUSIONS

1. Previous research studies conducted by the Texas SDHPT and the Texas Transportation Institute have defined typical engineering properties of asphalt concrete and seal coats made with a variety of aggregates. Data collected in this study defined certain engineering properties of LRA materials. Comparisons of these data indicated the following:
   a. The load carrying capability of fully cured limestone rock asphalt cold mixes is similar to that of asphalt concrete. This statement is based on field deflection testing and laboratory testing of field cores. However, field data indicated greater amounts of alligator cracking associated with limestone rock asphalt concrete. (This may be influenced by the fact that limestone rock asphalt overlays are generally thinner than those with asphalt concrete.)
   b. Hveem and Marshall stability values for limestone rock asphalt cold mix are within the range normally obtained for asphalt concrete.
   c. The air void content of in-service limestone rock asphalt cold mixes is higher than that normally experienced for asphalt concrete.
   d. Limestone rock asphalt cold mixes exhibit a greater tendency to ravel than asphalt concrete. This tendency did not appear

to be detrimental to performance of the pavements and is probably a mixture characteristic occurring during or soon after construction rather than progressing throughout the life of the pavement.

e. Surfaces constructed with limestone rock asphalt cold mixes have less flushing than asphalt concrete surfaces.

f. Pavement Rating Score for the 106 limestone rock asphalt surfaced pavements is 79 while an average of 83 was obtained on 245 randomly selected pavements in Texas.

2. Statistical evaluation of Skid SN 40 data using multiple regression techniques shows a reliable relationship between SN 40 and ADT/Lane for both LRA cold mixes and seal coats. A reliable relationship between SN 40 and accumulated traffic on seal coats was also shown.

3. The sections studied in District 22 exhibited the best overall skid performance. This is attributed to good construction techniques and the fact that poor performing A and B mixes are not used. The District 22 data as shown in Figures A, B, D and E indicate the best performance that can reasonably be expected. Under these conditions the regression analysis shows that SN 40 values of 35 or greater were achieved on approximately 95% of the sections when:

ADT/LANE	is less than 1500 for cold mixes
ADT/LANE	is less than 1600 for seal coats
ACCUMULATED Traffic/LANE	is less than 3,300,000 for seal coats

Regression analysis also shows that SN 40 values of 35 or greater were achieved on approximately 50% of the sections when:

ADT/LANE	is less than 2,000 for cold mixes
ADT/LANE	is less than 2,200 for seal coats
ACCUMULATED Traffic/LANE	is less than 5,000,000 for seal coats

4. Flushing of limestone rock asphalt seal coats can significantly decrease skid number. (Figure F.)
5. Type A and B mixes exhibited lower skid numbers than Type C and CC mixtures. Regression analyses indicate that Type C and CC mixtures may exhibit higher skid numbers with low traffic levels than Type A and B mixes but the rate of loss of skid number with increasing traffic appears to be higher for the Type C and CC mixes.
6. Within the limits of the data evaluated, the percent flux oil, percent water, percent bitumen, bitumen in minus No. 10 fraction and percent white rock did not appear to be significant variables in predicting skid performance of limestone rock asphalt cold mixtures. They may have significant influence on other performance factors.
7. Climate cannot as yet be definitely eliminated as a factor controlling skid properties of the surfaces studied.
8. The report makes an assessment of resource utilization and concludes that rock asphalt products can be utilized as a surfacing material on all but a small percentage of the state's highways. While this statement appears to reduce the utilization of this valuable natural resource; other definitive engineering data are contained in the report which may open new markets as conditions are defined under which limestone rock asphalt products can be successfully utilized.

RECOMMENDATIONS

1. The use of limestone rock asphalt as a surfacing material on the State Highway system should be considered a satisfactory alternative up to a design average daily traffic per lane of 2,000. This is based on good construction techniques and recognizing that local district experience may dictate the use of other values.
2. Existing Type A and B limestone rock asphalt cold mixtures should not be used for surface courses. Gradations and mixture designs other than those presently specified should be investigated.
3. Consideration should be given to developing improved mixture design methods and field construction techniques.
4. Proper methods for placing limestone rock asphalt cold mixes should be well documented and training films prepared.

Table A. Comparison of Properties and Pavement Performance*

	Property or Performance Measure	Comparison based on indicated types of surfaces: LRA Surfaces	Comparison based on indicated types of surfaces: Other Surfaces	Value of Property or Performance: LRA Surfaces	Value of Property or Performance: Other Surfaces
Property	Polish value	aggregate		37-46	Variable
Property	Air Void Content, percent	CM	HMAC	12	6
Property	Hveem Stability	CM	HMAC	>35	>35
Property	Marshall Stability, lbs	CM	HMAC	>1,500	>1,500
Property	Resilient Modulus, psi	CM	HMAC	790,000	1,000,000
Property	Dynaflect Coefficient	CM	HMAC	0.90	1.00
Performance	Pavement Rating Score	ST,SC,CM	ST,SC,HMAC	79	83
Performance	Amount of flushing, percent of total pavements	CM	HMAC	3	29
Performance	Amount of raveling, percent of total pavements	CM	HMAC	68	7
Performance	Amount of alligator cracking, percent of total pavements	ST,SC,CM	HMAC	50	20
Performance	Surface Texture cu. in. per sq. in.	CM	HMAC	0.030	0.026
Performance	Pavement Life, Yrs.	ST	ST	8.1	5.1
		SC	SC	6.5	7.0
		CM	HMAC	6.2	6.6

ST=Surface Treatment
SC=Seal Coat
CM=limestone rock asphalt cold mix
HMAC=hot mix asphalt concrete
LRA= limestone rock asphalt

*Values are to be considered representative only

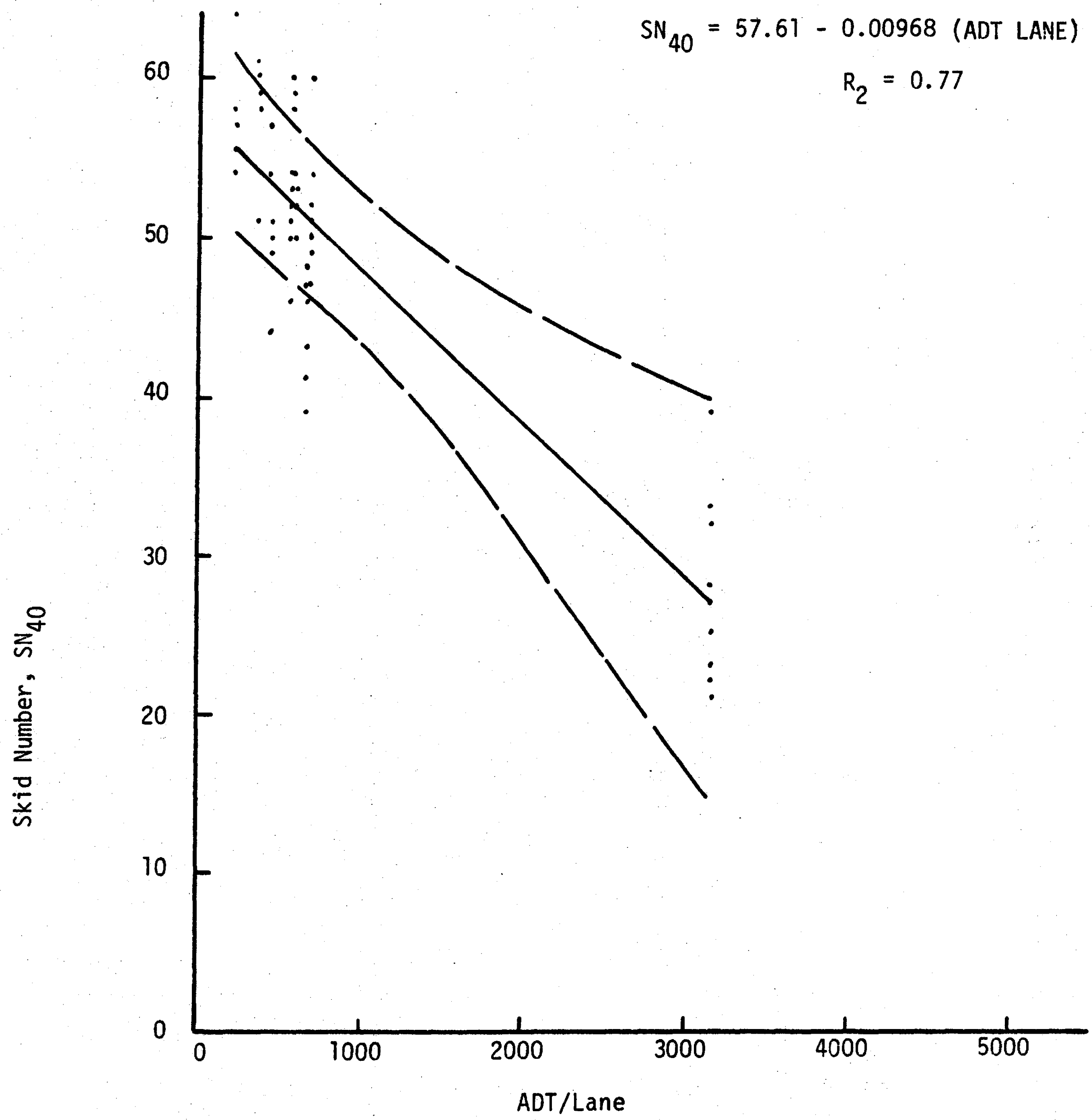

Figure A. Skid Number versus ADT/Lane for Limestone Rock Asphalt Type CMOD Cold Mixes in District 22 with 90 % Confidence Bands for the Regression Equation.

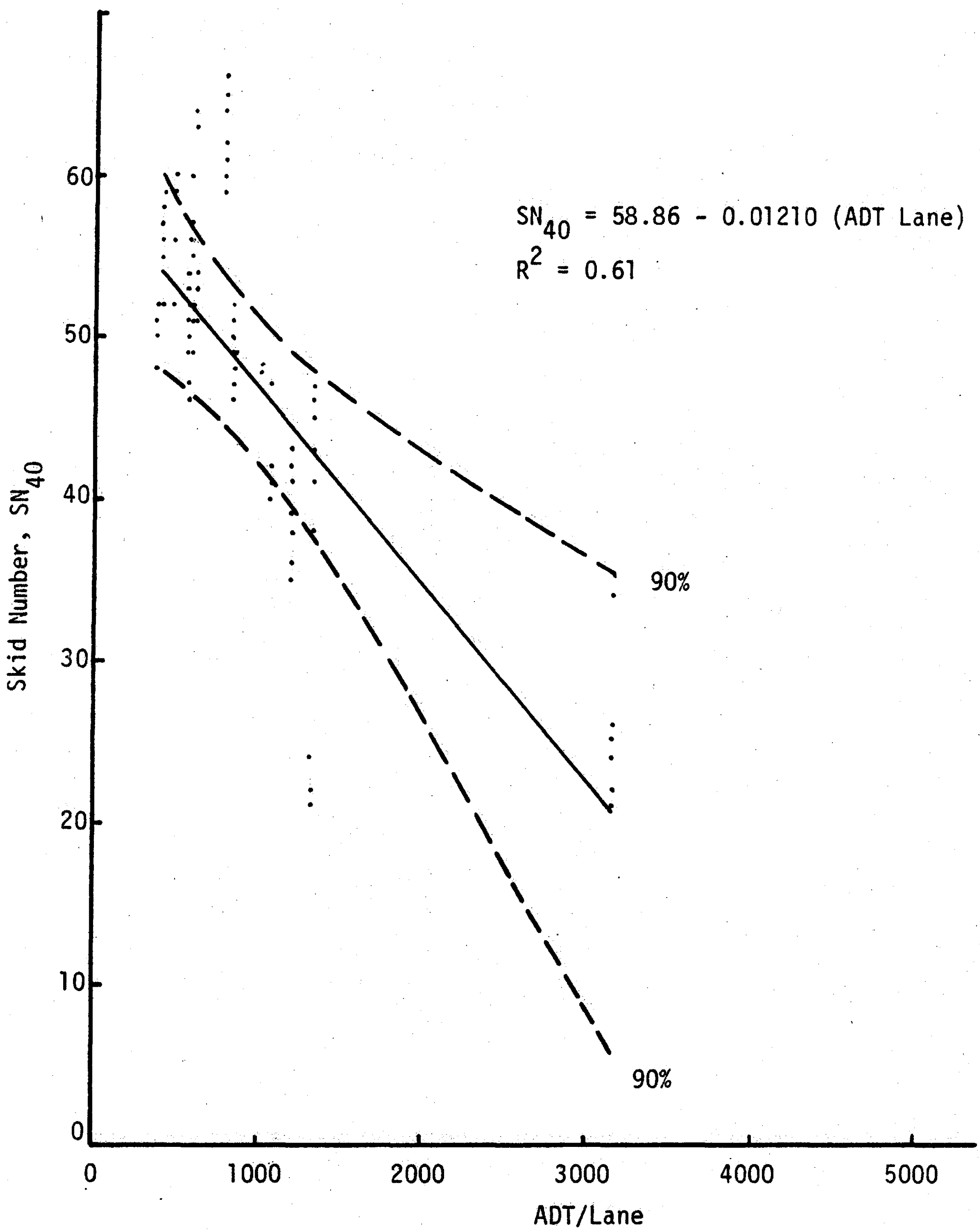

Figure B. Skid Number versus ADT/Lane for Limestone Rock Asphalt Type C Cold Mixes in District 22 with 90 Percent Confidence Bands for the Regression Equation.

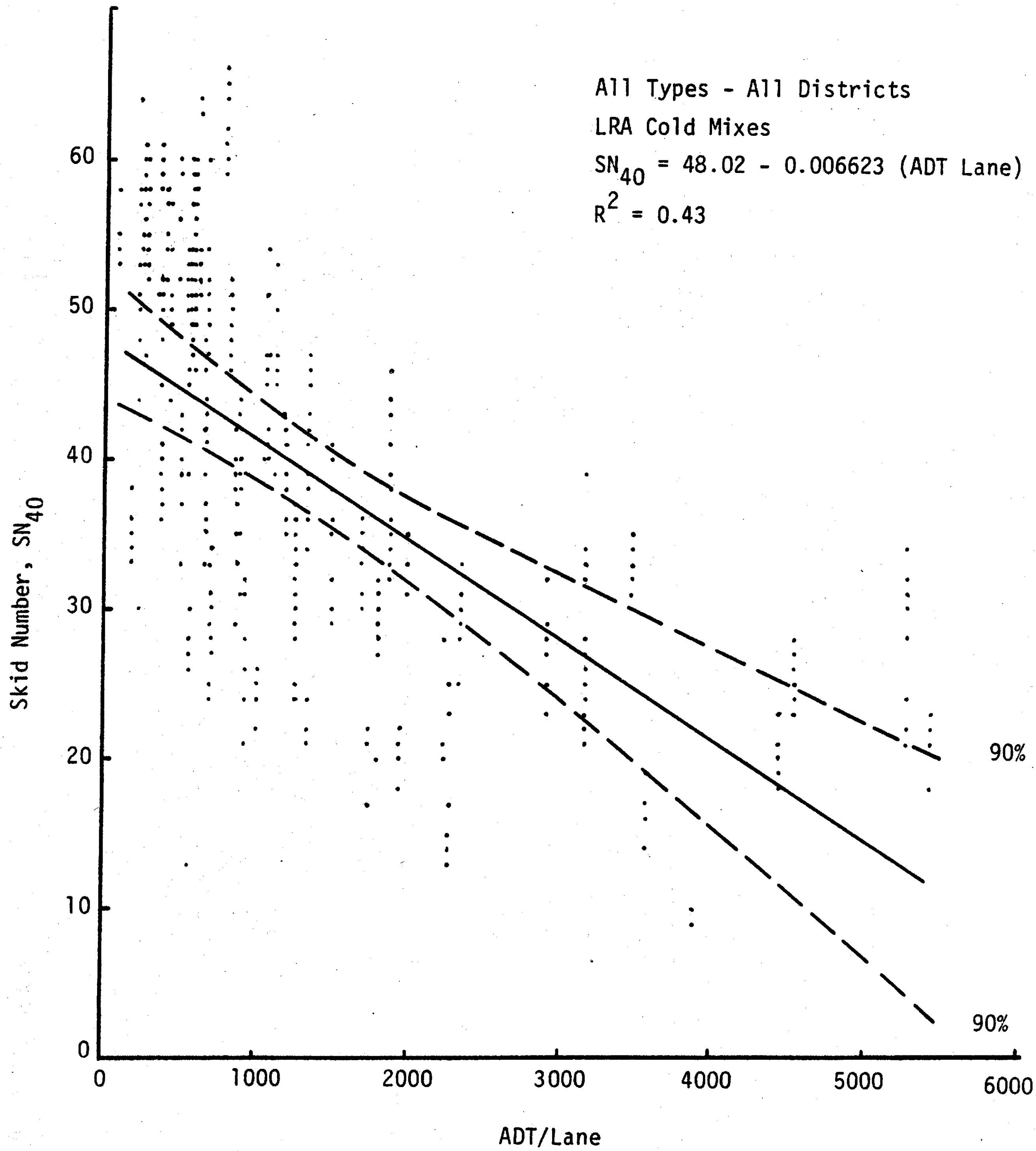

Figure C. Skid Number versus ADT/Lane for "Good" to "Average" Limestone Rock Asphalt Cold Mixes with 90 Percent Confidence Bands for the Regression Equation.

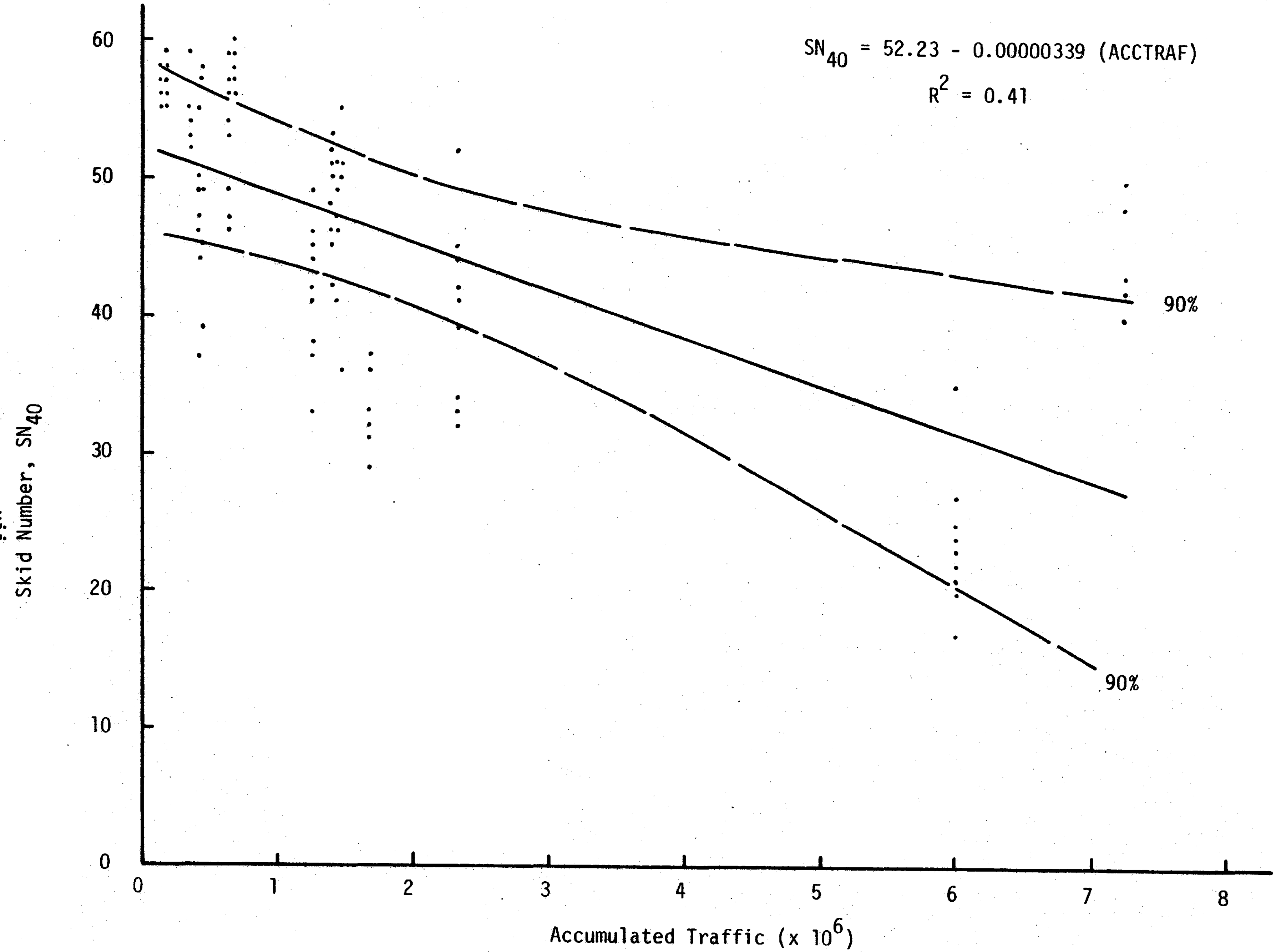

Figure D. Skid Number versus Accumulated Traffic for Limestone Rock Asphalt Seal Coats in District 22 with 90 Percent Confidence Bands for the Regression Equation.

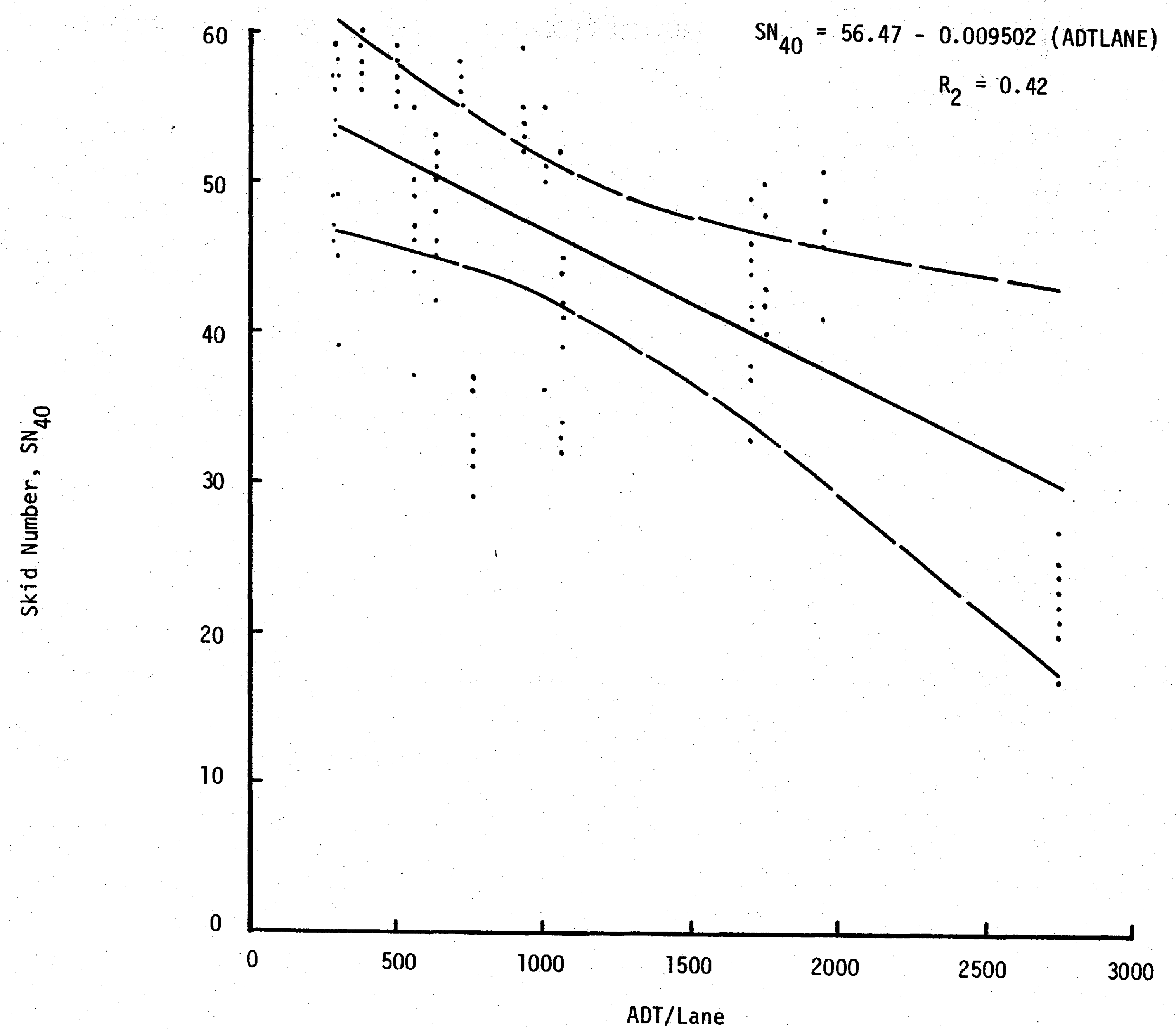

Figure E. Skid Number versus ADT/Lane for Limestone Rock Asphalt Seal Coats in District 22 with 90 Percent Confidence Bands for the Regression Equation.

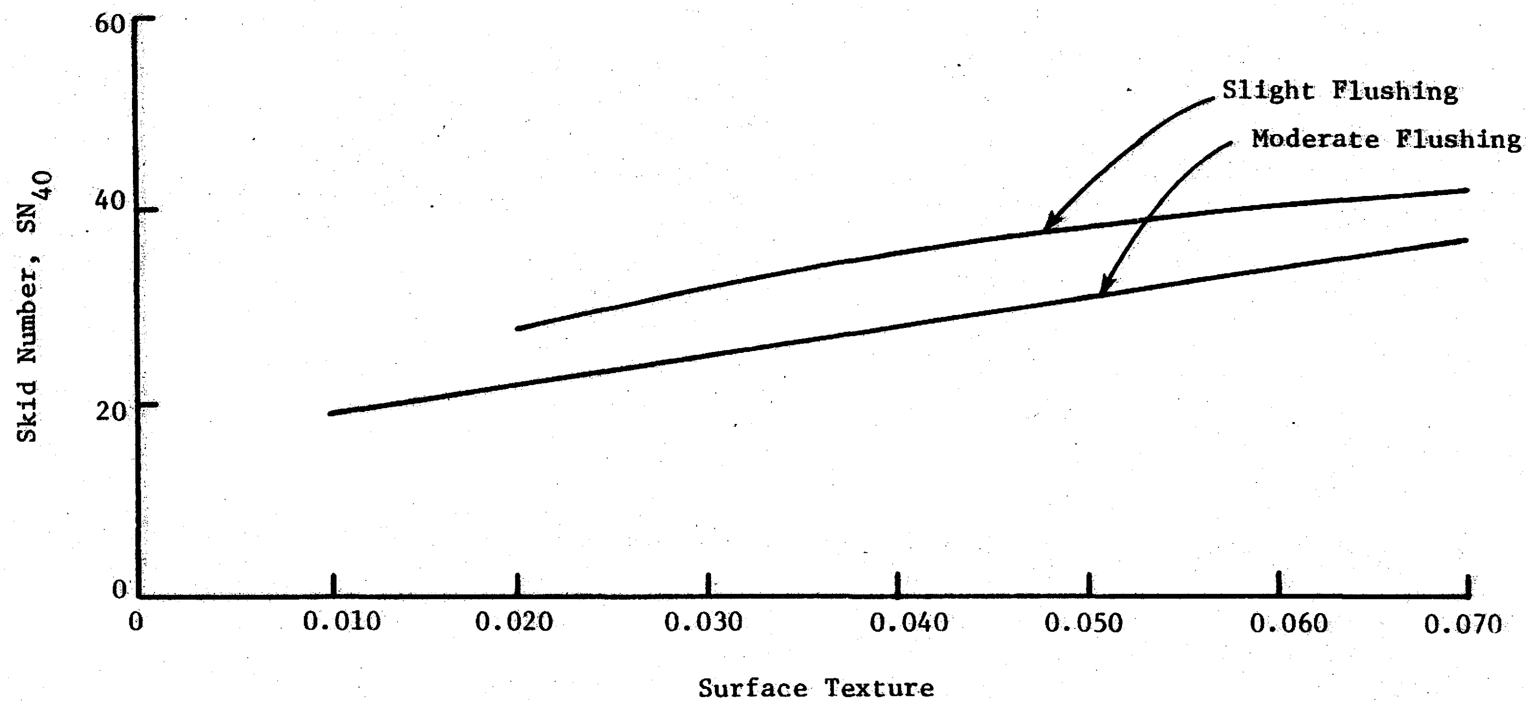

Figure F. Skid Number versus Surface Texture - Limestone Rock Asphalt Seal Coats for Slight and Moderate Flushing

TABLE OF CONTENTS

Page

INTRODUCTION

The Uvalde rock asphalt deposits were first developed in 1891 for the purpose of utilizing the extracted asphalt in the paint and rubber industries (1). Six years later the Uvalde Asphalt Company shipped material to New York City for road building purposes (2). In the late 1890's the quarried asphalt limestone was utilized on city streets and sidewalks in San Antonio (3). In 1912 this paving product was being utilized in highway projects. During 1920 to 1930 several companies operating in the Uvalde area supplied materials for the nation's expanding highway system. For example, in 1929 three companies made shipments totaling 320,931 tons. Restricted fiscal resources in the mid-1930's and the war effort in the early 1940's limited the overall annual production of rock asphalt to an average of about 20,000 tons during this period. With increased highway building in the late 1940's and early 1950's production exceeded the half-million tons per year level. Production levels from 1947 to 1974 are shown on Figure 1 and have exceeded 50,000 tons since 1950 and approached 1,000,000 tons in 1967. Annual production approached 1,000,000 tons in 1978 (4).

It is estimated that approximately 65 percent of the total rock asphalt production is utilized by the Texas State Department of Highways and Public Transportation (SDHPT) (5). White's Mines and Uvalde Rock Asphalt Company, the current producers, supply the state with materials for new construction, rehabilitation and maintenance purposes. Cold mixes utilizing flux oils and cover

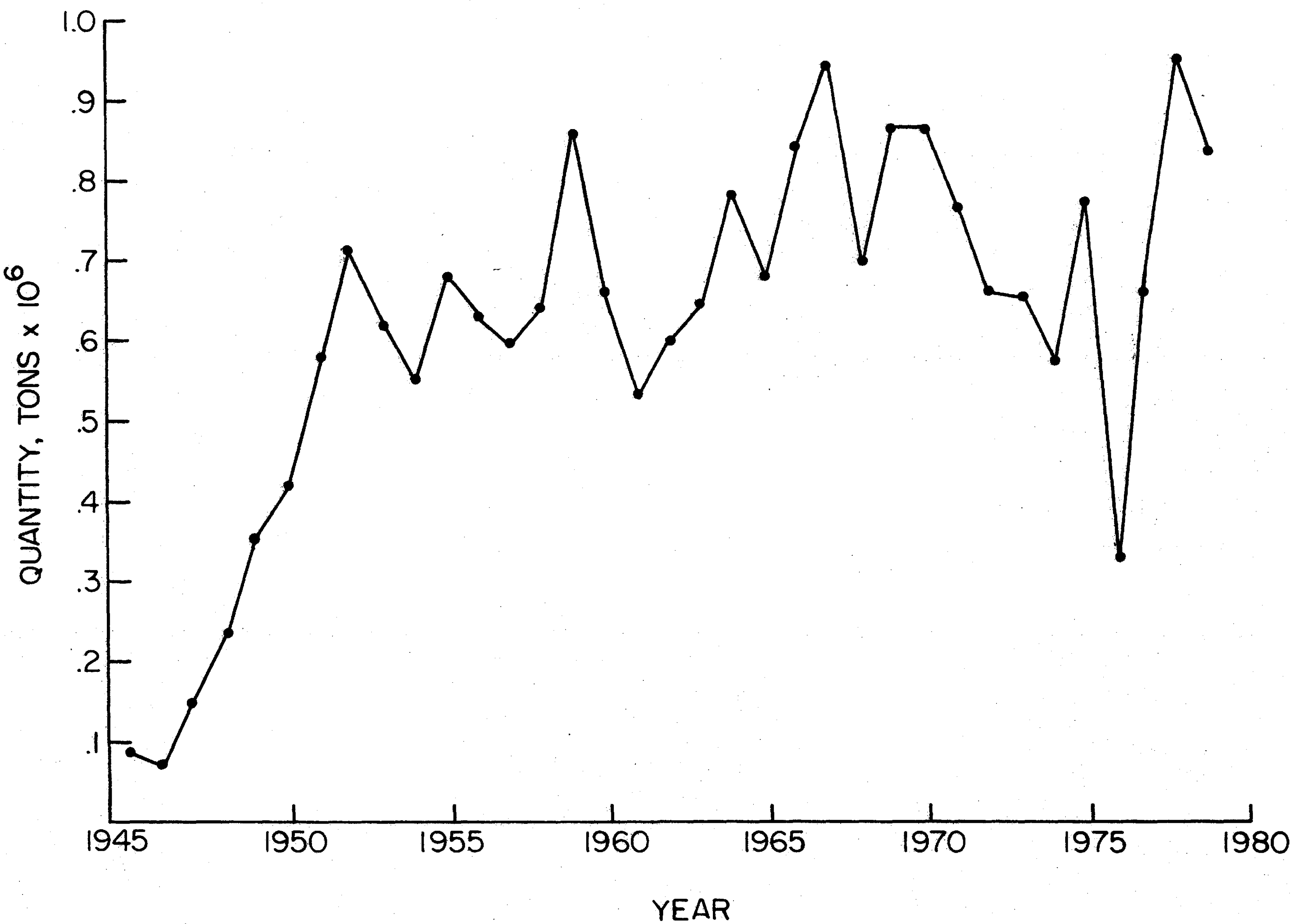

Figure 1. Quantities of Limestone Rock Asphalt Used by the Texas Highway Department from 1945 to 1979. (After reference 4.)

stone for surface treatments and seal coats are the products utilized by the state. These are Specification Items 301, Type E (Aggregate for Surface Treatment Class A), Item 302, Type E (Aggregates for Surface Treatments, Class B), Item 304, Type PE (Aggregate for Surface Treatments, Precoated, Class B), Item 305, Type PE (Aggregate for Surface Treatments, Precoated, Class A) and Item 330 (Cold Mix Limestone Rock Asphalt Pavement, Class A) (6).

From the above discussion it is apparent that limestone rock asphalt is one of the most frequently utilized materials in the state and thus its performance on highway pavements is of particular interest to the Texas SDHPT. As a result, the state has undertaken several studies to investigate the properties of the limestone rock asphalt mixtures and to study the performance of these mixes on the roadway. As a result of these studies several reports have been published (3, 4, 6, 7, 8, 9, 10, 11, 12) and several internal memoranda have been prepared by SHDPT Districts and Divisions. Among the factors investigated have been the effect of flux oil type and content, white rock count, bitumen content of aggregate and gradation of mixture performance (7, 9, 10, 11); the skid properties of limestone rock asphalt pavements (3, 4, 12); the properties of rock asphalt screenings (8); and the use of rock asphalt coarse aggregate in hot mix asphalt (3). These studies have contributed to the preparation of specifications governing the production of limestone rock asphalt products.

Since the completion of many of these studies, new tools and techniques have been developed to define the properties of materials and to define the performance of pavements. Because of the development of these new tools and techniques, a study was under -

taken to define the performance of limestone rock asphalt pavements. Of particular interest was the load carrying ability of limestone rock asphalt mixtures and the skid properties of limestone rock asphalt utilized in cold mixes, surface treatments and seal coats on the state highway system. It should therefore be noted that all collected data were obtained from the state highway system. Thus the conclusions and recommendations advanced by the report may not necessarily apply to city or county roadway systems where traffic speeds, traffic volumes, and the percent truck traffic are often different. Details of this study are given below.

STUDY APPROACH

As stated above the purpose of this study is to define the performance of limestone rock asphalt materials as a pavement surfacing material. Specifically, the study is concerned with defining the traffic and environmental conditions where limestone rock asphalt materials can be expected to provide satisfactory performance from a skid resistance and structural adequacy standpoint.

Since limestone rock asphalt products are utilized by almost all 25 Districts of the Texas SDHPT, it was desirable to select pavement projects from a number of districts. A review of available information indicated that Districts 15, 16, 20, 21 and 22, use the largest quantities of these materials. Thus pavement sections in Districts 20, 21 and 22 were selected for study as they provided a fairly wide range of climatic and subgrade soil conditions (Table 1) (13).

District 20 (Beaumont) is a district located on the northern Gulf Coast of Texas. Gulf coastal soils as well as soils typical of the Southern Coastal Plains are within the limits of this district. The mean annual precipitation ranges from 48 -56 inches with an average temperature of 68°F.

District 21 (Pharr) is a district located on the southern Gulf Coast of Texas. The major soils are sands near the Gulf Coast, flood plain soils and soils derived from weathered limestones. The mean annual precipitation ranges from 16 - 26 inches with an average temperature of 74°F.

District 22 (Del Rio) is a district located along the central

Table 1: General Environmental Conditions of Districts Studied

District	Mean Annual Total Precipitation, In.	Mean Annual Temperature	Mean Length of Warm Season*, Days	Physiographic Provinces of the United States	Major Landscape Areas
20 - Beaumont	48 - 56	67 - 69	230 - 260	Coastal Plain	Gulf Coast Marsh Gulf Coast Prairie Southern Coastal Plain Bottom Lands
21 - Pharr	16 - 26	72 - 75	290 - 330	Coastal Plain	Bottom Lands Rio Grande Plain
22 - Del Rio	13 - 28	68 - 71	245 - 290	Coastal Plain Great Plains	Rio Grande Plain Edwards Plateau
Texas	8 - 56	56 - 75	180 - 330		

*Number of days between the mean dates of last 32°F freezing in spring and the first 32°F freeze in fall. (after reference 13) portion of the Texas - Mexico border. Two major types of soils are encountered; those common to the Rio Grande Plain and the Edwards Plateau. The mean annual precipitation ranges from 13 to 28 inches with an average temperature of 70°F.

Within these three districts, roadway sections were selected to include surface treatments, seal coats and cold mixes made with limestone rock asphalt aggregates. Sections were made so as to obtain a range in pavement age and traffic volume. Initially a total of 106 sections were identified for the research team by the districts. Four sections with surface treatments, 43 sections with seal coats and 59 sections with cold mixes were included in this study. Of the cold mix pavements surveyed 38 were placed with a blade, 18 were placed with a laydown machine and 3 were placed with a special paving box attached to a truck. Twenty-four percent of the pavement sections were located in District 20, 33 percent in District 21 and 43 percent in District 22 (Table 2).

An attempt was made in 1978 to locate and study additional high traffic volume sections. Districts were surveyed and input from producers of limestone rock asphalt products was utilized to locate study sections. An additional 22 sections were located in Districts 1, 10, 13, 15, 16, 19, 20, 21, and 22 in an attempt to extend the applicability of the collected data to high traffic volumes. Few additional sections were located in the state which carried the desired high traffic volumes.

The study method included both field and laboratory phases for obtaining data, and an evaluation phase. The field phase of this project was established to provide skid numbers at specific locations on the pavement sections. This technique

Table 2: Summary of LRA Pavement Surface Type by District

DISTRICT	Surface Treatments		Seal Coats		Cold Mixes								TOTAL	
					Blade Laid		Machine Laid		Box Laid		Total			
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
20	1	4	11	44	3	12	7	28	3	12	13	52	25	24
21	3	9	18	51	5	14	9	26	0	0	14	40	35	33
22	0	0	14	30	30	66	2	4	0	0	32	70	46	43
20, 21, 22	4	4	43	40	38	36	18	17	3	3	59	56	106	100

allowed the engineers to evaluate the pavement section at the location of skid testing and to make other measurements that could be used for correlation with skid numbers. The types of field and laboratory data collected are described below. Techniques used for analysis of the data will be discussed in a later section of this report.

Field Data

The types of field data collected included a general history of the section under study, a visual condition survey, photographs, deflection testing, surface texture measurements, core samples, traffic information and skid measurement. In order to obtain this information a study team was assembled consisting of personnel from the Texas SDHPT Districts and Divisions and from the Texas Transportation Institute, Texas A&M University. Members of the study team are listed below:

W. F. Adams - Maintenance Construction Superintendent II, District 22, SDHPT

S. G. Cox - District Maintenance Engineer, District 21, SDHPT

W. N. Dudley - Supervising Resident Engineer, District 20, SDHPT

J. A. Epps - Research Engineer, Texas Transportation Institute

K. D. Hankins - Supervising Research Engineer, Division 10, SDHPT

A. J. Hill - Materials and Test Bituminous Engineer, Division 9, SDHPT (now retired)

A. B. Hubbard - Administrator, Technical Programs, Division 10, SDHPT

C. H. Hughes, Sr. - Materials and Tests Field Research Engineer, Division 9, SDHPT

A discussion of the specific information collected is described below.

General History of Section. A general history of the section was obtained from the district files and from a "first hand" knowledge of the section provided by the research team member from the district under study. Information obtained included:

1. Year surface placed,
2. Type of surfacing material,
3. D-9 laboratory numbers,
4. Supporting pavement structure material and thicknesses,
5. History of the performance of the section,
6. Construction problems,
7. Maintenance requirements,
8. Future maintenance requirements and
9. Traffic data.

This information was collected on a form as shown in Figure A1 of Appendix A and later transferred to computer input forms as shown in Appendix A.

Visual Condition Survey. The condition of the pavement was determined by use of a survey technique described in Reference 14. This technique involves the recording of the extent and degree of the following types of flexible pavement distress: rutting, raveling, flushing, corrugations, alligator cracking, longitudinal cracking, transverse cracking, patching and failures. This information is then utilized to determine a Pavement Rating Score. A Pavement Rating Score of 100 indicates the pavement section has no visual pavement distress. Deduct points associated with the type, extent and degree of distress are subtracted from 100 to obtain a Pavement Rating Score of a distressed pavement.

Use of the condition survey technique dates to 1974 in several districts (15); therefore, data are available for comparison purposes. Data were recorded on a form as shown in Figure A2 of Appendix A.

Photographs. Three photographs were obtained for each section of pavement studied. These photographs were taken to provide an overall view of the section and two close-up views. Photographs can be found in Volume II of this report, copies of which are available from the Materials and Tests Division (D-9) of the Texas SDHPT and from the Texas Transportation Institute.

Deflection Testing. The deflection readings of cold mix limestone rock asphalt pavement were obtained utilizing the Dynaflect (16). These deflection data were utilized to determine the stiffness coefficients for the pavements utilizing a technique developed at TTI (17).

Five sections were tested in District 20, three sections in District 21 and sixteen sections in District 22. Deflections were made over a one mile length at the site of the condition survey and skid measurements. A set of two measurements was made 10 feet apart at ten locations along the one mile section.

Surface Texture. Surface texture measurements were made in the inner and outer wheel paths as well as between the wheel paths using the "silly putty" method (18). Single measurements were made at each of these designated areas for each pavement section studied.

Core Samples. Three core samples were obtained from those pavement sections containing cold mixtures of limestone rock asphalt. The cores were taken to the depth of the unstabilized base course or to the overlaid portland cement concrete pavement. These cores were subjected to a laboratory testing program described later in this report.

Traffic. Average daily traffic (ADT) volumes were obtained from District Traffic maps prepared by the Texas SDHPT Transportation Planning Division (19). Accumulated traffic was calculated from average ADT and age of the roadway. The average ADT was obtained by averaging yearly ADT values obtained from the district maps over the life of the surfacing material. If the roadway was more than a single lane in one direction, a limited traffic count was performed to establish the lane distribution of the traffic. All traffic volumes reported have been converted to average daily traffic per lane (ADT/Lane) and accumulated traffic per lane.

Skid Measurements. Skid measurements were made in the inner wheel path at 40 miles per hour utilizing the Texas locked wheel skid trailer. This trailer conforms to that described in ASTM Method of Test E274-70 "Skid Resistance of Paved Surfaces Using a Full-Scale Tire" (20). Ten skid measurements were obtained for most of the sections. Under certain situations, measurements were made between the wheel path, at the center of the pavement or on the shoulder. The resulting skid numbers were corrected for temperature and the average and range of values determined.
Data were transferred to computer input forms as shown in Appendix A.

Laboratory Data

The types of laboratory data collected on the pavement cores included: specific gravity, percent air voids, resilient modulus, Marshall stability, Hveem stability and indirect tensile properties. Additionally, the specification item, type and grade together with percent flux oil, percent water, average bitumen, bitumen in the passing No. 10 fraction, percent white rock, average stability and gradation were obtained from Materials and Test Division, Plant Inspection Reports. These reports were obtained through the use of a laboratory number assigned to a particular shipment of material. District personnel supplied these numbers from project records.

Specific Gravity. Specific gravity of the core samples was determined by use of ASTM Method D2726 "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface - Dry Specimens" (20). The maximum specific gravity of the crumbled cores was obtained by ASTM Method D2041, "Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures" (20).

Air Voids. The air void content of the core samples was obtained by use of the following equation:

$$\text{Air, \%} = \left(1 - \frac{A}{B}\right) \times 100$$

where

A = Bulk specific gravity of core and

B = Theoretical maximum specific gravity of mixes

Resilient Modulus. The resilient modulus was determined by the method developed by Schmidt (21). A light pulsating load is applied through a load cell across the vertical diameter of the core. This load causes a corresponding elastic deformation across the horizontal diameter which is measured and a resilient modulus calculated. The load is applied for a 0.1 second duration and is repeated 20 times per minute.

The resilient modulus measured as described above is an approximation of the elastic modulus determined under loading and temperature conditions which simulate traffic loadings in the field. This non-destructive test is an indication of the load distributing characteristics of a material and can be used in rational pavement design methods. Approximate relationships between resilient modulus or stiffness and fatigue behavior have been established. Additionally, the temperature susceptibility of asphalt mixtures can be established. Results of this test are more sensitive to mixture variables (asphalt content, type of asphalt, aggregate characteristics, aggregate gradation, etc.) than conventional stability tests.

Percent Flux Oil, Percent Water, Gradation, etc. The percent flux oil, percent water added, percent bitumen, bitumen in minus No. 10 fraction, percent white rock, Hveem stability and gradation were determined according to standard Texas SDHPT practice (22).

Data Summary

Data collected in the field and laboratory were coded on computer input cards shown in Appendix A and a data summary was obtained for each pavement section studied. An example of this data summary is shown in Figure 2 for Section 76. The data summary for all sections in the project can be found in Volume III of this report. Copies of Volume III are available from the Materials and Tests Division (D-9) of the Texas SDHPT and from the Texas Transportation Institute.

LOCATION

- SECTION NO: 76
- DISTRICT NO: 22
- COUNTY NO: 23[illegible]
- CONTROL & SECTION NO: 22 08
- HIGHWAY NO: US 90
- FROM MP 45.3 TO MP 46.3
- LANE R

TRAFFIC

- ADT PER LANE 770
- ACC TRAFFIC PER LANE 2150000

PAVEMENT EVALUATION

- PAVEMENT RATING SCORE 65.
- SERVICEABILITY INDEX 0.0
- SKID NUMBER
  - AVERAGE: 50.
  - LOW: 47.
  - HIGH: 54.
- SURFACE TEXTURE
  - IWP 0.019
  - BWP 0.013
  - OWP 0.013
- SURFACE CURVATURE INDEX
  - AVERAGE 0.0

STRUCTURAL SECTION

LAYER	MATERIAL	TYPE	GRADE	THICKNESS INCH	YEAR PLACED
1	LRA COLD MIXTURE	CM		0.8	1967
2	SEAL COAT	B	3	0.5	1962
3	LRA COLD MIXTURE	CC		0.7	1955
4	SEAL COAT	M		0.2	1944
5	SURFACE TREATMENT	M		0.2	1937
6	BASE			1.2	1937

SHOULDER: UNPAVED

SURFACE COURSE

					PCT
MATERIAL	LRA COLD MIXTURE	% FLUX OIL	3.0	RET. 1 INCH	
ITEM	330	% WATER	2.0	RET. 3/4 INCH	
TYPE	CM	AVG BIT	5.8	RET. 5/8 INCH	
GRADE		BIT PASS NO. 10	6.3	RET. 1/2 INCH	0
SOURCE	WHITES MINE	% WHITE ROCK	25	RET. 3/8 INCH	1
CONSTRUCTION	BLADE	BIT WHITE ROCK	.23	RET. 1/4 INCH	30
RES MODULUS	0000	AVG HVEEM STAB	42.	RET. NO. 4	46
SP GR	0.0			RET. NO. 20	
% AIR VOIDS	0.0			RET. NO. 40	
				PASS NO. 10	39

PAVEMENT DISTRESS

- RAVELING - SLIGHT , 1 TO 15 PERCENT OF THE AREA
- ALLIGATOR CRACKING - SLIGHT , 1 TO 5 PERCENT OF THE AREA
- LONGITUDINAL CRACKING - MODERATE, 10 TO 99 FT. PER STATION , NOT SEALED
- TRANSVERSE CRACKING - SEVERE , 5 TO 9 PER STATION , NOT SEALED

COMMENTS:

PRIMARILY A TRANSVERSE PATTERN WITH SOME LONGITUDINAL CRACKS
TRANSVERSE CRACKS ARE SPALLING AND SOME ARE PUMPING

CONSTRUCTION PROBLEMS

NONE

FUTURE MAINTENANCE

CRACK SEALING SHOULD BE SCHEDULED
SEAL COAT SHOULD BE SCHEDULED AS SOON AS POSSIBLE

GENERAL COMMENTS

FINER GRADATION THAN SECTIONS 74 AND 75
FRANK ADAMS BELIEVES LONGITUDINAL AND TRANSVERSE CRACKING CAUSED BY SUBGRADE

Figure 2. Typical Data Summary for Test Sections.

RESULTS

Description of Materials

As indicated above the performance of limestone rock asphalt as coverstone for surface treatments and seal coats and for cold mixes was studied. Coverstone conforming to Item 302 and 304 and modifications of these standard specifications were investigated. Cold mixtures conformed to Item 330 or modifications of this standard specification. Gradation, percent flux oil, percent water, average bitumen, bitumen content in the minus No. 10 fraction, percent white rock and bitumen in the white rock for the sections under study are shown in Tables 3 and 4 for the cold mixes and coverstone respectively.

Gradation. Gradations of the cold mixes studied are shown in Figure 3 and Table 5. Sections were studied which contain Grades A, B, C, CC, D, C modified and CC modified. All modified gradations are from District 22. Type A, B and C gradations have 30 percent (by weight) passing the No. 10 sieve while other gradations have 40 or 45 percent passing the No. 10 sieve. The Type A material has 30 percent retained on the 3/8 inch sieve while grades C, CC, D, and C modified have 100 percent passing the 3/8 inch sieve. Type B material has 10 percent retained on the 3/8 inch sieve. It should be noted that the gradations on a volume basis will not be identical to the gradation on a weight basis as a specific gravity difference exists between the coarse and fine aggregate fraction of limestone rock asphalt materials.

Gradations of the surface treatments and seal coats studied

Figure 3: **AGGREGATE GRADING CHART** For Cold Mixes

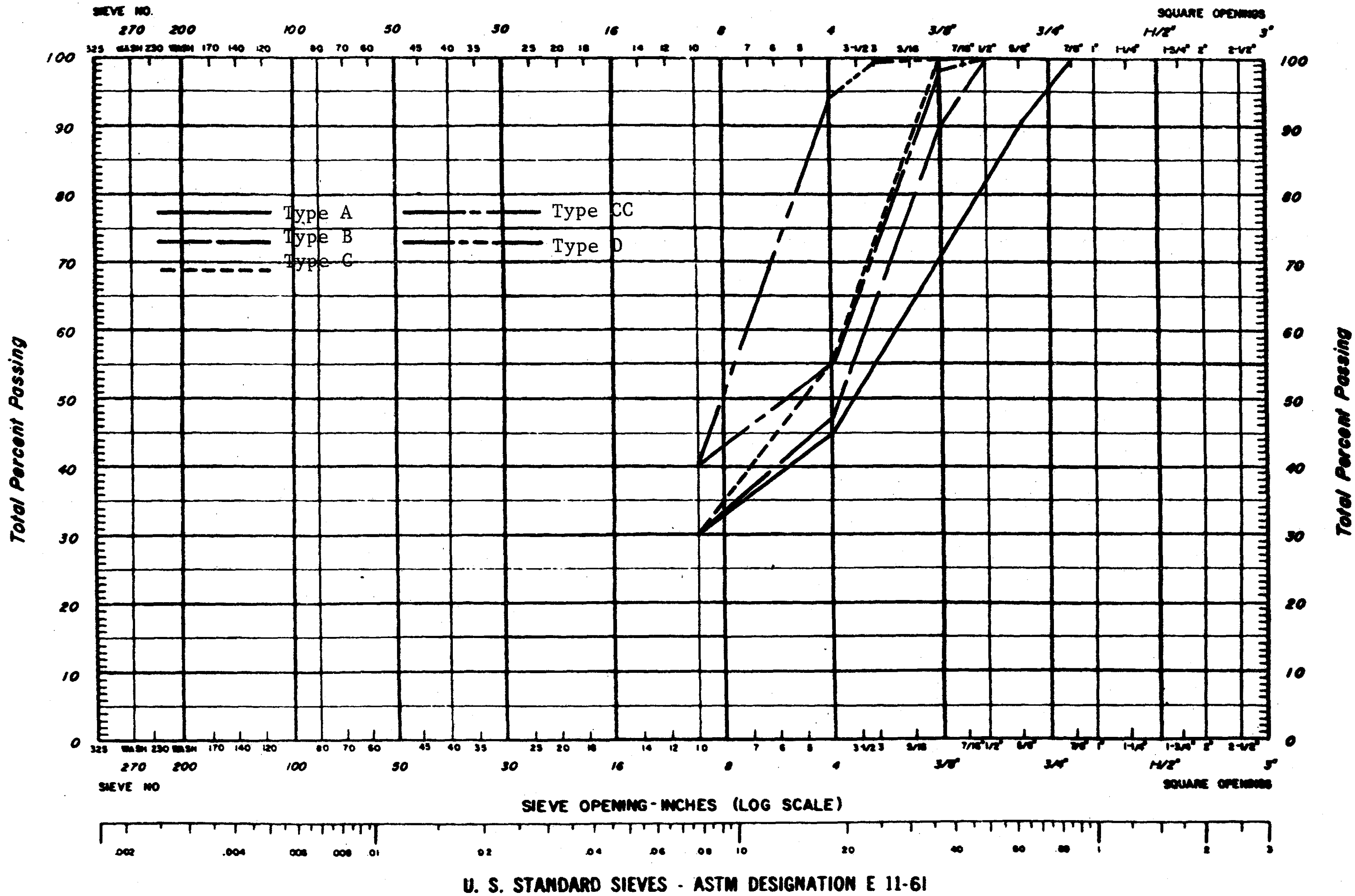

Table 3: Limestone Rock Asphalt Cold Mix Cold Laid Surface Corner

District	Section	Year Placed	ADT Per Lane	X106 Accum. Traf.	Type	Const.	Skid No. Avg	Skid No. Low	Skid No. High	Flushing Slight	Flushing Mod.	Flushing Severe	Raveling Slight	Raveling Mod.	Raveling Severe	Sieve Analysis Ret 5/8	Ret 1/2	Ret 3/8	Ret 1/4	Ret 4	Ret 20	Ret 40	Pass 10	% Flux Oil	% Water	Avg. Bit	Bit. Base No. 10	% White Rock	Bit. White Rock	Avg. Hveem Stab.	IWP. Surface Texture
21	2	1970	1550	2.7	A	M	21	18	22				1			11		30		57			30	2.8	2.1	5.7	6.3	24	.28	47	.015
	4	1970	4070	7.0	A	M	19	18	23							11		30		57			30	2.8	2.1	5.7	6.3	24	.28	47	.027
	7	1967	850	2.4	A	M	31	27	34				1			7		30		55			30	2.8	2.3	5.6	5.7	23	.10	69	.022
	9	1972	3500	3.5	A	M	17	14	19							6		32		56			33	2.7	2.5	6.1	6.7	27	.22	52	.027
	10	1972	4300	4.3	A	M	10	9	10							6		32		56			33	2.7	2.5	6.1	6.7	27	.22	52	.013
	11	1969	1710	3.6	A	M	18	15	21							9		32		57			30	2.8	2.4	6.0	6.5	26	.19	41	.014
	31	1972	950	0.94	A	M	25	22	28							9		30		53			32	2.6	0.8	6.1	6.8	22	.39	40	.019
	32	1969	950	0.66	A	M	24	21	25				1			12		30		57			30	2.6	2.1	5.8	6.0	27	.45	54	.010
20	43	1970	3080	4.7	A	M	27	23	32				1			10		32		55			32	2.9	2.4	6.9	7.3	27	.33	42	.025
	48	1969	1500	3.2	A	B	31	28	34				1			9		29		57			30	2.6	2.1	5.7	6.0	28	.22	44	.029
	52	1969	5500	11.4	A	M	21	18	23					3		10		29		57			31	2.6	2.1	5.8	6.2	28	.31	46	.018
	62	1971	1250	1.7	A	M	33	29	36				3			9		30		56			31	2.6	1.9	6.2	6.4	22	.29	47	.034
21	17	1969	1875	3.9	B	M	33	29	35				1			0		10		54			30	2.6	2.4	6.3	7.2	25	.43	41	.020
20	35	1971	1730	2.3	B	M	34	32	38				1			0	0	12		53			32	2.8	1.7	5.8	6.4	26	.20	46	.045
	45	1969	5100	8.4	B	X	25	22	28							—	0	—		—			—	—	—	—	—	—	—	—	.022
	55	1970	1500	2.6	B	M	34	25	41								0	9		52			31	2.8	1.9	5.5	5.9	27	.21	47	.034
	59	1970	1350	2.8	B	M	39	35	42				3					9		52			31	3.0	2.5	5.5	6.3	27	.20	45	.040
21	1	1972	715	0.2	C	B	41	35	44				3					2		47			31	3.2	2.0	5.6	5.9	28	.26	50	.023
20	53	1971	915	1.2	C	B	27	21	32							—		—		—			—	—	—	—	—	—	—	—	.045
	65	1965	550	1.9	C	B	39	33	43					3		—		—		—			—	—	—	—	—	—	—	—	.032
22	70	1966	4480	14.1	C	B	25	21	34				1				0	1	27	44			30	3.2	2.5	6.0	6.2	25	.40	45	.029
	73	1971	570	0.77	C	B	51	47	54								0	1	29	44			32	3.1	2.5	5.7	5.9	27	.30	48	.056
	74	1970	630	1.1	C	B	56	51	64								0	1	31	47			32	3.0	2.5	6.0	6.4	26	.27	43	.047
	75	1967	650	1.8	C	B	53	46	60								0	1	30	48			30	3.0	2.3	5.6	5.8	27	.22	41	.038
	77	1963	780	3.3	C	B	62	56	65						3		0	1	30	49			31	2.8	2.0	5.9	6.7	27	.20	44	.088
	78	1962	1350	6.3	C	B	39	35	43				1				0	0	29	50			29	3.0	1.5	5.9	6.5	27	.16	44	.027
	79	1966	1690	5.3	C	B	44	40	47								0	1	27	44			30	3.2	2.5	6.0	6.2	25	.40	45	.029
	80	1966	1690	5.3	C	B	30	21	45								0	1	27	44			30	3.2	2.5	6.0	6.2	25	.40	45	.000
	85	1964	500	2.1	C	B	56	52	58				3				0	1	29	48			28	3.0	2.2	5.7	6.0	29	.13	46	.040
	86	1966	570	1.8	C	B	56	52	60				3				0	1	27	44			30	3.2	2.5	6.0	6.2	25	.40	45	.035
	87	1974	1070	.27	C	B	43	40	54				1				0	1		44			32	3.0	2.5	5.9	6.4	30	.36	49	.065
	93	1968	1030	2.5	C	M	48	46	52				2				0	1	32	50			30	2.9	1.5	5.5	5.4	26	.24	45	.040
22	83	1959	330	1.9	CC	B	55	52	60				1				0	4		37			40	3.0	2.0	6.0					.065
	94	1973	500	0.30	CC	B	47	39	50				2				0	2		46			41	3.2	2.5	5.6	6.0	29	.30	46	.010
	97	1973	835	0.52	CC	B	40	31	45				1				0	1		45			41	3.2	2.5	5.8	6.3	28	.32	47	.032
	99	1973	280	0.17	CC	B	53	47	56				1				0	1		48			40	3.0	2.5	5.7	6.0	29	.32	47	.009
	101	1974	550	0.14	CC	B	30	24	35				1				0	2		46			41	3.2	2.5	5.6	6.0	29	.30	46	.029
	115	1973	1990	1.18	CC	B	41	31	47	1							0	1		45			41	3.2	2.5	5.8	6.3	28	.32	47	.040
20	46	1968	6150	15.0	D	X	27	21	34				1				—	—		—			—	—	—	—	—	—	—	—	.032
	47	1970	2280	3.9	D	X	30	25	33								—	—		—			—	—	—	—	—	—	—	—	.003
	63	1971	1250	1.69	D	M	32	24	37					3			—	—		—			—	—	—	—	—	—	—	—	.029
22	108	1963	305	1.3	D	B	58	53	61									0	1	8			40	3.2	1.9	6.2	6.7	25	.14	43	.027
	109	1964	490	1.9	D	B	40	36	45									0	1	7			43	3.2	1.8	6.4	6.8	23	.28	41	.011
	71	1967	4480	12.6	CMOD	B	28	21	39				1				0	1	30	46			39	3.0	2.0	5.8	6.3	25	.23	42	.027
	76	1967	770	2.2	CMOD	B	50	47	54				1				0	1	30	46			39	3.0	2.0	5.8	6.3	25	.23	42	.019
	90	1967	660	1.8	CMOD	B	52	46	54				1				0	1	30	46			39	3.0	2.0	5.8	6.3	25	.23	42	.019
	95	1971	470	0.64	CMOD	B	50	44	57				1				0	1	32	44			45	3.0	2.5	6.0	6.4	28	.26	42	.024
	98	1970	375	0.64	CMOD	M	51	48	53				1				0	1	34	48			37	2.9	0.3	5.6	5.8	29	.21	46	.023
	100	1968	200	0.49	CMOD	B	58	54	64				1				0	1	32	48			42	3.0	2.5	5.5	5.8	28	.25	46	.032
	104	1964	920	3.9	CMOD	B	44	39	48				1				0	1	29	47			40	2.9	2.3	6.5	6.9	22	.19	44	.020
	111	1962	490	2.2	CMOD	B	59	51	61				1				0		27	47			37	2.9	2.0	6.0	6.8	28	.20	46	.023
	112	1968	680	1.6	CMOD	B	55	50	60					2			0	1	31	45			39	3.2	1.4	5.5	5.7	29	.25	46	.029
21	92	1974	1010	0.26	CCMOD	B	46	40	55								0	10		47			45	3.0	1.9	5.8	6.1	31	.30	47	.016
	110	1974	650	0.17	CCMOD	B	39	33	45								0	13		47			46	3.0	2.0	5.8	6.0	30	.36	50	.024
	113	1974	1215	0.31	CCMOD	B	46	39	53				1				0	13		47			46	3.0	2.0	5.8	6.0	30	.36	50	.045
	3	1963	245	1.05		B	35	33	38					3																	.029
	6	1954	400	.73		B	33	30	37					2					34				3	1.4	1.7	6.8					.023
	8		100			B	55	53	58					3																	.034
	22	1968	235	0.57		B	47	30	53	1			1																		.040

M = Machine Laid
B = Blade Laid
X = Box Laid

TABLE 4: LIMESTONE ROCK ASPHALT SEAL COATS AND SURFACE TREATMENT

	District	Section	Year Placed	ADT per lane	Accum. Traffic x10^6	Item	Type	Grade	SN Avg	SN Low	SN High	Sieve Analysis Ret 3/4	Ret 5/8	Ret 1/2	Ret 3/8	Ret 1/4	Ret No. 4	Ret No. 20	Ret No. 40	Pass No. 10	% Flux Oil	% Water	Avg. Bit.	Bit. Pass No. 10	% White Rock	Bit. White Rock	IWP Surface Texture	Flushing Slight	Flushing Mod.	Flushing Severe	Raveling Slight	Raveling Mod.	Raveling Severe
		5	1972	4070	7.0	302	B	4	16	14	19				24		97			1	0.0	0.0	5.6	0.0			0.016	3					
		12	1971	1250	1.2	302	B	4	28	21	34																0.156	1					
		13	1973	2100	1.4	304	PB	4	15	12	20				27		98			1	0.6	1.0	5.5	0.0			0.031		3				
		14	1975	1500	0.040	304	PB	4	38	31	41				38		97			1	0.5	1.0	4.9	0.0			0.108				1		
		15	1973	1750	1.1	304	PB	4	49	46	51				27		98			1	0.6	1.0	5.5	0.0			0.098						
		16	1974	1750	0.45	304	PB	4	54	53	56			1	37		96			1	0.5	1.0	5.9	0.0			0.091						
		19	1970	125	0.21	302	PB	5	31	29	34				1		75			1	0.0	0.0	5.7	0.0			0.039	2					
		20	1970	140	0.24	302	B	5	19	16	23				1		75			1	0.0	0.0	5.6	0.0			0.007		3				
	21	23	1971	100	0.14	302	B	4	62	58	64			1	20		4			1	0.0	0.0	6.1	0.0			0.083	2					
		24	1972	70	0.068	302	B	4	61	49	67				24		97			1	0.0	0.0	5.6	0.0			0.104	1					
		25	1973	445	0.29	304	B	4	41	36	49				27		98			1	0.6	1.0	5.5	0.0			0.072	2			1		
		26	1973	425	0.26	304	PB	4	40	29	45				27		98			1	0.6	1.0	5.5	0.0			0.031	2			1		
		27	1975	810	1.1	304	PB	4	23	21	25																0.033	3					
		28	1972	425	0.42	302	PB	4	56	52	61				24		97			1	0.0	0.0	5.6	0.0			0.051						
		29	1973	1050	0.74	304	B	4	14	11	19				27		98			1	0.6	1.0	5.5	0.0			0.001			3			
		30	1971	360	0.49	302	PB	4	30	19	38				24		97			1	0.0	0.0	5.6	0.0			0.024	3					
		33	1972	810	2.0	302	B	4	37	35	39				24		97			1	0.0	0.0	5.6	0.0			———		3				
		34	1969	945	2.0	304	B	3	29	21	32		1	13			98			1	0.6	1.0	4.7	0.0			0.008		3				
		36	1971	860	1.0	304	PB	4M	20	18	23	0	2	10	28		98			1	0.6	1.0	5.4	0.0			0.042		3				
		37	1972	530	0.52	302	PB	4M	36	27	45																0.054		3				
		41	1971	840	1.1	304		4M	20	18	23	0	2	10	28		98			1	0.6	1.0	5.4	0.0			0.027		3				
		42	1972	2680	1.2	304	PB	4	26	23	30			0	30		98			1	0.6	1.0	5.5	0.0			0.035		3				
		44	1970	2030	5.6	304	PB	4M	17	15	22	0	2	10	30		98			1	0.6	1.0	5.3	0.0			0.029		3			3	
Seal Coat	20	49	1965	545	1.7	302	PB	3	41	28	48	0	1	16			98			1	0.0	0.0	5.6	0.0			0.067	3			1		
		51	1972	1860	1.8	304	B	4	20	16	23			0	30		98			1	0.6	1.0	5.5	0.0			0.032		3				
		57	1970	690	1.1		PB	3M	37	32	42																0.072						
		60	1971	1950	2.7	304	B	4M	28	22	33	0	2	10	28		98			1	0.6	1.0	5.4	0.0			0.056		3				
		64	1970	1375	2.4	304	PB	4M	26	20	32	0	2	10	30		98			1	0.6	1.0	5.3	0.0			0.029		3				
		68	1972	580	0.35	304	PB	4	21	15	29			0	30		98			1	0.6	1.0	5.5	0.0			0.045		3				
		72	1969	2870	0.60	304	PB	M	25	17	35	0	1	14	54		98			1	0.6	1.0	4.8	0.0			0.008		3		1		
		81	1971	320	0.48	304	PB	3M	46	29	58	0	1	10	61		98			1	0.5	1.0	5.5	0.0			0.083		3				
		82	1969	325	0.67	304	PB	3	53	46	59																0.080		3		1		
		84	1970	400	0.68	304	PB	3M	58	56	60	0	1	12	56		98			1	0.5	1.0	5.1	0.0			0.091						
		88	1971	1030	1.4	304	PB	3M	49	43	55	0	1	10	61		98			1	0.5	1.0	5.5	0.0			0.077	3					
		89	1974	930	0.24	304	PB	4M	55	52	59		0	1	43		98			1	0.5	1.0	4.9	0.0			0.115	3					
	22	91	1969	1150	2.4	304	PB	M	40	32	45	0	1	14	54		98			1	0.6	1.0	4.8	0.0			0.070	3					
		96	1974	500	0.12	304	PB	4M	57	55	59		0	2	48		98			1	0.5	1.0	4.7	0.0			0.104					1	
		102	1973	520	0.40	304	PB	4	47	37	55																0.010				1		
		103	1973	1630	1.0	304	PB	4	42	33	49			0	28		98			1	0.5	1.0	5.6	0.0			0.034	3			1		
		105	1974	720	0.13	304	PB	4M	57	55	59		0	1	43		98			1	0.5	1.0	4.9	0.0			0.104						
		106	1969	720	1.5	304	PB	3M	48	42	53	0	1	14	54		98			1	0.6	1.0	4.8	0.0			0.035	1			1		
		107	1969	820	1.7	304	PB	4M	34	29	38			0	46		98			1	0.5	0.7	5.4	0.0			0.049	3			1		
		114	1973	2000	1.2	304	PB	4	45	33	51			0	30		98			1	0.5	1.0	5.2	0.0			0.049	3					
Surface Treatment	21	18	1969	70	0.15	302	B	3	58	48	64																0.070						
		21	1973	55	0.034		B	3	46	38	52																0.042		3				
	22	38	1967	760	2.2	302	B	3	35	30	39																0.070		3		1		
		66	1966	310	0.70	302	B	3	42	37	45																0.072	1			1		

Table 5: Average Gradations of Limestone Rock Asphalt Cold Mixtures Investigated.

Sieve Size	TYPE						
	A	B	C	CC	D	CMod*	CCMod**
Retained 7/8 inch	0						
Retained 5/8 inch	10						
Retained 1/2 inch		0	0	0		0	0
Retained 3/8 inch	30	10	1	2	0	1	13
Retained 1/4 inch			30		1	30	
Retained No. 4	55	53	45	45	7	47	47
Passing No. 10	30	30	30	40	40	40	45
No. of Sections***	12	5	13	6	2	9	3

*District 22 Type C Modified

**District 22 Type CC Modified

***Gradation Data was not available on 9 sections are shown in Figure 4 and Table 6. Sections were studied which contained Grades 3 and 4 and modifications of these grades. The gradations studied are not one sized.

Percent Flux Oil, Percent Water, etc. Percent flux oil, percent water, average bitumen content in the minus No. 10 fraction, percent white rock and bitumen in white rock for each section studied are shown in Tables 3 and 4. For the cold mixes studied a slight increase in flux oil was noted as the amount of coarse aggregate decreased. For example, an average percent flux oil content for the Type A mixes was 2.7 while the type C, CC, D, C modified contained about 3.1 percent.

The percent water added for the vast majority of the mixes ranged from 2.0 to 2.5 percent. Type C and CC as produced for District 22 contained 2.5 percent additional water while Type A and B mixes produced for Districts 20 and 21 average about 2.0 percent. It should be noted that the lower water contents were associated with those mixes laid with a machine while the higher water content mixes were associated with blade laid materials.

The average percent bitumen in the rock asphalt ranged between 5.5 to 6.3. Little difference was noted between gradations.

The percent bitumen in the minus No. 10 fraction range from 5.0 to 7.3. The average value was slightly higher for Type A mixes as compared to Type C mixes.

The percent white rock ranged from 22 to 29 percent. The usual range was between 27 and 29. Little difference was noted between gradations.

The bitumen in the white rock ranged from 0.10 to 0.40 percent.

Figure 4: **AGGREGATE GRADING CHART** For Surface Treatments and Seal Coats

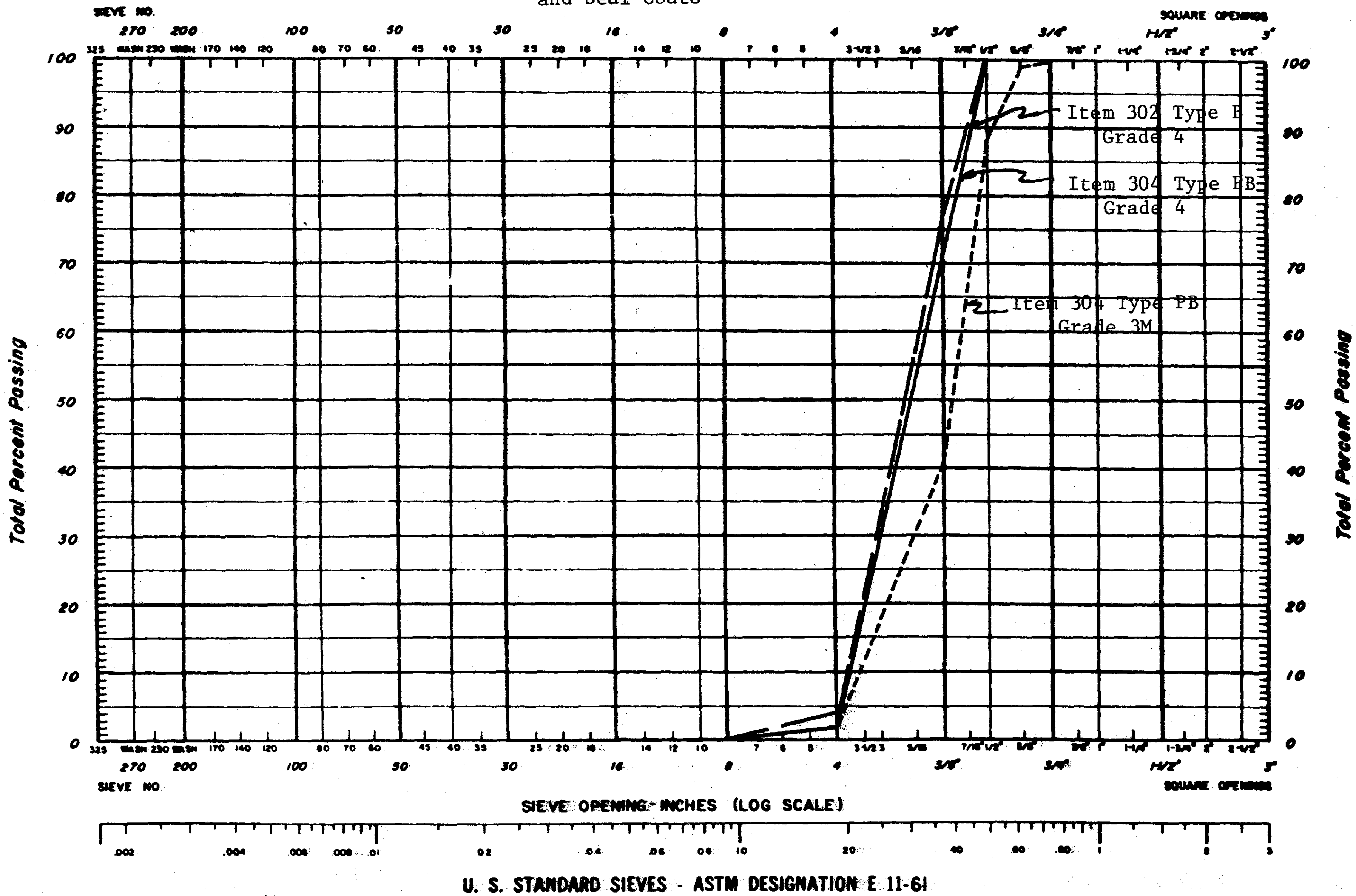

Table 6: Average Gradations of Limestone Rock Asphalt Surface Treatments and Seal Coats

Sieve Size	Item, Type and Grade				
	Item 302 Type B Grade 4	Item 304 Type PB Grade 3M	Item 304 Type PB Grade 4M Dist. 20	Dist. 22	Item 304 Type PB Grade 4
Retained 3/4 inch		0	0		
Retained 5/8 inch		1	2	0	
Retained 1/2 inch	0	12	10	1	0
Retained 3/8 inch	24	58	29	45	30
Retained No. 4	97	98	98	98	98
Passing No. 10	1	1	1	1	1
No. of Sections*	5	4	5	4	12

* Sufficient data was not available to group 17 sections.

Little difference was noted between gradations.

For the coverstone material the recorded percent flux oil, percent water, average bitumen and the bitumen in the minus No. 10 fraction were extremely uniform. Based on an analysis of the available data, no significant differences between materials were noted (Table 4).

It is interesting to note that all pavement sections studied were either cold mixes, surface treatments or seal coats. No hot mixed limestone rock asphalt mixes were studied even though all mixes produced prior to 1928 were hot mixed (23). In 1928, the first cold mixes were produced. Mixing was performed at the quarry and mixtures were ready to lay when they reached the construction project. The advantage of the cold mixes appears to be that little equipment is required at the job site to satisfactorily place the material, air quality problems associated with the hot mix process are eliminated and an energy saving is appreciated (3).

Geological Description. The limestone rock asphalt is presently mined from an impregnated Anacacho limestone of Upper Cretaceous age. This deposit out-crops at several sites along an east-west line through Medina, Uvalde and Kinney Counties which are located in south-central Texas. The formation in Uvalde County dips to the southeast at about 25 feet per mile. In the southern part of Uvalde County the Anacacho limestone is overlaid with the Escondido sandstone formation. This formation is also impregnated with bitumen (4).

Petrographic studies made on samples taken from the present quarry sites indicate that the rock is cream colored, very porous, coarse-to-fine grained fossil shell debris or Coquina cemented with asphalt and/or secondary calcite. Microscopic analyses have indicated quartz, calcite, glauconite and pyrite are present as accessory minerals. Both the pores around and within the shell fragments are filled with asphalt. Within individual hand-sized pieces, the bitumen content will vary depending upon the size and distribution of the pores. The bitumen content ranges from about 1 to 15 percent in both a vertical and horizontal direction (4).

The "white rock" found in the deposit is a relatively dense calcareous cemented limestone. Most "white rocks" are nearly void of bitumen (4).

Mixture Properties

Properties of limestone rock asphalt mixtures were defined as described above. Air void content, Hveem stability, Marshall stability, indirect tension, resilient modulus and polish value test results are given below. Results from limestone rock asphalt cold mixes are compared with hot mix asphalt concrete mixes where possible. Sufficient data were not available from this study to make these comparisons on cold mixes made with aggregates other than limestone rock asphalt.

Air Void Content. The air void content was calculated on 37 cores obtained from the pavements under study (Table 7). A mean air void content of 12 percent was noted with a range from 3.6 to 16.6 percent (Table 8). The calculated air void content is in excess of the 4 to 8 percent experienced for hot mix asphalt

Table 7: Results of Laboratory Tests Performed on Field Core Samples

District	Section Number	Sample Number	Type	Specific Gravity	Air* Voids, Percent	Resilient Modulus, psi x 10^3 -10°F	32°F	68°F	76°F	100°F	Hveem Stability	Marshall Stability lbs.	Marshall Flow, 0.0. in.	Indirect Tension Failure Stress, psi	Failure Strain, x 10^{-6}	Elastic Modulus psi x 10^3	Water Susceptibility Resilient Modulus, psi x 10^3, 68°F Before	Satur-ated	Dry
	1	B	C																
	2	A	A	1.991	14.6			600											
	3	B																	
	4	A						957											
	4	B	A	2.245	3.6	2.330	1.454	865	619	224									
	4	C	A					797											
	6	B																	
	7	A	A	2.001	14.1			682	538		33	1800	22						
	7	B	A	1.944	16.6			640	439										
	7	C	A	1.973	15.4	1.680	1.250	665	505	231									
	9	A	A					696											
21	9	B	A	2.128	8.7				537		43	1900	17				410	259	265
	9	C	A					734											
	10	C	A	2.031	12.8			799											
	11	A	A	2.052	11.9				369										
	11	B	A	2.043	12.3				601		37			100	2250	44			
	11	C	A	2.053	11.9	2.210	1.620	881	454	259									
	17	C	B	2.118	9.1			783											
	27**	B		2.068	11.2	8.750	1.810	1.730		707	39			168	850	199			
	31	A	A	2.087	10.5			721											
	31	B	A					704											
	31	C	A	2.052	11.9			579											
	32	A	A	2.036	12.2			670	582		35			100	4010	25			
	32	B	A	2.052	11.9				576										
	35	A	B	1.989	14.6			613											
	43	A	A					1.160											
	43	B	A	2.057	11.7			996	440										
	43	C	A	2.075	10.9			1.190	519		28	1800	12				728	399	396
	45	B	B	1.072	11.1			879											
	46	A	D	1.916	17.8			738											
	48	A	A					1.040											
	48	B	A	2.107	9.6			1.180	788		41	1420	31				1.160	432	557
	55	A	B	2.024	13.2			533											
20	55	B	B	2.032	12.8														
	55	C	B	2.015	13.5				364										
	59	A	B	2.059	11.6	1.980	962	564	330	138									
	59	B	B	2.090	10.3			650	393		28	1900	13						
	59	C	B	2.051	12.0			575	425										
	62	A	A	2.054	11.8			790	589										
	62	B	A	2.047	12.1			639	481										
	62	C	A	2.052	11.9			1.030	491										
	63	A	D	2.034	12.7			650	409										
	78	B	C	2.032	12.8			899											
	97	B	CC					772			22	2610	16				779	430	520
	101	B	CC	2.092	10.2			583	340		31	2200	12						
22	105	A		2.014	13.6			926											
	112	A	CMOD***					915											
	112	B	CMOD	2.057	11.7			1.050	744		32	2200	12				1.160	547	967
	113	A	CCMOD	2.073	11.0			989	415										
	113	B	CCMOD	2.081	10.7			641	396										

* Maximum Specific Gravity of 2.330 Used for Calculation

** Sample of Hot Mix Asphalt Concrete with Limestone Rock Asphalt Seal

*** Modified Gradation

Table 8: Summary of Laboratory Tests Performed on LRA Core Samples

Property	Mean	Standard Deviation	Coefficient of Variation	Range of Values	No. of Measurements
Air voids, percent	12.0	2.3	19.3	3.6-16.6	37
Hveem Stability	33	6.3	19.2	22-43	10
Marshall Stability, lbs.	1980	355	18.0	1420-2610	8
Marshall flow, 0.01 in.	17	6.7	39.6	12-31	8
Failure stress, psi	100	0	0		2
Failure strain, x 10^{-6}	3130	1240	39.8	2250-4010	2
Elastic Modulus at Failure, psi	36,000	13,000	34.5	25,000 - 44,000	2
-10°F	2,050,000	286,000	14.0	1,680,000-2,330,000	4
32°F	1,320,000	283,000	21.4	962,000 - 1,620,000	4
68°F	794,000	183,000	23.1	564,000 - 1,180,000	40
76°F	496,000	116,000	23.4	330,000 - 788,000	26
100°F	213,000	52,000	24.5	138,000 - 259,000	4

concrete pavements in Texas after two years of service (24). Calculated air void contents for all limestone rock asphalt cold mixes are based on theoretical maximum specific gravity of 2.330 as determined by ASTM Method D2041.

Hveem Stability. Hveem stability values reported by the Texas SDHPT on laboratory compacted and laboratory cured samples ranged from 41 to 69 (Table 3). Stability values in the high 40's were common. Hveem stability measurements made on 10 core samples ranged from 22 to 43 with a mean value of 33 (Tables 7 and 8). The range of Hveem stability is within the range normally associated with hot mix asphalt concrete in the state of Texas.

Marshall Stability. Marshall tests were performed on 8 core samples (Table 7). The average Marshall stability value reported was 1980 lbs with values ranging from 1420 to 2610 lbs. Marshall flow values ranged from 12 to 31 with an average value of 17 (Table 8). Typical Marshall stability and flow values for mix design purposes are 1500 lbs or greater for stability and flow values within the range of 8 to 16.

From the stability values reported on laboratory and field compacted samples it appears as if adequate stability can be achieved with limestone rock asphalt cold mixes after curing. However, low stabilities can be expected early in the life of a compacted cold mix. This is particularly true if the cold mix is improperly aerated prior to compaction.

Indirect Tension. Indirect tensile tests were performed on only two core samples. Results are shown in Table 8. The tests were performed at a deformation rate of two inches per minute at 68°F.

Resilient Modulus. Resilient modulus values were obtained at 68°F on 40 core samples. An average value of 790,000 psi was obtained with a range of 560,000 to 1,200,000 (Table 8). Values were also obtained at -10, 32, 76 and 100°F on selected samples (Table 8). These data allowed the temperature susceptibility of the limestone rock asphalt mixes to be compared with typical asphalt concrete mixes (Figure 5).

For comparison purposes, typical values of resilient modulus have been summarized and are shown on Table 9 and Figure 6 for bituminous stabilized materials compacted in both the laboratory and field. The value of resilient modulus for limestone rock asphalt determined on the core samples compares favorably with the values obtained on asphalt concrete mixes.

Polish Values. Polish value test results on limestone rock asphalt were first evaluated in 1969 on an experimental basis. The Materials and Tests Division have routinely tested rock asphalt samples since 1970 in accordance with Test Method Tex. 438-A "Accelerated Polish Test for Coarse Aggregate" (22). Published test values on 24 samples submitted from both commercial sources range from 37 to 46 (25). Values for samples containing only white rock ranged from 35 to 37, whereas, polish values for "asphalt rich" rock are 44 to 46. Typical rock asphalt samples with blends of lean and richer rock exhibit polish values of 40 to 42 (4).

Figure 5. Resilient Modulus-Temperature Relationship For Limestone Rock Asphalt Cold Mixes and Typical Asphalt Concrete Mixes

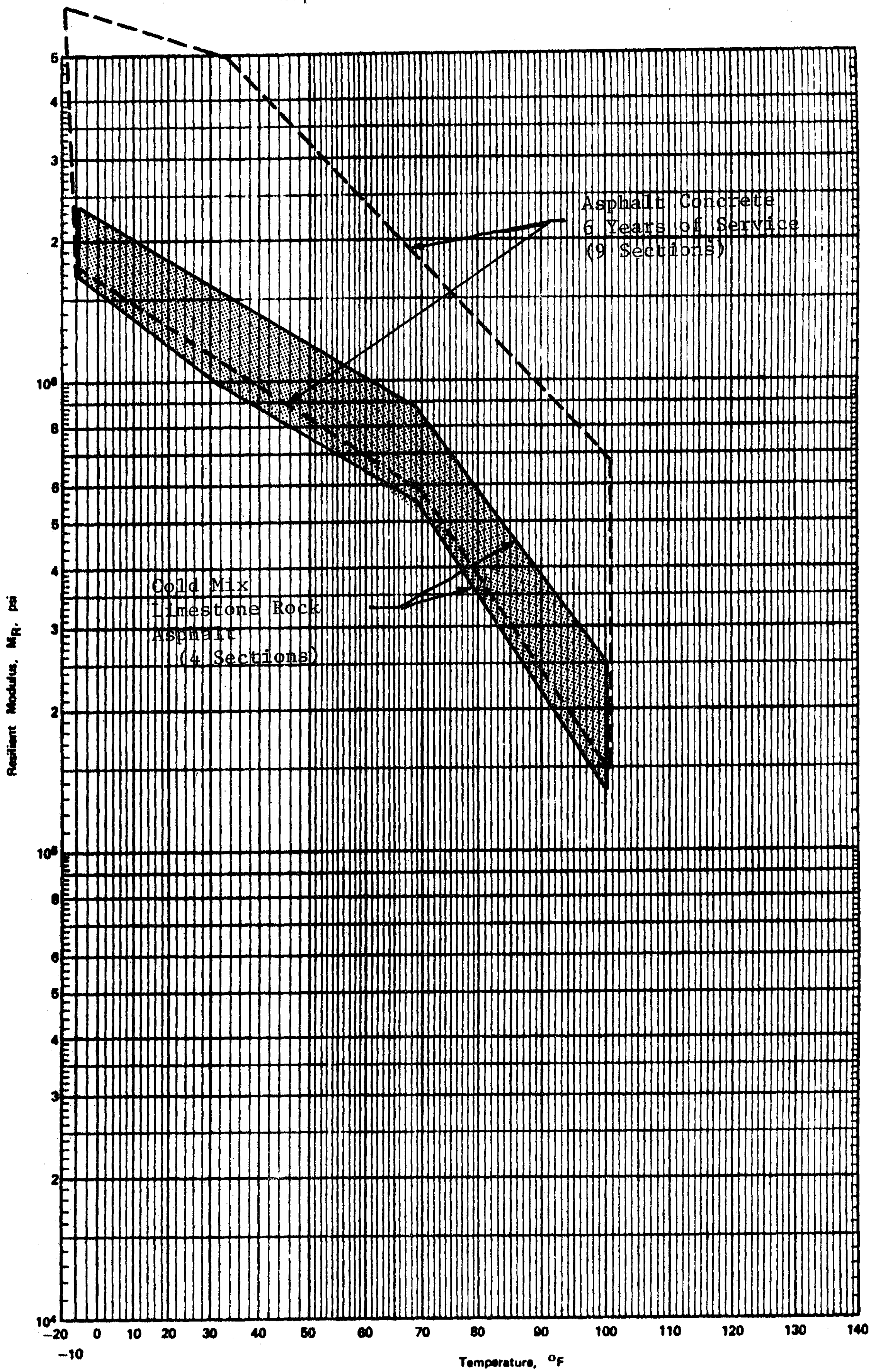

Table 9: Typical Values of Resilient Modulus for Bituminous Stabilized Materials

Type of Material	Type of Compaction	Test Temp., °F	Resilient Modulus, psi x 10^3					
			Mean	Deviation	Variation	Low	High	N.
LRA-Surface Course	Field	68	794	183	23.1	564	1180	40
LRA-Base Course	Lab	68	743	122	16.4	583	887	6
LRA-Base Course (US 57)	Field	68	261	78	30.1	117	423	21
LRA-Base Course (US 77)	Field	68	780	246	31.6	431	1120	10
Black Base-Sandstone (Dist. 15)	Lab	73	282	123	43.6	138	526	24
Black Base-Crushed Limestone (Dist. 15)	Lab	73	738	352	47.7	247	1420	18
Black Base-Crushed Caliche Gravel (Dist. 15)	Lab	73	368	266	72.2	66	994	14
Black Base-Crushed Sandstone (Dist. 15)	Lab	73	167	113	67.6	35	355	19
Black Base-Austin Chalk (Dist. 18)	Lab	73	214	210	98.0	27	658	12
Black Base-Beck Pit (Dist. 21)	Lab	73	490	206	42.1	178	748	9
Hot Mixed Sand Asphalts	Lab	73	152	91	60.2	71	364	27
Hot Mixed Sand Asphalt	Field	68	266	179	67.4	94	748	20
Black-Base-IH 37 (Dist. 15)	Field	73	496	271	54.6	260	977	7
Road Mixed Sand Asphalt	Field	68	122	71	58.2	80	276	7
Asphalt Concrete-Recycled PCC.	Field	73	395	326	82.7	151	866	4
Asphalt Concrete-Recycled AC	Field	73	471	243	51.5	250	970	7
Asphalt Concrete-1.5 Years in Service	Field	68	976	446	45.8	226	1870	75
Asphalt Concrete-6.0 years in Service	Field	68	1250	435	34.7	817	2020	26
Asphalt Concrete-9.0 Years in Service	Field	68	1390	475	34.1	650	2560	33

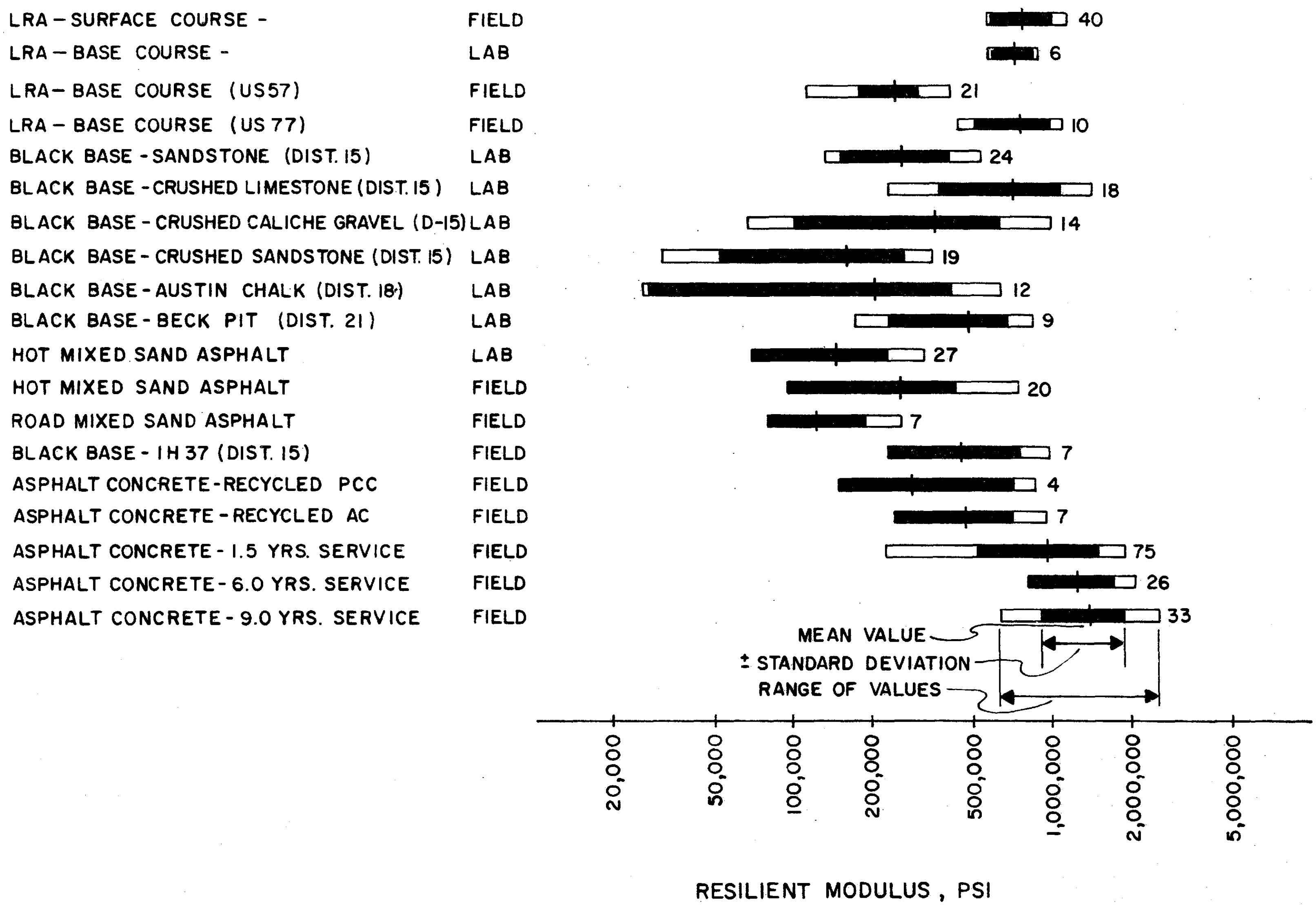

Figure 6. Typical Values of Resilient Modulus for Bituminous Stabilized Materials.

Pavement Performance

Pavement performance information in terms of life and the types of pavement distress present on the limestone rock asphalt study sections was obtained as described above. Pavement performance information obtained on 245 randomly selected pavements in Texas was utilized for comparison purposes. Seven percent of the randomly selected sites were surface with surface treatments (ST), 63 percent with seal coats (SC) and 30 percent with hot mix asphalt concrete (HMAC) (26).

Pavement Life. The lives of surface treatments, seal coats and cold mixtures made with limestone rock asphalt are summarized in Table 10 while the distribution of life in the form of a cumulative frequency graph is shown in Figure 7. The average life of a limestone rock asphalt surface treatment is 8.1 years, a seal coat 6.5 years and a cold mixture 6.2 years. These mean lives compare with 5.1, 7.0 and 6.6 for conventional aggregate surface treatments, seal coats and asphalt concretes as determined from randomly selected pavement sites (26).

For the purposes of this study, pavement life is defined as the length of time between construction and a subsequent seal coat, overlay or reconstruction. The reason for seal, overlaying or reconstructing the pavement was not determined in the study.

The majority of data upon which the pavement life study was made is from District 22. The lives of pavement with limestone rock asphalt materials as surface courses are slightly in excess of those representing average pavements throughout Texas.

Table 10: Pavement Life* - Limestone Rock Asphalt Materials

Type of Surfacing	Pavement Life, Years			
	Mean	Standard Deviation	Coefficient of Variation	Number of Data Points
Surface Treatment	8.1	4.8	59.1	15
Seal Coat	6.5	2.9	45.1	32
Cold Mixture	6.2	2.4	39.4	30
All Types	6.7	3.2	48.5	77

* Pavement life - length of time between construction and subsequent seal coat, overlay or reconstruction.

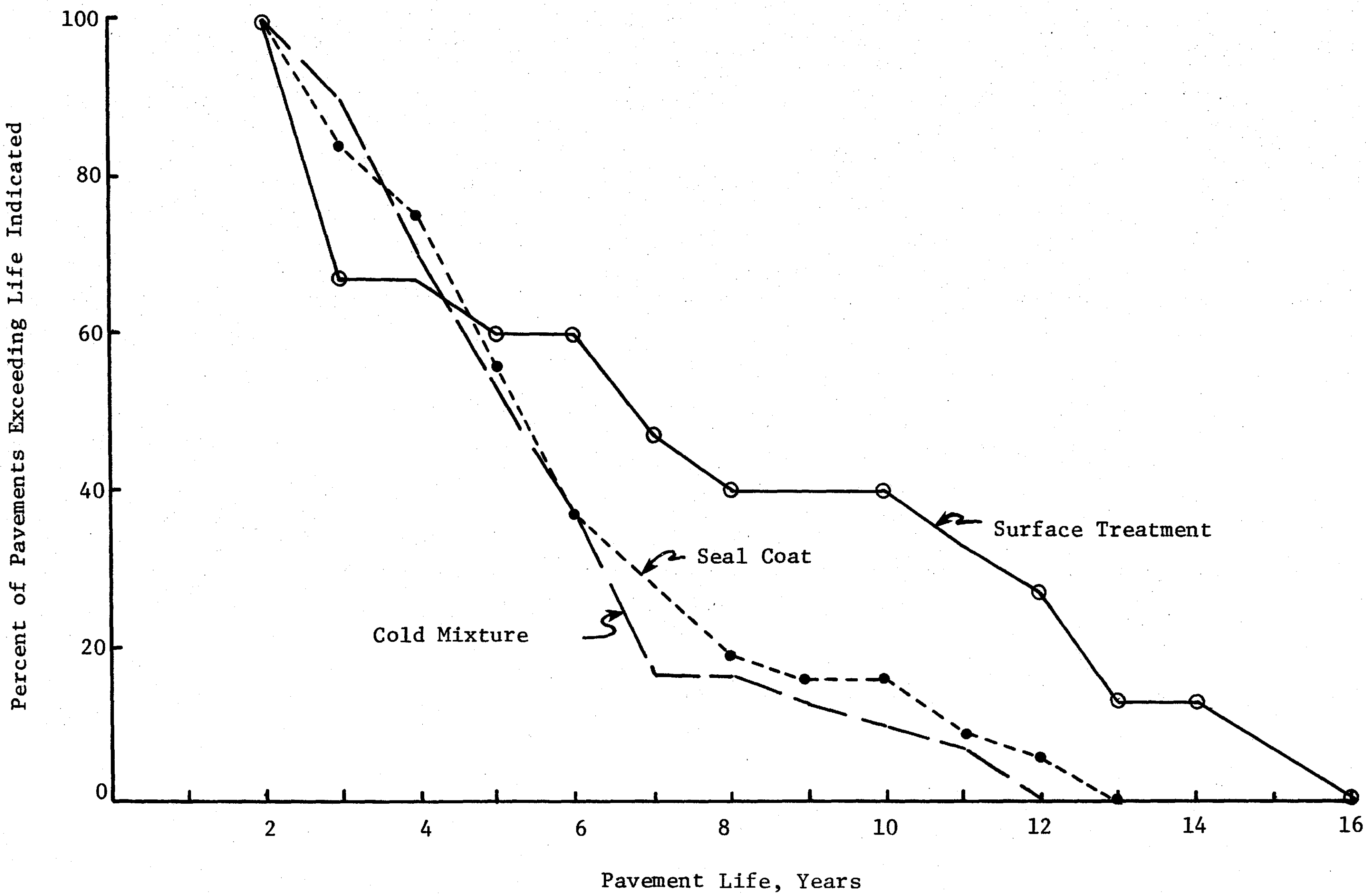

Figure 7. Cumulative Frequency Distribution of Pavement Life for LRA Surface Treatments, Seal Coats and Cold Mixtures

Pavement Distress. The visual condition survey performed on the limestone rock asphalt test sections provided information which defined the type, amount and severity of pavement distress. The specific types of distress noted were the following: flushing, raveling, corrugations, alligator cracking, longitudinal cracking, transverse cracking, patching and failures per mile. The extent and severity of these types of distress for each district and for the entire state are shown on Table 11. These data were obtained from the randomly selected pavement sections previously discussed.

Flushing. The number and percent of limestone rock asphalt pavement sections with various degrees of flushing and raveling were determined (Table 3 and 4). These data are summarized on Table 12. Seventy nine percent of the seal coats and surface treatments made with limestone rock asphalt have slight, moderate or severe flushing. This compares with 64 percent of the seal coats with flushing as determined from the random pavement sections throughout the state of Texas.

Only 3 percent of the limestone rock asphalt cold mixes had slight, moderate or severe flushing as compared to 29 percent for the randomly sampled hot mix asphalt concrete sections throughout the state.

Raveling. Twenty-six percent of the surface treatments and seal coats made with limestone rock asphalt exhibited some degree of raveling while 41 percent of the seal coats from the state-wide survey exhibited some form of raveling. Only seven percent of the

Table 11. Percentage of Three Pavement Types Affected by Various Type of Distress*

TYPE OF DISTRESS	SEVERITY	SURFACE TYPE	STATEWIDE PERCENTAGE OF SECTIONS WITH DISTRESS TYPE
RUTTING	Slight (0-½")	SC	84
		ST	88
		HMAC	64
	Moderate (½"-1")	SC	8
		ST	0
		HMAC	14
	Severe (>1")	SC	1
		ST	0
		HMAC	0
FLUSHING	Slight	SC	64
		ST	44
		HMAC	29
	Moderate	SC	27
		ST	17
		HMAC	5
	Severe	SC	6
		ST	0
		HMAC	0
RAVELING	Slight	SC	41
		ST	35
		HMAC	7
	Moderate	SC	14
		ST	11
		HMAC	0
	Severe	SC	1
		ST	11
		HMAC	0
CORRUGATIONS	Slight	SC	16
		ST	12
		HMAC	7
	Moderate	SC	4
		ST	0
		HMAC	3
	Severe	SC	0
		ST	0
		HMAC	0

*Based on random sample survey.

SC-Seal Coat
ST-Surface Treatment
HMAC-Hot Mix Asphalt Concrete

Table 11. Continued

TYPE OF DISTRESS	SEVERITY	SURFACE TYPE	STATEWIDE PERCENTAGE OF SECTIONS WITH DISTRESS TYPE
ALLIGATOR CRACKING	Slight	SC	13
		ST	18
		HMAC	20
	Moderate	SC	4
		ST	12
		HMAC	12
	Severe	SC	0
		ST	6
		HMAC	1
LONGITUDINAL CRACKING	Slight	SC	37
		ST	53
		HMAC	51
	Moderate	SC	10
		ST	29
		HMAC	26
	Severe	SC	3
		ST	6
		HMAC	3
TRANSVERSE CRACKING	Slight	SC	34
		ST	41
		HMAC	54
	Moderate	SC	10
		ST	24
		HMAC	28
	Severe	SC	3
		ST	0
		HMAC	4
PATCHING	Good	SC	68
		ST	82
		HMAC	36
	Fair	SC	23
		ST	29
		HMAC	8
	Poor	SC	5
		ST	12
		HMAC	1
FAILURES/MILE	1-5	SC	9
		ST	18
		HMAC	3
	6-10	SC	1
		ST	6
		HMAC	0
	>10	SC	1
		ST	0
		HMAC	0

Table 12: Limestone Rock Asphalt Pavement with Flushing and Raveling

District	Type of Surface Course	Severe Flushing No.	Severe Flushing %	Moderate Severe Flushing No.	Moderate Severe Flushing %	Slight Moderate Severe Flushing No.	Slight Moderate Severe Flushing %	Severe Raveling No.	Severe Raveling %	Moderate Severe Raveling No.	Moderate Severe Raveling %	Slight Moderate Severe Raveling No.	Slight Moderate Severe Raveling %	Severe Flushing And Raveling No.	Severe Flushing And Raveling %	Moderate & Severe Flushing & Raveling No.	Moderate & Severe Flushing & Raveling %	Slight Moderate Severe Flushing & Raveling No.	Slight Moderate Severe Flushing & Raveling %	Total Number of Sections
	SC & ST	0	0	10	77	12	92	0	0	0	0	3	23	0	0	10	77	12	92	13
	LRA-M	0	0	0	0	0	0	0	0	2	29	6	86	0	0	2	29	6	86	7
20	LRA-B	0	0	0	0	0	0	0	0	1	33	2	67	0	0	1	33	2	67	3
	LRA-M, X, B	0	0	0	0	0	0	0	0	3	23	9	69	0	0	3	23	9	69	13
	SC, ST, LRA	0	0	10	38	12	46	0	0	3	11	12	46	0	0	13	50	21	81	26
	SC & ST	1	5	6	30	15	75	0	0	0	0	3	15	1	5	6	30	16	80	20
	LRA-M	0	0	0	0	0	0	0	0	0	0	4	44	0	0	0	0	4	44	9
21	LRA-B	0	0	0	0	1	20	0	0	4	80	5	100	0	0	4	80	5	100	5
	LRA-M, X, B	0	0	0	0	1	7	0	0	4	29	9	64	0	0	4	29	9	64	14
	SC, ST, LRA	1	3	6	18	16	47	0	0	4	12	12	35	1	3	10	29	25	74	34
	SC & ST	0	0	3	21	10	71	0	0	1	7	6	43	0	0	4	29	11	79	14
	LRA-M	0	0	0	0	0	0	0	0	0	0	2	100	0	0	0	0	2	100	2
22	LRA-B	0	0	0	0	1	3	1	3	2	7	20	67	1	3	2	7	21	70	30
	LRA-M, X, B	0	0	0	0	1	3	1	3	2	6	22	69	1	3	2	6	23	73	32
	SC, ST, LRA	0	0	3	7	11	23	1	2	3	7	28	61	1	2	6	13	34	74	46
	SC & ST	1	2	19	40	37	79	0	0	1	2	12	26	1	2	20	43	39	83	47
	LRA-M	0	0	0	0	0	0	0	0	2	11	12	67	0	0	2	11	12	67	18
21,22,23	LRA-B	0	0	0	0	2	5	1	3	7	18	27	71	1	3	7	18	28	74	38
	LRA-M, X, B	0	0	0	0	2	3	1	2	9	15	40	68	1	2	9	15	41	69	59
	SC, ST, LRA	1	1	19	18	39	37	1	1	10	9	52	49	2	2	29	27	80	75	106

SC - seal coat
ST - surface treatment
LRA-M - machine laid limestone rock asphalt
LRA-B - blade laid limestone rock asphalt
LRA-X - box laid limestone rock asphalt

hot mix asphalt concrete surface have raveling as defined from the state-wide survey while 68 percent of the cold mixes made with limestone rock asphalt exhibited some degree of raveling.

A review of data presented in Table 12 indicates that little difference was noted as to the amount or degree of flushing or raveling between the two methods of placing the cold mixes (blade laid or machine laid). Pavement sections studied in District 22 had less flushing and more raveling than those studied in District 20 and 21.

Alligator Cracking. The occurrence of alligator cracking for the limestone rock asphalt pavements surveyed is shown in Table 13. Fifty percent of the 106 sections evaluated contained alligator cracking. This compares to 20 percent which is noted for hot mix asphalt concrete pavements studied state-wide. As noted in Table 13, the majority of the pavements with alligator cracking occurred in District 22. The majority of pavements in this district have been surfaced with limestone rock asphalt pavements and the concept of stage construction has been utilized. Additionally, thinner overlays of limestone rock asphalt are normally used as compared to hot mix asphalt concrete overlays.

Pavement Rating Score. The Pavement Rating Score has been calculated for all sections studied and is reported in Volume III of this report. A summary of Pavement Rating Score by District and surface type is shown in Table 14. The average Pavement Rating Score for the 106 pavement sections studied is 79. This compares with an average score of 83 for 245 random pavement

Table 13: Occurrence of Alligator Cracking

District	Severe		Moderate and Severe		Slight, Moderate and Severe		Total No. of
	No.	%	No.	%	No.	%	Sections
20	1	4	5	11	11	42	26
21	0	0	6	18	11	32	34
22	3	7	11	24	31	67	46
20, 21, 22	4	4	22	21	53	50	106

Table 14: Summary of Pavement Rating Score Data

District Number	Type of Surface	Mean	Standard Deviation	Coefficient of Variation	Low and High Values	Number of Data Points
20	ST	85.0	7.1	8.3	80-90	2
	SC	76.1	10.7	14.1	60-85	11
	CM	70.7	7.5	10.6	60-82	13
	All Type	74.1	9.6	13.0	60-90	26
21	ST	89.5	6.4	7.1	85-94	2
	SC	83.8	13.9	16.6	51-100	19
	CM	78.0	14.3	18.4	54-95	13
	All Type	81.9	13.9	16.9	51-100	34
22	ST					
	SC	80.4	14.6	18.1	67-100	14
	CM	79.3	11.9	15.0	55-100	32
	All Type	79.6	12.6	15.9	55-100	46
20, 21, 22	ST	87.3	6.1	7.0	80-94	4
	SC	80.8	13.5	16.7	51-100	44
	CM	77.1	12.0	15.6	54-100	58
	All Type	79.0	12.6	16.0	51-100	106

ST - Surface Treatment

SC - Seal Coat

CM - Cold Mix

samples studied state-wide (15).

A comparison of scores from the three districts indicates that District 20 has a lower average score than District 21 and 22. District 20 however, has higher traffic volumes and heavier traffic on the average than the other districts surveyed.

A comparison by surface type indicates that slightly better performance was obtained from the pavements with seal coats as compared to cold mixes (Table 14).

Typical Types of Distress. Photographs for all pavement sections surveyed can be found in Volume II of this report. Examples of flushing, raveling, alligator cracking, longitudinal cracking, transverse cracking and patching can be found in these photographs. Typical examples of these distress types will not be presented in Volume I of the report, except for photographs of Section 9 which is a Type A of cold mix placed in a high traffic urban area. The skid number on this section is 17 and the pavement has a "glazed" appearance (Figure 8). This "glazed" appearance was common on Type A and Type B cold mixes studied in Districts 20 and 21.

The cause or causes of this "glazed" condition is not well defined, however several possibilities exist. For example, the "glazing" associated with the Type A and B mixes may be associated with a higher volume of rich fines in the mix as compared to other gradations. Other possible causes include the use of excessive flux oil and/or water, gap gradations, and floating of fines to top due to specific gravity differences.

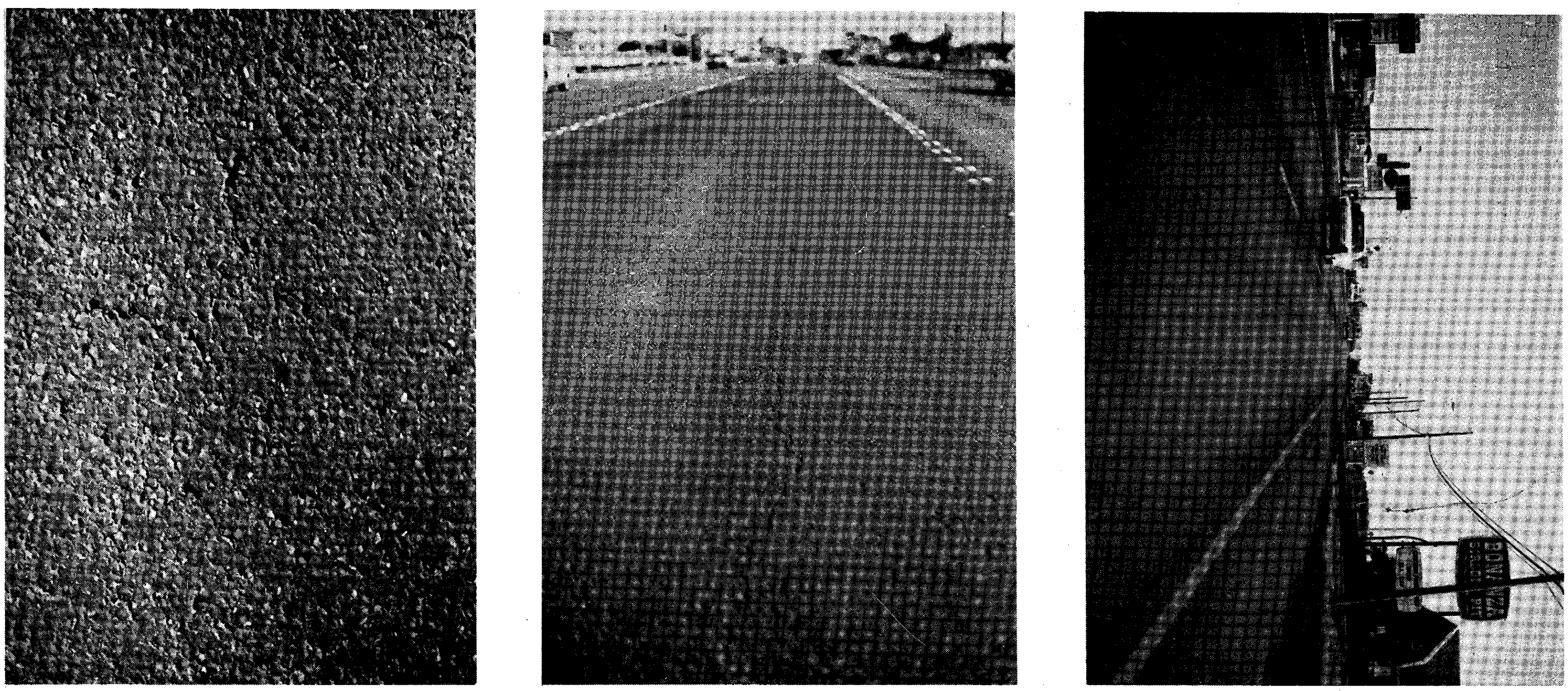

Figure 8. Section Number 9 - Type A Limestone Rock Asphalt Cold Mix.

It should be noted that corrugations were not noted in the survey of test sites. However, the test sites were located in mainly rural areas where vehicle acceleration and deceleration are not common. A pavement survey conducted on pavements surfaced with limestone rock asphalt in urban areas would almost certainly reveal the presence of corrugations. These corrugations are primarily due to the low stability of these cold mixes early in their life. Cold mixes properly aerated prior to compaction have performed satisfactorily in many urban areas within the state.

Structural Adequacy

The Dynaflect non-destructive testing machine was utilized to test 24 pavements constructed with cold mix limestone rock asphalt materials. A summary of the stiffness coefficients for these pavements is shown in Table 15. An average stiffness coefficient of 0.90 was obtained for the sections tested. This stiffness coefficient is within the range normally expected for hot mix asphalt concrete surfacing materials and high quality black base materials currently utilized in Texas (Table 16) (27).

Values of resilient modulus obtained on cores of cold mix limestone rock asphalt confirm the contention that field cured limestone rock asphalt cold mixes have a structural capacity or load carrying ability similar to that of hot mix asphalt concrete surfaces and black bases (Figure 6). However, condition survey results indicate a high occurrence of alligator cracking - more than normally associated with conventional hot mix asphalt concrete pavement. This increased occurrence of alligator cracking may

Table 15: Summary of LRA Cold Mixture Stiffness Coefficients

Location	Predominant Type of Distress Present on the Roadway (Cracking Only)	Number of Pavement Sections	Average Stiffness Coefficient	Standard Deviation
District 20	Slight Alligator Cracking	2	1.20	0.02
	Moderate Alligator Cracking	1	0.94	----
	Moderate Longitudinal and Transverse Cracking	1	0.672	----
	Severe Alligator Cracking	1	1.13	----
District 21	Slight Alligator Cracking	2	0.94	0.13
	Moderate Alligator Cracking	1	0.96	----
District 22	No Distress	2	1.04	0.36
	Slight Alligator Cracking	10	0.83	0.13
	Moderate Alligator Cracking	4	0.82	0.10
District 20, 21 and 22		24	0.90	0.18

Table 16: Stiffness Coefficients for Asphalt Stabilized Materials

Location			Thickness of Material, Inches	Type of Material	Stiffness Coefficient		
District	Highway	County			Mean	Standard Deviation	No. of Readings
5	US 87	Lubbock	6.25	ACP	0.99	0.27	14
	US 87	Lubbock	6.25	ACP	1.06	0.25	14
			1.5	ACP			
	US 87	Lynn	4.5	B.B.	1.16	0.15	9
			0.5	ST			
	US 87	Lynn	4.0	B.B.	1.13	0.10	6
11	US 69	Angelina	10.0	ACP	1.18	0.15	24
	US 69	Angelina	10.0	ACP	1.21	0.22	49
15	IH 35	Frio	10.0	B.B.	0.70	0.05	24
			10.0	B.B.			
	IH 35	Frio	6.0	A.S.B.	0.52	0.03	24*
17	IH 45	Walker	12.0	B.B.	0.77	0.09	27
			8.0	H.S.B.			
	IH 45	Madison	4.0	A.S.B.	0.70	0.11	19
			8.0	H.S.B.			
	IH 45	Madison	4.0	A.S.B.	0.87	0.11	21
	IH 45	Walker	12.0	B.B.	0.65	0.08	25
			1.0	ACP			
	US 290	Washington	5.0	B.B.	1.87	0.58	14
			1.0	ACP			
	US 290	Washington	7.0	B.B.	1.43	0.30	21
19	IH 30	Titus	8.0	B.B.	2.06	0.45	67
			8.0	ACP			
	SH 98	Bowie	8.0	A.S.B.	0.48	0.01	5
			8.0	ACP			
	SH 98	Bowie	8.0	A.S.B.	0.49	0.03	5
			4.0	ACP			
	SH 98	Bowie	8.0	A.S.B.	0.47	0.13	14

ST- Surface treatment
ACP- Asphalt concrete pavement
B.B.- Black Base
A.S.B.- Road mixed asphalt stabilized base
H.S.B.- Hot mixed sand base

*Contains 6 inches of asphalt treated subgrade be due to design and overlay strategies associated with the use of limestone rock asphalt cold mixes.

Surface Texture

Surface texture measurements were made for each section studied at the inner, outer and between the wheel paths. Data for each section can be obtained from Volume III of this report. Analyses of surface texture information were made on data obtained on the inner wheelpath only.

The surface texture for various gradations of cold mixes is shown in Table 17. The average surface texture for the cold mixes studied is 0.030 cubic inches per square inch. Type A and Type D have the lowest average surface texture. Type C has the greatest surface texture. Of the districts surveyed District 22 has the greatest surface texture.

Surface texture for the various types of surfaces (surface treatment, seal coat and cold mixes) by district and for various degrees of flushing is shown in Table 18. As expected the surface texture of the seal coats and surface treatments exceeds that of the cold mixes. Blade laid cold mixes with an average surface texture of 0.033 exceeded that of the machine laid and box laid cold mixes (0.025 and 0.019 respectively). The greater surface texture noted for the cold mixes placed in District 22 can be partially accounted for by the large number of blade laid sections placed in the district.

The reduction in surface texture associated with flushing of seal coats and surface treatments can be noted by review of Table 18. The average surface texture for seal coats from all

Table 17: Surface Texture for Various Gradations of Cold Mixes by District

Gradation of LRA	District 20 $\bar{X}$	S	Cv	N	District 21 $\bar{X}$	S	Cv	N	District 22 $\bar{X}$	S	Cv	N	All Districts $\bar{X}$	S	Cv	N
Type A	.027	.007	25.5	4	.018	.007	35.3	8					.021	.007	35.3	12
Type B	.035	.010	49.6	4	.020			1					.032	.011	34.0	5
Type C	.039			2	.023			1	.044	.018	40.0	12	.042	.017	40.0	15
Type CC									.029	.021	73.3	6	.029	.021	73.3	6
Type D	.021	.016	74.8	3					.020			2	.021	.012	58.0	5
Type CMOD									.024	.005	19.0	9	.024	.005	19.0	9
Type CCMod									.028	.015	52.9	3	.028	.015	52.9	3
Type Unknown					.032	.007	23.0	4					.032	.007	23.0	4
All Types	.030	.011	38.1	13	.023	.008	37.2	14	.033	.017	52.5	32	.030	.015	49.7	59

$\bar{x}$ = mean

S = standard deviation

Cv = coefficient of variation

N_2 = number of data points

Table 18: Surface Texture For Various Types of Surfaces and Degree of Flushing

District No.	Type of Material & Construction	None				Slight				Moderate				Severe				Total for District(s)			
		$\overline{x}$	s	c_v	n	$\overline{x}$	s	c_v	n	$\overline{x}$	s	c_v	n	$\overline{x}$	s	c_v	n	$\overline{x}$	s	c_v	n
	LRA-B	.035	.009	24.1	3				0				0				0	.035	.009	24.1	3
	LRA-M	.032	.009	28.3	7				0				0				0	.032	.009	28.3	7
	LRA-X	.019	.015	77.5	3				0				0				0	.019	.015	77.5	3
	SC	.072			1	.067			1	.039	.011	28.4	9				0	.044	.016	35.8	11
	ST				0	.072			1	.070			1				0	.071	.001	2.0	2
	LRA-B	.027	.005	19.5	4	.040			1				0				0	.030	.007	24.6	5
	LRA-M	.019	.006	32.7	9				0				0				0	.019	.006	32.7	9
	LRA-X				0				0				0				0				0
	SC	.087	.025	28.7	4	.062	.046	74.4	9	.016	.013	84.9	3				1	.056	.044	78.9	17
	ST				0	.070			1	.042			1				0	.056	.019	35.3	2
	LRA-B	.033	.018	54.9	29	.040			1				0				0	.033	.018	53.7	30
	LRA-M	.031			2				0				0				0	.031			2
	LRA-X				0				0				0				0				0
	SC	.077	.045	58.6	4	.061	.029	46.8	7	.057	.042	74.5	3				0	.065	.035	53.3	14
	ST				0				0				0				0				0
	LRA-B	.031	.008	24.6	7	.040			1				0				0	.032	.008	24.2	8
	LRA-M	.025	.010	41.0	16				0				0				0	.064	.014	22.6	4
	LRA-X	.019	.015	77.5	3				0				0				0	.033	.016	48.9	38
	SC	.084	0.23	27.0	5	.063	.044	69.6	10	.033	.015	46.5	12				1	.025	.010	40.1	18
	ST				0	.071	.001	2.0	2	.056	.020	35.3	2				0	.019	.015	77.5	3
	LRA-B	.032	.016	50.6	36	.040			2				0				0				
	LRA-M	.025	.010	40.1	18				0				0				0				
	LRA-X	.019	.015	77.5	3				0				0				0				
	SC	.081	.032	39.8	9	.062	.037	59.8	17	.038	.023	61.6	15				1				
	ST				0	.071	.001	2.0	2	.056	.020	35.3	2				0				

districts without flushing is 0.081. Pavements with slight flushing have an average surface texture of 0.062 while pavements with moderate flushing have a surface texture of 0.038. Only one pavement was classified as having severe flushing. The surface texture of this pavement was 0.0001.

For comparison purposes, Figure 9 has been prepared which illustrates the range and average values expected for pavements constructed with materials other than limestone rock asphalt. As shown in this figure, machine laid limestone rock asphalt cold mixes and asphalt concrete have similar surface textures. On the average, blade laid cold mixes made with limestone rock asphalt exceed the surface texture values normally obtained on asphalt concrete pavements. As expected, seal coats made with limestone rock asphalt are similar to those made with other aggregates. Typical values for open graded friction courses and portland cement concrete surfaced pavements are also shown in Figure 9.

SKID RESISTANCE

One of the major purposes of this study is to define the performance of pavements surfaced with limestone rock asphalt materials in terms of skid resistance. Thus considerable effort has been expended to collect and analyze skid information collected on pavements of various ages and subjected to different traffic levels. As discussed above a locked wheel skid trailer was used to collect these data. The majority of data were collected in the inside wheelpath and all numbers reported except those

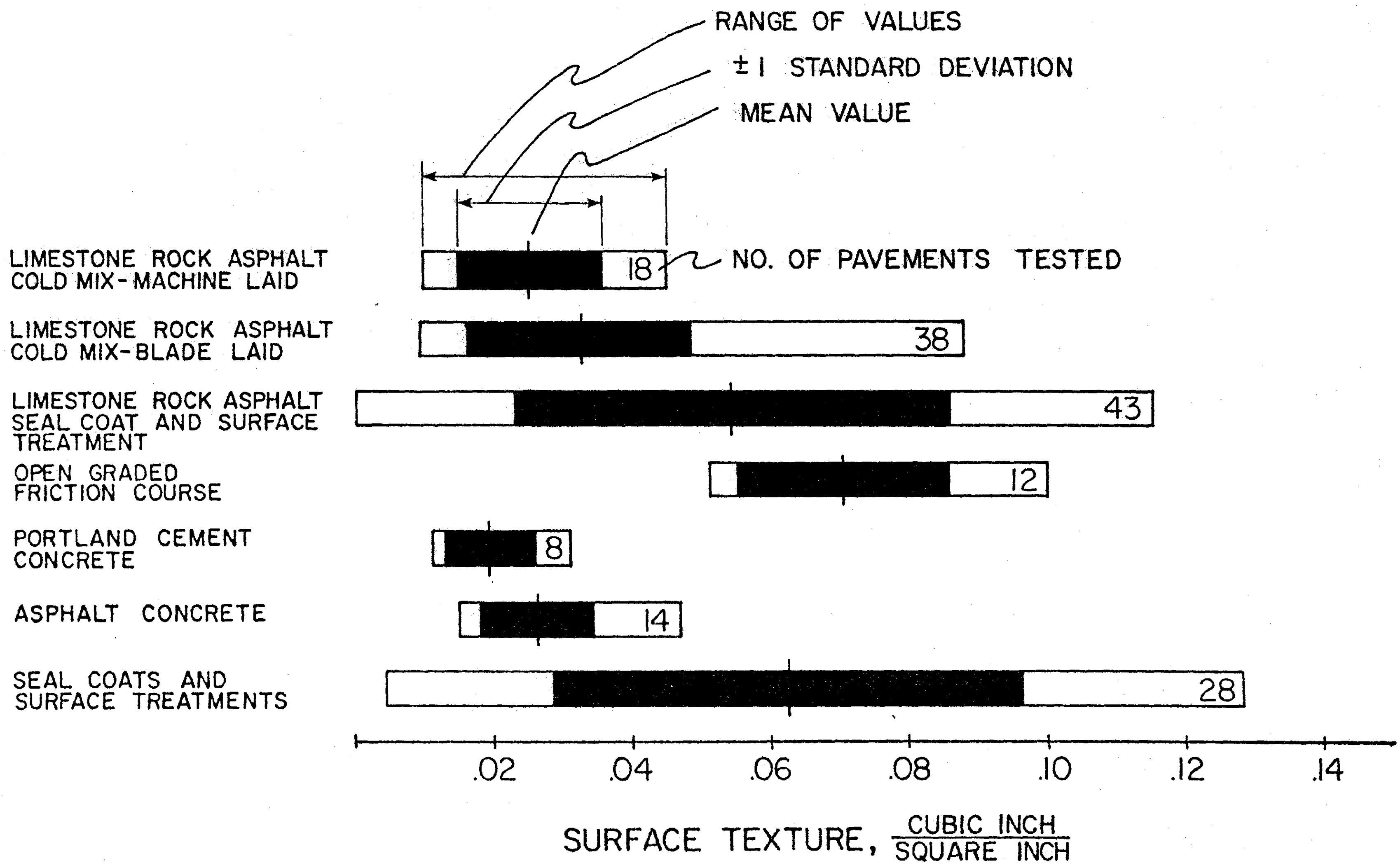

Figure 9. Typical Values of Surface Texture as Measured by Putty Test.

noted in Table 19 are from this wheelpath.

The report refers to a skid number of 35 and by reference implies that this value is a criterion for acceptance. The reader should be aware that there is no value universally accepted by the engineering community as being a "safe" skid number; however, skid numbers greater than 35 are generally considered to be representative of pavement surfaces which do not have a significant potential for wet weather vehicle skidding accidents.

Location of Skid Tests

Table 19 indicates the variation of skid number as a function of the location of the test (wheelpath, shoulder, centerline, between wheelpath). These data indicate that the skid number decreases under the action of traffic as values in the wheelpath are noticeably lower than those values collected on the shoulder, centerline and between the wheelpath which are subjected to relatively low volumes of traffic. From these data it appears as if limestone rock asphalts will have a skid number of the order of 50 to 60 if allowed to weather without the polishing action of traffic.

Figure 10 illustrates the distribution of skid numbers for all seal coats and cold mixes. This distribution indicates little difference between these two types of surfaces. Detailed data will be presented for cold mixes and seal coats treated separately.

Cold Mixes

A great difference in skid numbers was found to exist in the data as shown in Figure 11 for the three districts studied.

Table 19: Variation in Skid Number as a Function of Location of Test

Section Number	District	Average Skid Number SN40				Type of Surface	Construction Method	Age, yrs.	ADT per lane	Accumulated Traffic per Lane x 10^6
		Wheel Path	Shoulder	Centerline	Between Wheel Path					
9	21	17	51			LRA	M	2.7	3500	3.5
10	21	10	35			LRA	M	2.7	4300	4.3
11	21	18	51			LRA	M	5.7	1710	3.6
12	21	28		50		SC		2.7	1250	1.2
13	21	15		40*		SC		1.8	2100	1.4
15	21	50		63		SC		1.7	1750	1.1
16	21	62		54		SC		0.6	1750	0.4
20	21	19			47	SC		3.9	140	0.2
21	21	46		31**				1.5	55	0.03
31	21	25			45	LRA	M	2.6	950	0.9
32	21	24		40		LRA	M	2.0	950	0.7
35	20	34			39	LRA	M	3.7	1730	2.3
36	20	20			50	SC		3.2	860	1.0

* Taken in passing lane
** 46 inside wheelpath, 31 outside wheelpath
LRA = Limestone rock asphalt (Cold mix-cold laid)
SC = Seal coat
M = Machine Laid

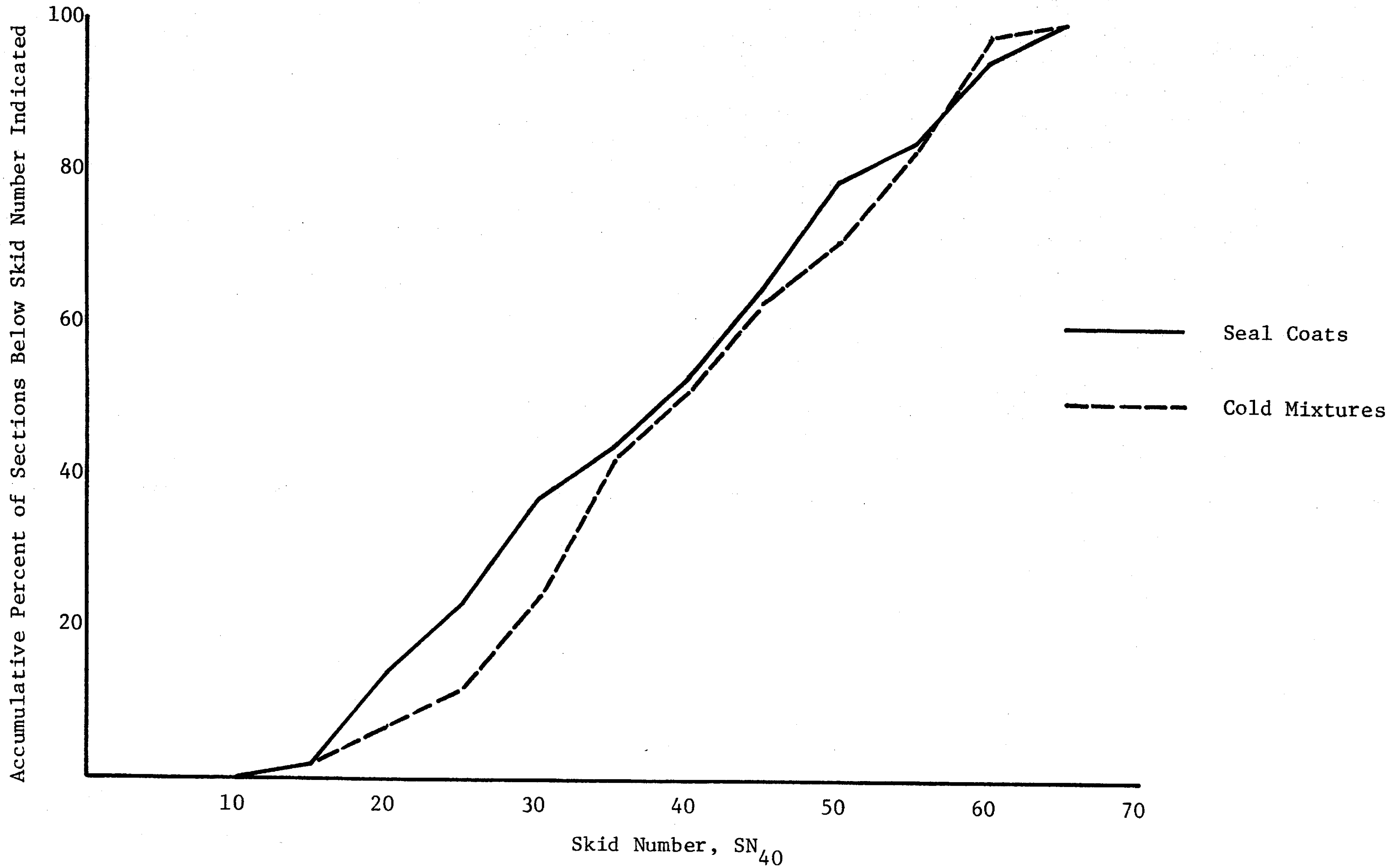

Figure 10. Distribution of Skid Numbers for Limestone Rock Asphalt

This variation occurred due to a number of factors including: those effects due to different districts, lay-down techniques, climate, mix types, traffic, age, surface texture, and accumulated traffic. Many other factors undoubtedly affect the skid resistance of these surfaces but primary analysis was focused on these variables.

To examine skid resistance of limestone rock asphalt cold mixtures two principal analysis techniques were used. One was to compute general statistics which included means (averages), standard deviations, low and high values, and coefficient of variations for separate subgroupings of the available data. Secondly, extensive regression modeling was accomplished to determine which variable could best predict skid number for the various subgroupings of the data. Additionally, skid number summaries stored on magnetic tape for all pavement sections which have been skidded throughout the state were made available by the SDHPT Transportation Planning Division for another in-progress research effort. These summaries contain an average skid number for various construction sections (CSN) along with other data such as average daily traffic (ADT), pavement type, aggregate type, date of skid data, etc. A computer program was prepared which accessed these data and prepared overall summaries of selected data. All of this analysis will be presented in greater detail later in this section on limestone rock asphalt cold mixtures.

Available data for each cold mixture pavement section selected for this research effort was stored on computer readable cards. This greatly facilitated processing the data with various statistically oriented computer programs. Most of the general statistics and regression modeling were obtained by using the Statistical Analysis System computer program package developed at North Carolina State University.

Subgroupings of the original data were used to examine the skid related data. These subgroupings were based upon the district in which the pavement section was located, the type of cold mixture, and raveling condition of the surface. It was decided early in the analysis that this method of examining the data should reveal any major differences in skid number between the various pavement sections surveyed. Table 20 shows these groupings for the cold mixtures and the number of pavement sections contained in each. As can be seen in the table, a total of 65 limestone rock asphalt cold mixture surface pavement sections were evaluated.

A total of fifteen separate variables were considered in examining skid number trends for limestone rock asphalt cold mixes. These variables were:

1. Age
2. Surface texture (inner wheelpath)
3. Accumulated traffic
4. Average daily traffic per lane
5. Material retained 5/8 inch sieve
6. Material retained 1/2 inch sieve
7. Material retained 3/8 inch sieve
8. Material retained No. 4 sieve
9. Percent flux oil
10. Percent flux oil
11. Percent water
12. Percent average bitumen
13. Bitumen in minus No. 10 fraction
14. Percent white rock
15. Percent bitumen in white rock

The first four variables listed were used as the basis for detailed examination. This decision was made using a preliminary screening of the variables based on general statistical summaries and regression

Table 20. Grouping of Limestone Rock Asphalt Cold Mix Data

Group Number and Description	Number of Pavement Sections in Group
1. All LRA Cold Mixes - All Districts	65
2. LRA Cold Mixes - Type A	12
3. LRA Cold Mixes - Type B	5
4. Lra Cold Mixes - Type C	16
5. LRA Cold Mixes - Type D	5
6. LRA Cold Mixes Without Moderate or Severe Raveling	51
7. LRA Cold Mixes With Moderate or Severe Raveling	7
8. LRA Cold Mixes - Type C District 22	13
9. LRA Cold Mixes - Type CMOD District 22	8
10. LRA Cold Mixes - Type CC District 22	7
11. LRA Cold Mixes - Type CCMOD District 22	2
12. LRA Cold Mixes - Types C,D,CC,CMOD CCMOD - District 22	32
13. LRA Cold Mixes - Types D, CMOD, CC, CMOD - Districts 20 and 22	22
14. LRA Cold Mixes Without Moderate or Severe Raveling - Type C, All Districts	14
15. LRA Cold Mixes - Type A - District 20	4
16. LRA Cold Mixes - Types A, B - District 20	8
17. LRA Cold Mixes - Types A, B, C, D - District 20	13
18. LRA Cold Mixes - Type A - District 21	8
19. LRA Cold Mixes - Types A, B - District 21	9
20. LRA Cold Mixes - Types A, B, C, - District 21	10

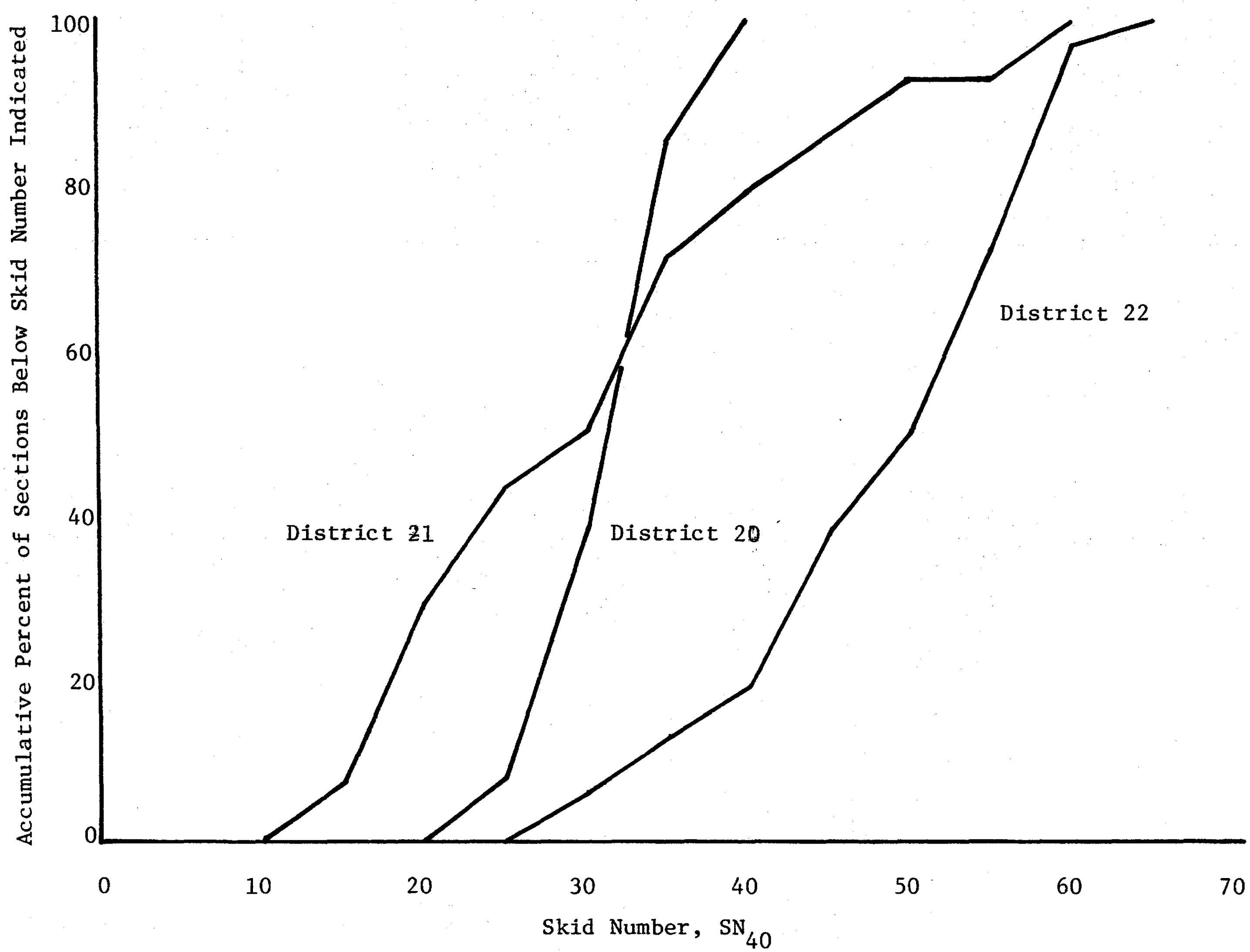

Figure 11. Distribution of Skid Number for Cold Mixtures in Various Districts.

analysis. Of the remaining eleven variables (material retained 5/8 inch sieve through bitumen in white rock) only material retained on 3/8 inch sieve proved to be a significant indicator of skid resistance; although this variable was not used in further analysis since it indicated the gradation (types) of cold mix and the different types were each studied separately. Table B-5 and B-6 (Appendix B) contain general statistical summaries for the variables not used for both cold mixes and seal coats.

General Statistics. Table 21 is a summary of the means obtained for each grouping of data. More detailed tables containing this information and more can be found in Appendix B (Tables B-1 and B-3). The means shown in the table are for the following variables: skid number, age, average daily traffic per lane (ADT/Lane), accumulated traffic and surface texture (inner wheelpath). How these individual variables were obtained was previously discussed with the exception of age variable. Age of a pavement surface was taken as the difference between its construction date and when the field data were collected.

Comparing mean skid numbers for the twenty groupings of data, the Type C modified (CMOD) cold mixes in District 22 have the highest value. The next highest grouping is Type C mixtures also located in District 22 followed by various groupings of Types C, D, CC, CMOD and CC modified (CCMOD). The lowest mean skid numbers are observed for Type A and B cold mixtures in District 21. This is followed by Type A mixes overall and Type A mixes in District 20. The mean values for Type B are higher than Type A but are relatively low. Figure 12 shows how the skid

Table 21. Summarized Means for Various Groupings of Limestone Rock Asphalt Cold Mixes

Data Grouping	Means				
	SN_{40}	Age	ADT/Lane	Accumulated Traffic	Surface Texture
All LRA Cold Mixes	39.0	6.2	1,414	3,028,300	0.029
Type A	24.7	4.8	2,434	3,833,800	0.021
Type B	32.6	5.2	2,311	3,994,600	0.032
Type C	45.0	7.4	1,098	3,036,200	0.039
Type D	37.3	7.8	2,095	4,765,000	0.020
Without Moderate or Severe Raveling	39.7	5.9	1,496	2,928,600	0.028
With Moderate or Severe Raveling	42.3	8.4	1,301	3,495,700	0.037
Type C - Dist. 22	47.0	7.8	1,183	3,479,500	0.040
Type CMOD District 22	49.7	8.2	1,084	3,171,200	0.024
Type CC District 22	43.3	3.7	734	626,400	0.028
Type CCMOD District 22	46.3	1.0	1,112	285,000	0.030
Types C, D, CC, CMOD, CCMOD - District 22	46.9	6.8	1,007	2,461,500	0.032
Types D, CMOD, CC CCMOD, Dist. 20 and 22	44.5	6.0	1,205	2,461,200	0.025
Without Moderate or Severe Raveling Type C	44.1	6.9	1,160	3,098,500	0.036
Type A - Dist. 20	27.9	5.2	2,832	5,257,000	0.026
Types A, B, District 20	30.1	5.1	2,626	4,637,600	0.031
Types A, B, C, D District 20	30.5	5.5	2,473	4,679,200	0.030
Type A - Dist. 21	22.4	4.5	2,235	3,122,200	0.018
Type A, B, District 21	24.0	4.7	2,195	3,208,700	0.019
Types A, B, C, District 21	25.1	4.5	2,047	2,912,400	0.019

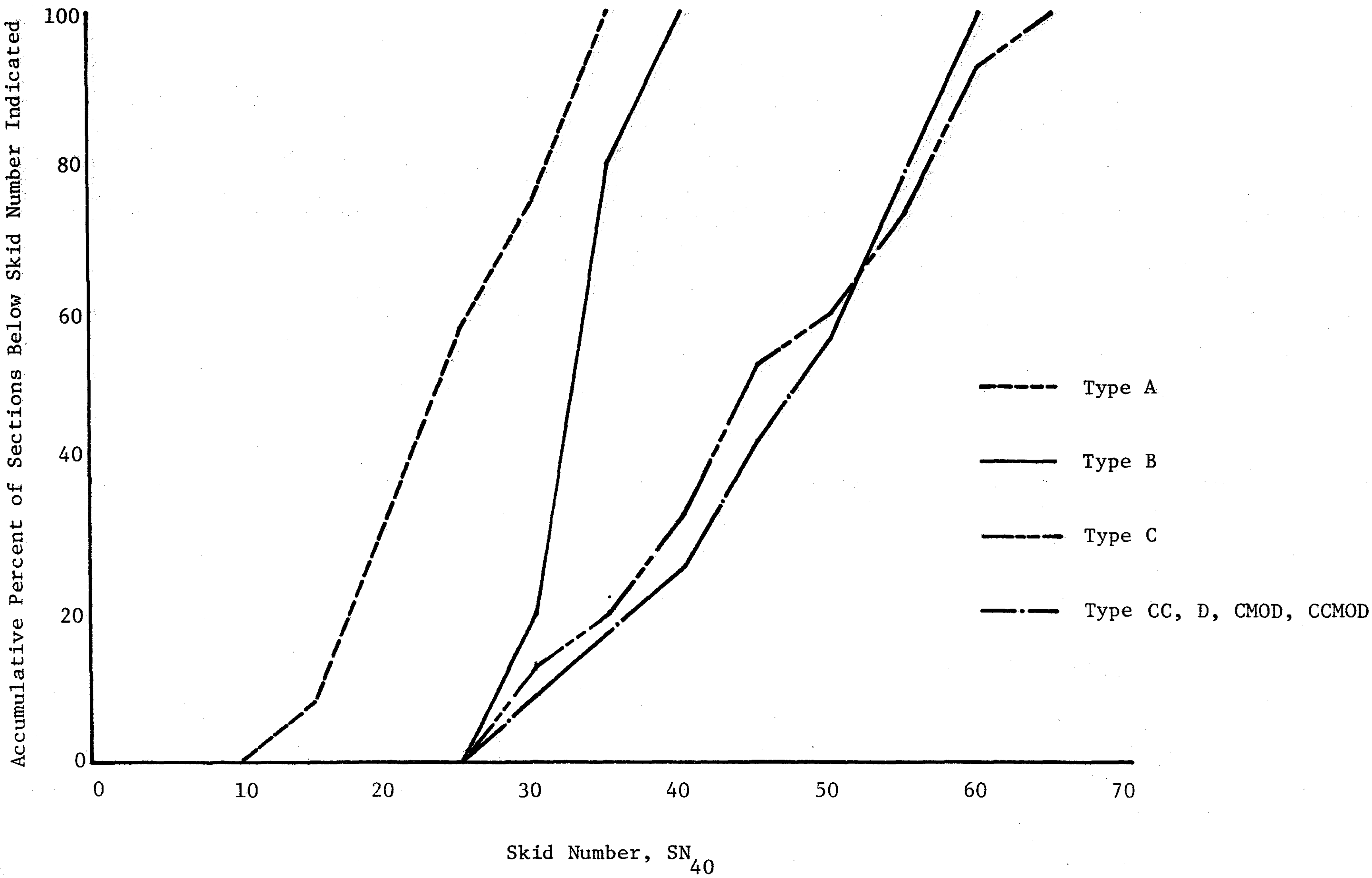

Figure 12. Distribution of Skid Number for Cold Mixtures of Various Types.

number major groupings vary for different mix types.

Even though there are clearly differences in mean skid number between the Type A and Type C cold mixes, variables such as traffic must be considered. For example, most of the Type C, D, CC, CMOD and CCMOD cold mixtures are located in District 22. The majority of the Type A and B mixtures examined are located in Districts 20 and 21. But even more importantly the ADT/Lane for the C-type mixes is approximately one-half of that recorded for the Type A and B Mixes. This problem was recognized early in the field data collection effort, but unfortunately C-type mixtures have generally been placed on low traffic highways. This resulted in having few high traffic C-type sections in this study. Additional discussion of this problem will occur later in this section.

Again referring to Table 21, the ages of the Type C and D mixes are about two years older than the Type A and B mixes. But the accumulated traffic for all four mixes is about the same - approximately 4,000,000 vehicles.

The measured surface textures are about the same for Type A and D mixes but their respective mean skid numbers are 24.7 and 37.3 for a difference of about 13 skid numbers. Additionally, the ADT/Lane is only slightly higher for the Type A mix, about 2,400 as opposed to 2,100 for the Type D mix. Mean surface textures for Type B and C mixes are 0.032 and 0.039 cu. in/sq.in, respectively. Even though the surface textures are similar, the skid numbers vary by a difference of about 14. But unlike the comparison between Types A and D, the ADT/Lane for Type B is over twice the amount of Type C.

Of additional interest in Table 21 is a comparison between the cold mix pavement sections with and without raveling. The amount and extent of raveling for each pavement section was obtained using standarized visual methods (14). The data shown in the table indicate that a small increase in skid number can be expected with increased raveling. The mean surface texture for pavements exhibiting moderate (10 to 50 percent of surface aggregate dislodged) or severe (greater than 50 percent of surface aggregate dislodged) raveling is significantly higher than the pavement sections without moderate or severe raveling. This is as one might expect. Fifty-one of the cold mixture sections had none to slight raveling and only seven had moderate to severe. But thirty of the fifty-one sections with none to slight raveling were located in District 22 - the district with the highest skid numbers. The number of sections with moderate or severe raveling were evenly distributed throughout all three districts. Thus it can be stated that raveling of limestone rock asphalt cold mixes can be expected to enhance skid resistance. Of course, raveling can be destructive to the pavement surface from a structural standpoint. Skid resistance and the structural qualities of a pavement surface are in conflict in this case.

To further examine the differences in skid number which may exist between the major types of limestone rock asphalt cold mixtures a separation of "high traffic" and "low traffic" levels was made. The resulting data are shown in Table 22. The problem was to see if the high skid number C-type mixes predominately located in District 22 could sustain their high skid numbers under traffic conditions more analogous to those experienced by Type A and B mixes. An examination of the data indicated a dividing

Table 22. Effect of High/Low Average Daily Traffic Per Lane on Various Types of LRA Cold Mixes

High Traffic Level
(≥ 1500 ADT/Lane)

LRA Cold Mix Type	Mean			Number of Sections
	SN_{40}	Age	ADT/Lane	
A	22.1	4.5	3151	8
B	31.6	5.2	2551	4
C	33.0	9.0	2620	3
CMOD	27.8	8.0	4480	1
CC	40.0	2.0	1990	1
D	28.7	6.0	4215	2

Low Traffic Level
(< 1500 ADT/Lane)

LRA Cold Mix Type	Mean			Number of Sections
	SN_{40}	Age	ADT/Lane	
A	28.7	5.2	1000	4
B	38.7	5.0	1350	1
C	48.0	7.1	747	13
CMOD	52.8	8.3	599	7
CC	43.7	4.0	524	6
D	43.0	9.0	682	3

point somewhere around 1500 ADT/Lane was appropriate.

For low traffic levels (<1500 ADT/Lane) the C-type and Type D mixes exhibit relatively high skid numbers with the averages ranging from 43.0 to 52.8. The low traffic Type A mixes indicate an average skid number of about 29. The ages for the C-type and Type D mixes are two to four years older than the Type A; although, the average ADT/Lane is slightly higher for the Type A mix. There was only one Type B surfaced pavement section in this category and thus is not compared to the other types.

The C-type and Type D mixes in the high traffic level category ($\geq$ 1500 ADT/Lane) show significantly reduced skid numbers with the averages ranging from 27.8 to 40.0. A weighted overall average for the C-type and Type D mixes is 32.0 for high traffic and 47.8 for low traffic conditions. The high traffic skid number averages for Type A and B mixes are 22.1 and 31.6, respectively. The ages for the C-type and Type D mixes were about one year older than the Type A and B mixes.

The Type A mixes decreased by about seven skid numbers going from low to high traffic. The C-type and Type D decreased approximately 16 skid numbers going from low to high traffic conditions. This indicates that the C-type and Type D mixes cannot be expected to sustain superior skid performance under high traffic conditions. Although, these mixes did tend to out perform Type A mixes significantly at both traffic levels. The C-type and Type D mixes also seem to perform better than Type B mixes but this distinction is not quite so apparent.

All of the data which have served as the basis for the preceding discussion was obtained from pavement sections which by necessity were selected in a nonrandom process. Nonrandom data can bias inferences drawn from such data. Thus any additional data which could be made available could be used as a check. Additionally, skid information about pavement surface types other than limestone rock asphalt cold mixes would be very informative. This allows limestone rock asphalt cold mixes to be ranked relative to other surface types.

To accomplish part of the above task skid data obtained by another in-progress research project were made available for Districts 20 and 21. No additional data were available for District 22. The additional data were obtained from a magnetic tape containing skid data summaries described earlier in this section of the report. To use these kinds of data, it is assumed that the statistics obtained are true representations of the various population categories described. This assumption was not validated. Tables 23 and 24 show these additional skid data for Districts 20 and 21. respectively. In both tables summaries for different surface/pavement types were made for skid number, age and ADT. Age was taken as the difference between when a given surface was placed and January 1977. The ADT shown is for two-way traffic not ADT/Lane as previously used.

For all surface types, Table 23 indicates an average skid number of about 36 with a corresponding ADT of over 5,000 vehicles per day for District 20. The highest skid number and ADT averages are shown for continuously reinforced and jointed concrete pavements with average skid of about 40 and ADT's of approximately 14,000 vehicles per day. The hot mix asphalt concrete segments have an average skid number of about 34 which is the lowest reported for

Table 23. Summary of Skid $Number_{40}$ and Related Data From SDHPT Skid Summaries for District 20.

Type* Surface	Skid $Number_{40}$		Age		ADT		Number of Sections
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
All	36.6	8.8	5.6	4.1	5032	7093	549
HMAC	33.5	6.3	4.6	3.2	7915	6746	115
ST/SC	36.4	9.7	5.2	3.4	1629	2440	315
LRACM	36.5	6.6	4.0	2.1	4324	4536	18
CRCP	39.9	3.5	8.1	3.1	14547	6112	23
JCP	39.7	5.0	10.5	5.8	14275	11036	60

* HMAC = Hot Mix Asphalt Concrete
ST/SC = Surface Treatment/Seal Coats
LRACM = Limestone Rock Asphalt Cold Mix
CRCP = Continuously Reinforced Concrete Pavement
JCP = Jointed Concrete Pavement

Table 24. Summary of Skid $Number_{40}$ and Related Data From SDHPT Skid Summaries for District 21

Type* Surface	Skid $Number_{40}$		Age		ADT		Number of Sections
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
All	31.1	7.7	5.7	5.0	4180	5148	567
HMAC	27.8	5.4	5.9	4.6	7978	5818	221
ST/SC	33.5	8.0	5.1	4.2	1472	2412	317
LRACM	21.0	11.6	11.9	9.1	3190	2059	4
CRCP	----	----	----	---	----	----	---
JCP	----	----	----	---	----	----	---

* HMAC = Hot Mix Asphalt Concrete
ST/SC = Surface Treatment/Seal Coats
LRACM = Limestone Rock Asphalt Cold Mix
CRCP = Continuously Reinforced Concrete Pavement
JCP = Jointed Concrete Pavement

any of the surface types shown. Limestone rock asphalt cold mix shows an average skid number of 36 which is slightly better than the hot mix asphalt concrete. The estimates for the cold mix are based on 19 different pavement types in this table. The limestone rock asphalt cold mix only has one-half the ADT as experienced by the hot mix asphalt concrete segments. The skid number estimates so obtained for limestone rock asphalt cold mixes in District 20 are about 6 skid numbers higher than were obtained for the sections field studied for this research effort.

Table 24 is the same basic treatment for skid data in District 21. The overall average skid number is about 31 which is about 5 skid numbers less than observed for the same category in District 20. The ages and ADT averages are about equal for this category. The hot mix asphalt concrete shows an average skid number of 28 and limestone rock asphalt 21. The estimates for limestone rock asphalt cold mix are based on four highway segments as opposed to over 200 segments for hot mix asphalt concrete. Therefore, detailed comparisons are not justified between these two surface types. It is of interest that hot mix asphalt concrete surfaces in District 21 are about six skid numbers less than the same type surfaces in District 20. The ages and ADT for both districts for hot mix surfaces are approximately the same. The difference between average skid numbers for surface treated/seal coated surfaces in District 20 and 21 is about two skid numbers with District 21 being the lower.

A final comparison of skid number mean values was made comparing blade laid versus machine laid construction techniques. A statistical summary for the primary variables considered is shown as Table 25. In this table all skid numbers obtained for each pavement section are used to compute the mean values (usually nine skid numbers per section). This accounts for the differences in the number of data points shown for skid number and the other variables summarized. The average skid number shown for blade laid pavement sections is about 45 and 30 for machine laid sections. But, these statistics can be deceiving in that 30 of the 37 blade laid sections studied are located in District 22 with correspondingly lower ADT and different mix types. Of the 18 machine laid sections, only two were located in District 22. Thus, no valid conclusions can be reasonably drawn from the available data.

Regression Analysis. Extensive regression modeling was accomplished to examine any significant correlations between skid number and other variables for data groupings as shown in Table 20. Skid number was used as the dependent variable and the principal independent variables were age, ADT/Lane, accumulated traffic and surface texture (inner wheelpath).

The generalized regression model which was used had the following form:

$$Y_i = \beta_o + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_k X_{ik} + \varepsilon_i \quad \ldots\ldots(1)$$

where:

Y_i = dependent variable

$\beta_o, \beta_1, \ldots, \beta_k$ = regression parameters

$X_{i1}, X_{i2}, \ldots, X_{ik}$ = independent variables

ε_i = error term

and k ranged from 1 to a maximum of 4.

Table 25. Blade Laid and Machine Laid Construction Statistics for Limestone Rock Asphalt Cold Mix Pavement Sections

Type of Pavement Surface: Blade Laid LRA Cold Mixes

District (No. of Sections): 20(4), 21(3), 22 (30)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid Number_{40}	318	45.3	10.9	21.0	66.0	24.0
Age	37	6.9	4.2	1.0	16.0	60.4
Surface Texture (Inner Wheelpath)	37	0.032	0.017	0.0	0.088	53.7
Accumulated Traffic	36	2,327,250	3,116,920	140,000	14,100,000	133.9
ADT/lane	37	948	964	100	4480	101.7

Type of Pavement Surface: Machine Laid LRA Cold Mixes

District (No. of Sections): 20(7), 21(9), 22(2)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid Number_{40}	139	30.4	10.1	9.0	52.0	33.3
Age	18	4.8	1.5	2.0	8.0	31.9
Surface Texture (Inner Wheelpath)	18	0.025	0.010	0.010	0.045	40.1
Accumulated Traffic	18	3,289,444	2,562,117	643,000	11,440,000	77.9
ADT/lane	18	2046	1424	375	5500	69.6

Additionally confidence bands were used for selected regression equations for the whole regression line. This allows one to use a probability statement to see the region within which the regression line lies. The procedure used to do this was developed by Working and Hotelling (29). Specifically, this procedure allows for drawing conclusions about the mean response of skid number for any given level of ADT/Lane. The confidence coefficient is defined by the following probability statement:

$$P\ \{\hat{Y} - Ws(\hat{Y}_h) \leq \beta + \beta_1 X_h \leq \hat{Y}_h + Ws(\hat{Y}_h)\ \} = 1 - \alpha$$

where:

$\hat{Y}_h$ = point estimator of $E(Y_h)$ and is computed by $b_o + b_1 X_h$

($E\ (Y_h)$ is the skid number mean response when $X = X_h$)

$W = [2F(1-\alpha,2,n-2)]^{\frac{1}{2}}$

$s(\hat{Y}_h)$ = the estimated standard deviation of $\hat{Y}_h$ and is computed

by $[MSE\ [\frac{1}{n} + \frac{(X_h - \overline{X})^2}{\Sigma(X_i - \overline{X})^2}]]^{\frac{1}{2}}$

β_o, β_1 = regression parameters

The level of significance was selected to be 0.10 in the paper, thus the probability was 0.90 that the entire regression line would lie within the bands if a number of samples (with the same ADT/Lane levels) were taken.

Regression equations were primarily developed to 1) allow prediction of skid numbers for limestone rock asphalt cold mix surfaces, 2) obtain regression models which use independent variables easy to measure in the field.

In many cases the research team was reasonably successful in accomplishing this task.

For each pavement section surveyed approximately nine skid numbers were obtained. Thus, the regression analysis could be performed in two ways: using all skid numbers as the dependent variable for each section or using the average skid number for the section as one data point. Extensive modeling was performed using both techniques with the result being only small differences between the two types of regression equations obtained. It was decided to present only the equations developed using all skid number values since it is felt these are more representative of actual field conditions. Additionally, all variables used in each model were used with and without transformations. A transformation is composed of changing a variable by some factor such as multiplying by a logarithm. Thus two basic models were prepared for each grouping of data: nontransformed and transformed by common logarithms (base 10).

Tables B-2 and B-4 contain summaries of all consistent models for the various groupings of data. This summary identifies the type of pavement surface (data grouping), districts in which pavement sections are located, transformation type, regression coefficients, coefficient of determination (single or multiple), total degrees of freedom in the model and the number of independent variables used. The regression models developed after the addition of higher traffic level sections are not shown in these tables.

The independent variable regression coefficients for nontransformed models are used as multipliers for the actual independent variable data values. The intercept regression coefficient for nontransformed models is added to the sum of the products of the independent variables and regression coefficients. An example is Model Number 1 shown in Table B-2.

Model No. 1: $SN_{40} = 48.14 - 0.00565$ ADTLANE

where:

SN_{40} = Skid number @ 40 mph

ADTLANE = Average daily traffic per lane

The regression coefficients for the logarithm transformed models have a different form. Model Number 3 is shown as an example of the common logarithm transformation.

Model No. 3: $\log_{10} (SN_{40}) = 2.47 - 0.296 \log_{10}$ (ADTLANE)

To obtain skid number directly this model changes to the following form:

Model No. 3: $SN_{40} = 10^{2.47} (\text{ADTLANE})^{-0.296} = 295.12 (\text{ADTLANE})^{-0.296}$

Tables B-2 and B-4 present all obtained models in a condensed form.

The coefficient of determination (R^2) shown for each model represents the amount of reduction in the variation of skid number associated by the use of the independent variables. This value ranges between 1 and 0. An R^2 of 1 indicates the independent variables. As one might expect all of the developed regression equations have R^2 values falling between the two extremes.

The total degrees of freedom also shown in Tables B-2 and B-4 represent the number of skid numbers used to develop a given regression equation minus one.

Table 26 shows the "best" regression models selected from Tables B-2 and B-4 for each data grouping. Selection of the models in this table was based on four criteria: maximize R^2, minimize the number of independent variables, select models without the independent variable of surface texture whenever possible and select nontransformed single independent variable models to be fitted with confidence bands for presentation in specific figures. Referring to the third criterion, it is recognized that obtaining surface texture measurements on a given pavement can involve almost as much effort as obtaining actual skid numbers. Thus it was felt the use of surface texture as an estimator of skid number should be minimized. Although, as can be seen in Table 26, surface texture often provided the best regression model.

From the models with the highest R^2 values in each of the twenty data groupings in Table 26, ADT/Lane is the single best estimator of skid number appearing as the single independent variable nine times. The next most common single independent variable is surface texture - appearing twice. For models with two independent variables, the combination of ADT/Lane and surface texture appears six times and the accumulated traffic and surface texture combination appears once.

The R^2 of all twenty-four models range from a high of 0.85 to a low of 0.34 with the logarithm transformed models providing the best overall fit of the data in most cases. The range of the independent variables for these models should not in any case exceed the low and high values for any of the variables shown in Tables B-1 and B-3. This is important in that regression equations are only valid for the range of the variables used to develop the equations. Figures 13 and

Table 26. "Best" Regression Models for Various Groupings of Limestone Rock Asphalt Cold Mix Data.

Group Number and Description	"Best" Regression Model and R^2
1. All LRA Cold Mixes - All Three Districts (20, 21, 22)	$SN_{40} = 48.02 - 0.00662\ (ADTLANE)$ $R^2 = 0.43$
2. LRA Cold Mixes - Type A	$SN_{40} = 165.96\ (ADTLANE)^{-0.255}$ $R^2 = 0.34$ $SN_{40} = 954.99\ (SURTEX)^{0.400}(ADTLANE)^{-0.282}$ $R^2 = 0.58$
3. LRA Cold Mixes - Type B	$SN_{40} = 275.42\ (ADTLANE)^{-0.281}$ $R^2 = 0.67$
4. LRA Cold Mixes - Type C	$SN_{40} = 537.03\ (SURTEX)^{0.180}(ADTLANE)^{-0.281}$ $R^2 = 0.48$
5. LRA Cold Mixes - Type D	$SN_{40} = 181.97\ (ADTLANE)^{-0.229}$ $R^2 = 0.70$
6. LRA Cold Mixes Without Moderate or Severe Raveling	$SN_{40} = 316.23\ (ADTLANE)^{-0.306}$ $R^2 = 0.53$
7. LRA Cold Mixes With Moderate or Severe Raveling	$SN_{40} = 2570.40\ (SURTEX)^{0.544}(ADTLANE)^{-0.160}$ $R^2 = 0.71$
8. LRA Cold Mixes - Type C - District 22	$SN_{40} = 58.86 - 0.01210\ (ADTLANE)$ $R^2 = 0.61$
9. LRA Cold Mixes - Type CMOD - District 22	$SN_{40} = 57.61 - 0.00968\ (ADTLANE)$ $R^2 = 0.77$
10. LRA Cold Mixes - Type CC - District 22	No Appropriate Model
11. LRA Cold Mixes - Type CCMOD - District 22	No Appropriate Model
12. LRA Cold Mixes - Types C, D, CC, CMOD, CCMOD - District 22	$SN_{40} = 389.5\ (SURTEX)^{0.143}(ADTLANE)^{-0.245}$ $R^2 = 0.54$

TABLE 26. Continued

Group Number and Description	"Best" Regression Model and R^2
13. LRA Cold Mixes - Types D, CC, CMOD, CCMOD Districts 20 and 22	$SN_{40} = 199.53\ (ADTLANE)^{-0.231}$ $R^2 = 0.52$
14. LRA Cold Mixes Without Moderate or Severe Raveling - Type C - All Three Districts	$SN_{40} = 363.08\ (ADTLANE)^{-0.310}$ $R^2 = 0.51$
15. LRA Cold Mixes - Type A - District 20	$SN_{40} = 346.74\ (SURTEX)^{0.693}$ $R^2 = 0.85$
16. LRA Cold Mixes - Types A, B District 20	$SN_{40} = 229.09\ (SURTEX)^{0.580}$ $R^2 = 0.75$
17. LRA Cold Mixes - Types A, B, C, D - District 20	$SN_{40} = 112.20\ (ADTLANE)^{-0.176}$ $R^2 = 0.41$
18. LRA Cold Mixes - Type A - District 21	$SN_{40} = 2884.02\ (SURTEX)^{0.400}(ADTLANE)^{-0.443}$ $R^2 = 0.79$
19. LRA Cold Mixes - Types A, B - District 21	$SN_{40} = 3630.78\ (SURTEX)^{0.452}(ADTLANE)^{-0.446}$ $R^2 = 0.59$
20. LRA Cold Mixes - Types A, B, C - District 21	$SN_{40} = 4365.16\ (SURTEX)^{0.473}(ADTLANE)^{-0.451}$ $R^2 = 0.65$

17 are used to represent the regression equation relationships between skid number and the independent variables.

Figure 13 is a plot of five regression equations for various types of limestone rock asphalt cold mix types. At the lower ADT/Lane levels there are significant differences between skid numbers. Type C mixes in District 22 have high skid numbers for ADT/Lane values ranging from 500 to 1000 vehicles per day. On the other extreme Type A mixes have low skid numbers for ADT/Lane values of about 1000 vehicles per day. All other mix types fall between the two extremes. It is of interest to note that only a nine skid number difference separates Type A and C mixes at a ADT/Lane level of 4000 vehicles per day. This indicates that although significant differences occur between the two types for low traffic levels they tend to converge at high traffic levels.

Figure 14 is a plot of skid number versus ADT/Lane for Types C and CMOD mixes in District 22. The curves indicate Type CMOD mixes tend to have slightly lower skid numbers at low traffic levels than do Type C mixes with just the opposite being true at high traffic levels. Although with the small differences between the two at the higher traffic levels and the inherent error in the regression equations, no firm conclusions should be made as to whether one type performs better with respect to skid resistance than another.

Again referring to Figure 13, Type B mixes exhibit superior skid performance when compared to Type A mixes by a difference of seven to nine skid numbers depending on the traffic level. But in Figure 15, a plot of skid number versus surface texture, regression equations are plotted for Type A and Type A and B mix data combined. The result is that both regression equations plot on top of each other. This indicates that for the range of surface textures studied no significant

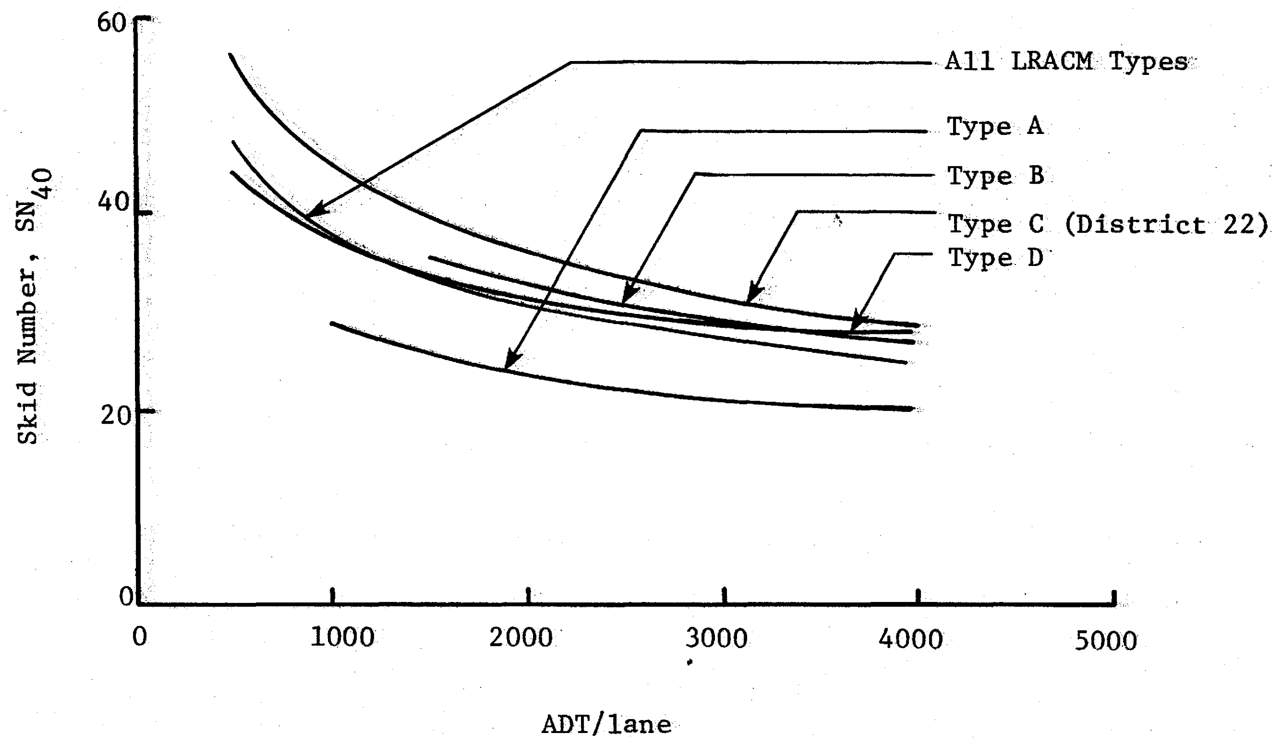

Figure 13. Skid Number versus ADT/lane - Limestone Rock Asphalt Cold Mixes for All Mix Types, Type A, Type B, Type C and Type D

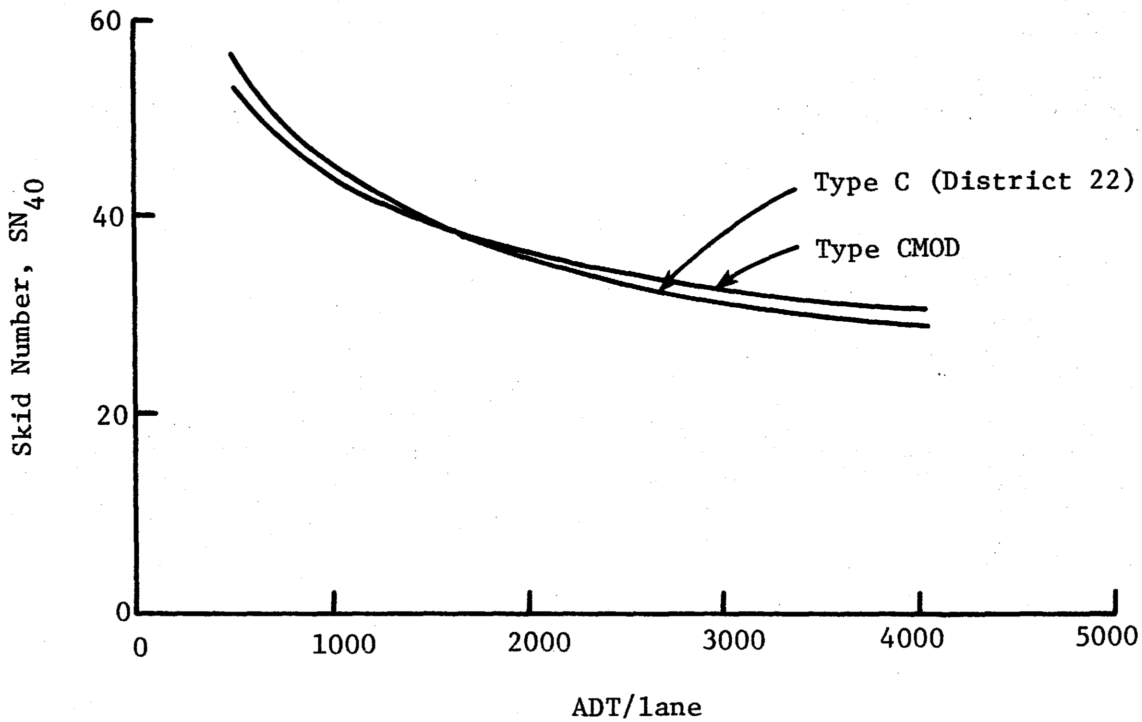

Figure 14. Skid Number versus ADT/lane - Limestone Rock Asphalt Cold Mixes for Type C (District 22), Type CMOD

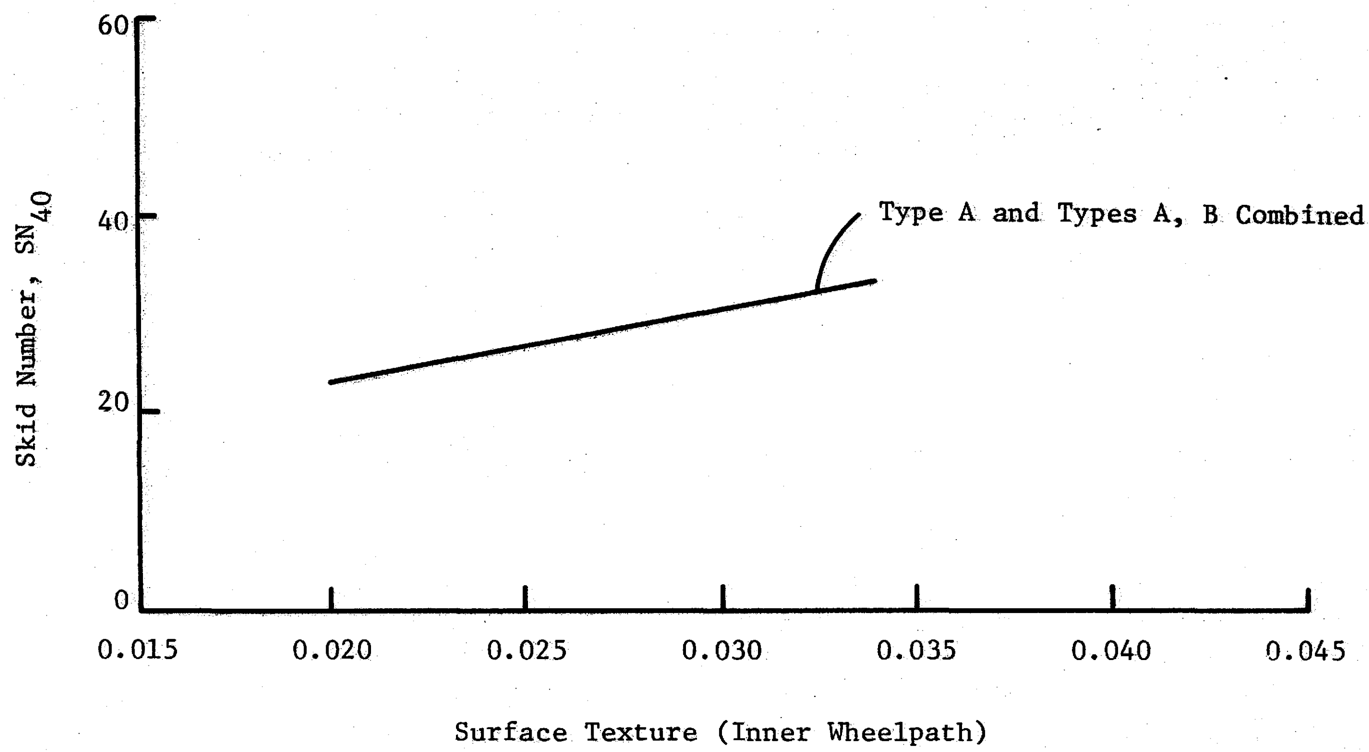

Figure 15. Skid Number versus Surface Texture - Limestone Rock Asphalt Cold Mixes for Type A and Type A, B Data Groups - District 20

difference exists between the two mixes. This presumably indicates that surface texture does not account for the real differences in skid number that do exist between these two cold mix types.

Figure 16 shows a plot of skid number and ADT/Lane for all mix types and Type C both without the distress manifestation of moderate or severe raveling. By additionally referring to Figure 13, Table 21, and previous narrative in this section, it can be observed that moderate or severe raveling appears to slightly increase skid resistance - particularly for Type C mixes. This does not mean that raveling of cold mixes is "good" - only that some raveling may slightly enhance the skid resistance of such surfaces.

Figure 17 is used to again compare Type A and C mixes - the poorest and the best skid performing mixes studied. The regression equations are plotted as a function of skid number, ADT/Lane and surface texture. As should be expected the skid number increases as the surface texture is increased. Of interest is that skid numbers for Type C mixes do not appear to be as sensitive to different levels of surface texture as do Type A mixes. This may be of significance in that Type A mixes are expected to be more susceptible to polishing due to the larger aggregate sizes. Thus, polishing and the corresponding changes in surface texture can be expected to adversely effect skid resistance for Type A mixes more than for Type C mixes.

To summarize this section on limestone rock asphalt cold mixes Figures 24, 25 and 26 are presented. Figure 24 is a regression plot of skid number versus ADT/Lane for the Type CMOD mixes in District 22 and Figure 25 is the same kind of plot except for Type C mixes in District 22. On both of these figures the 90 percent confidence bands

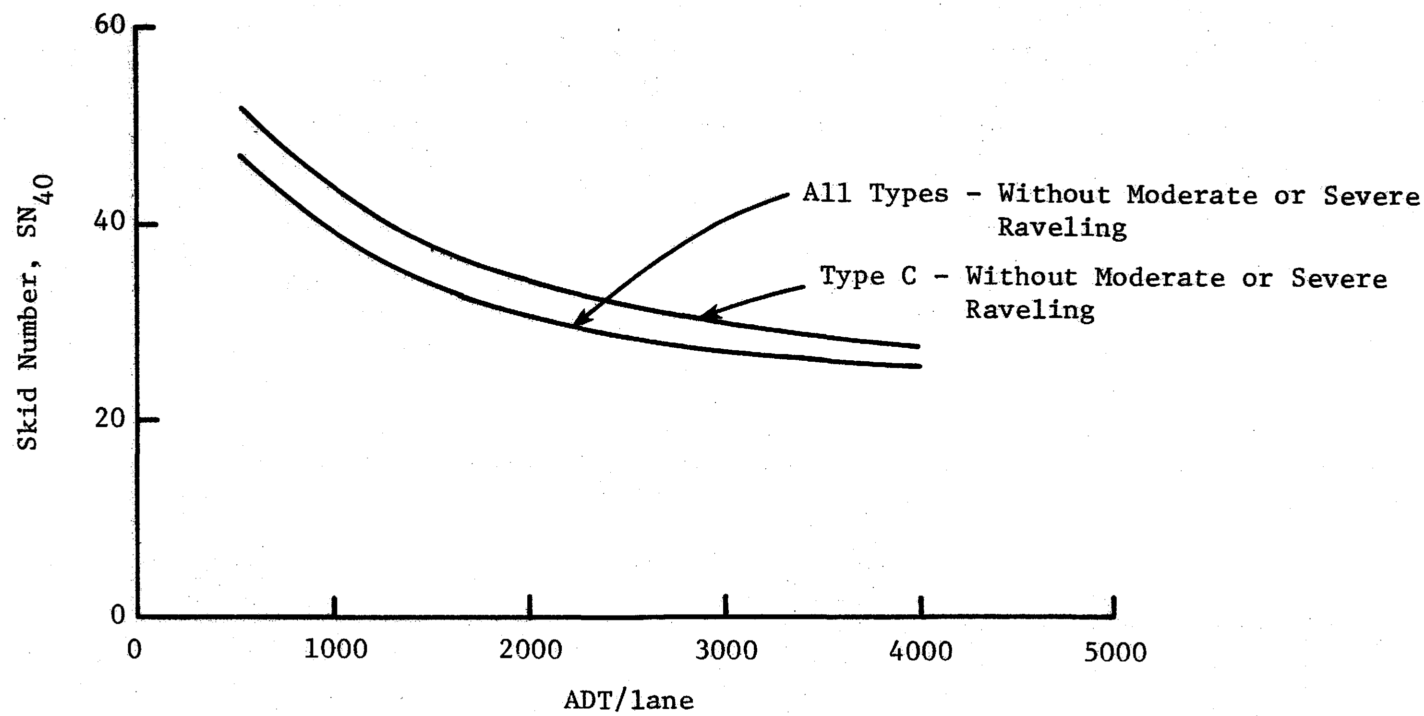

Figure 16. Skid Number versus ADT/lane - Limestone Rock Asphalt Cold Mixes Without Moderate or Severe Raveling

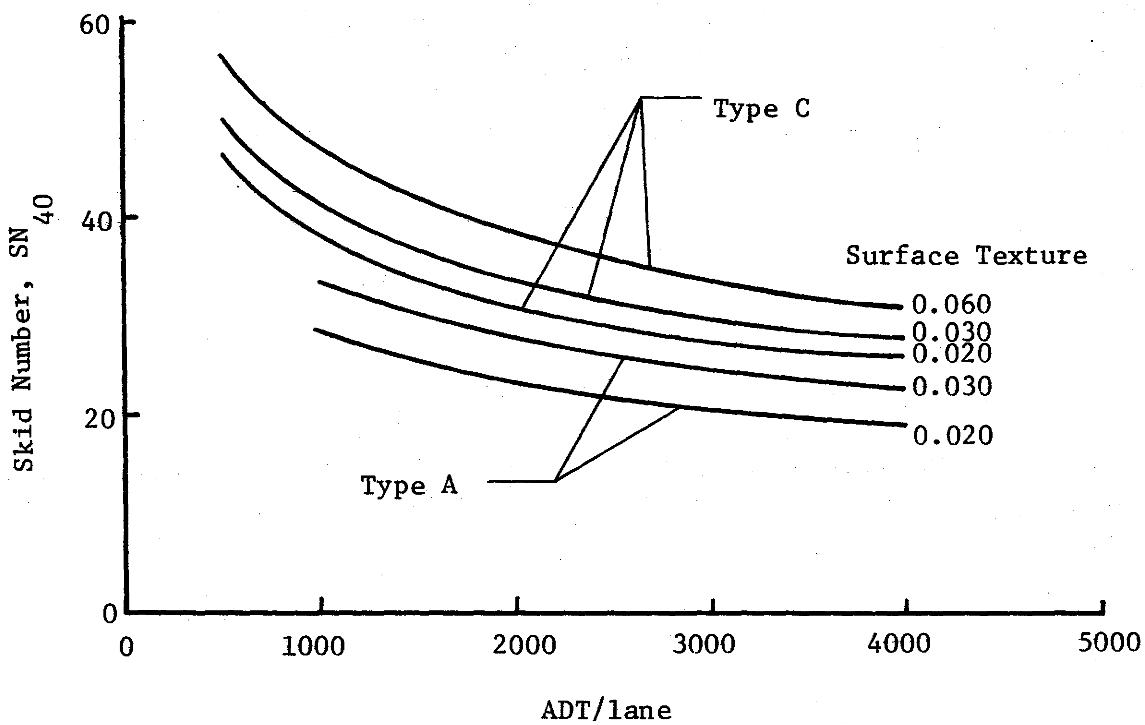

Figure 17. Skid Number versus ADT/lane - Limestone Rock Asphalt Cold Mixes for Types A and C using Two Levels of Surface Texture.

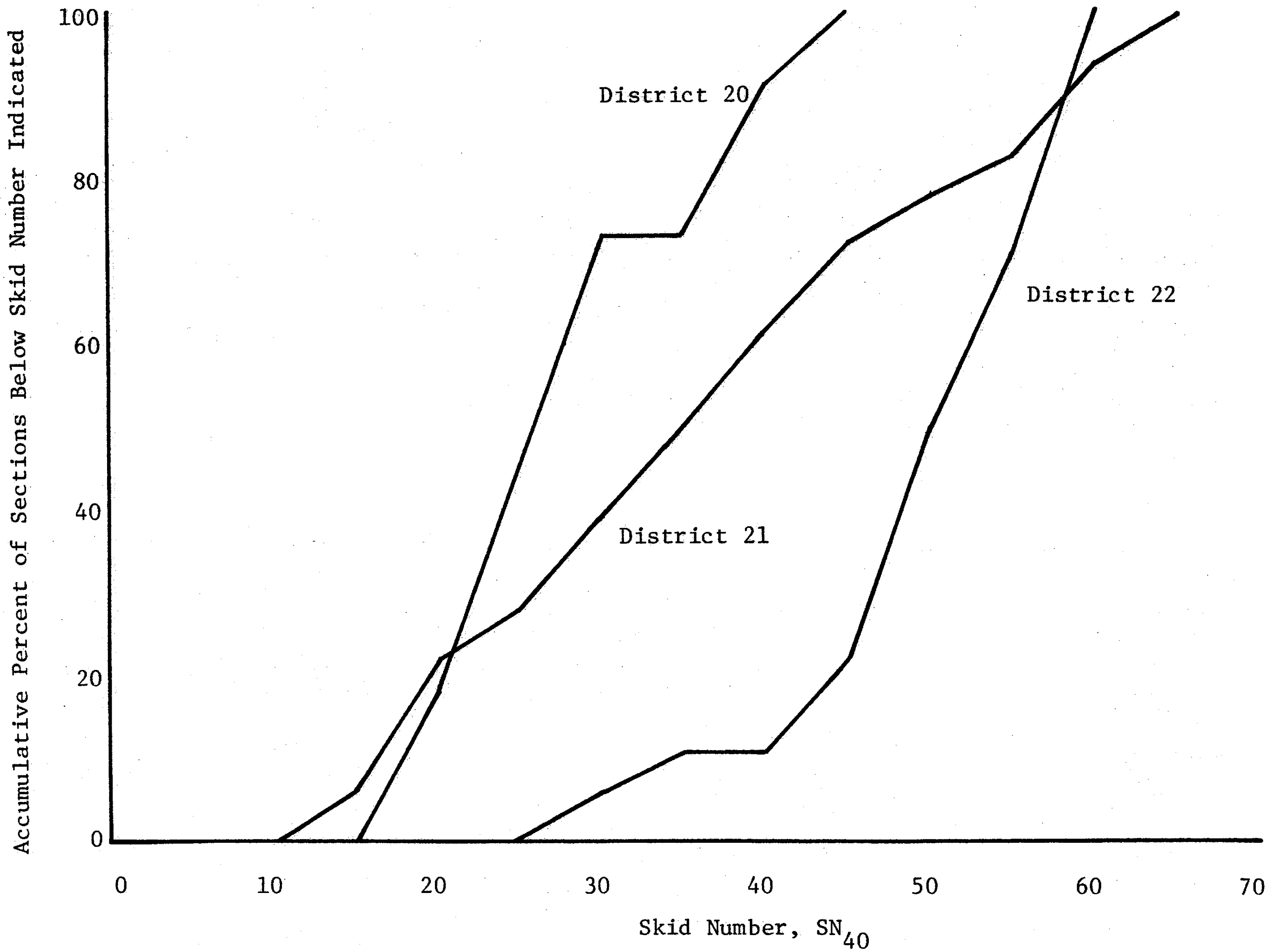

Figure 18. Distribution of Skid Number for Seal Coats in Various Districts.

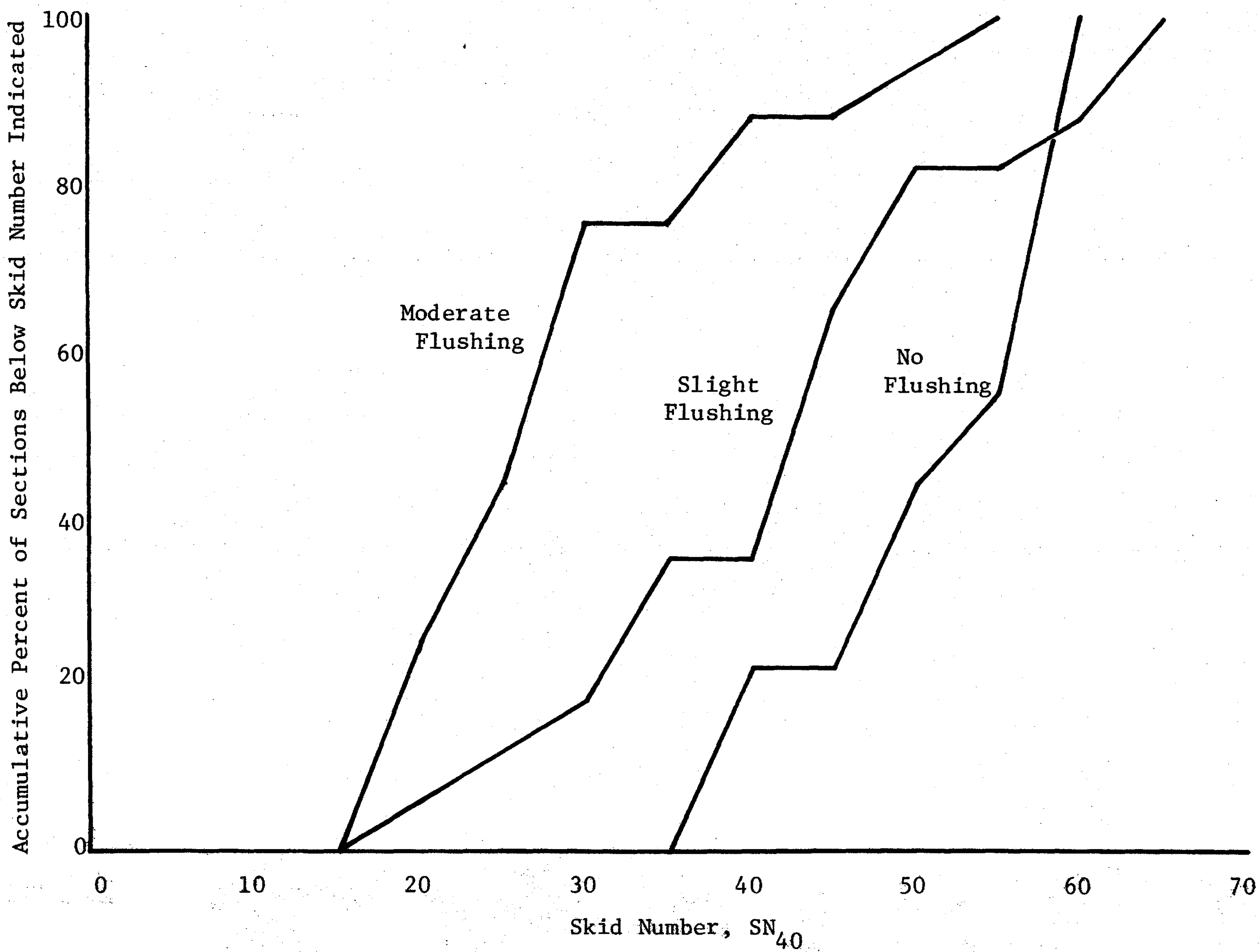

Figure 19. Distribution of Skid Number for Seal Coats with Various Degrees of Flushing.

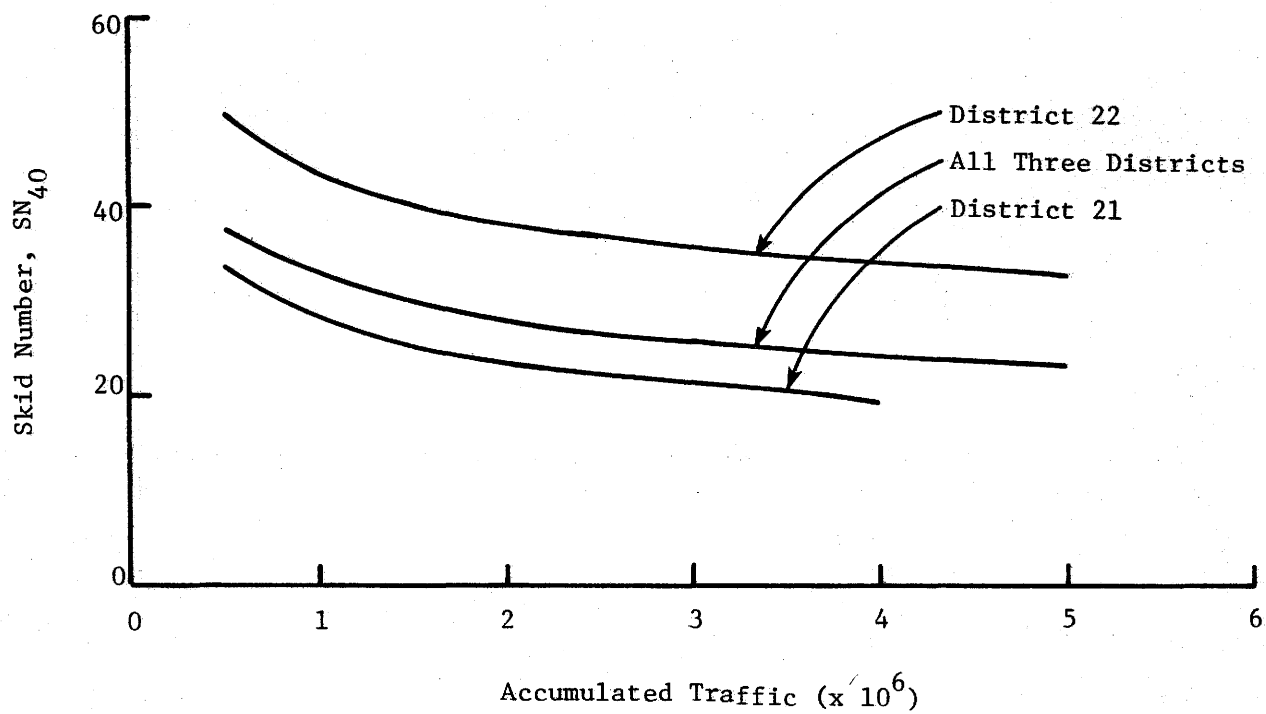

Figure 20. Skid Number versus Accumulated Traffic - Limestone Rock Asphalt Seal Coats for All Three Districts, District 21, and District 22

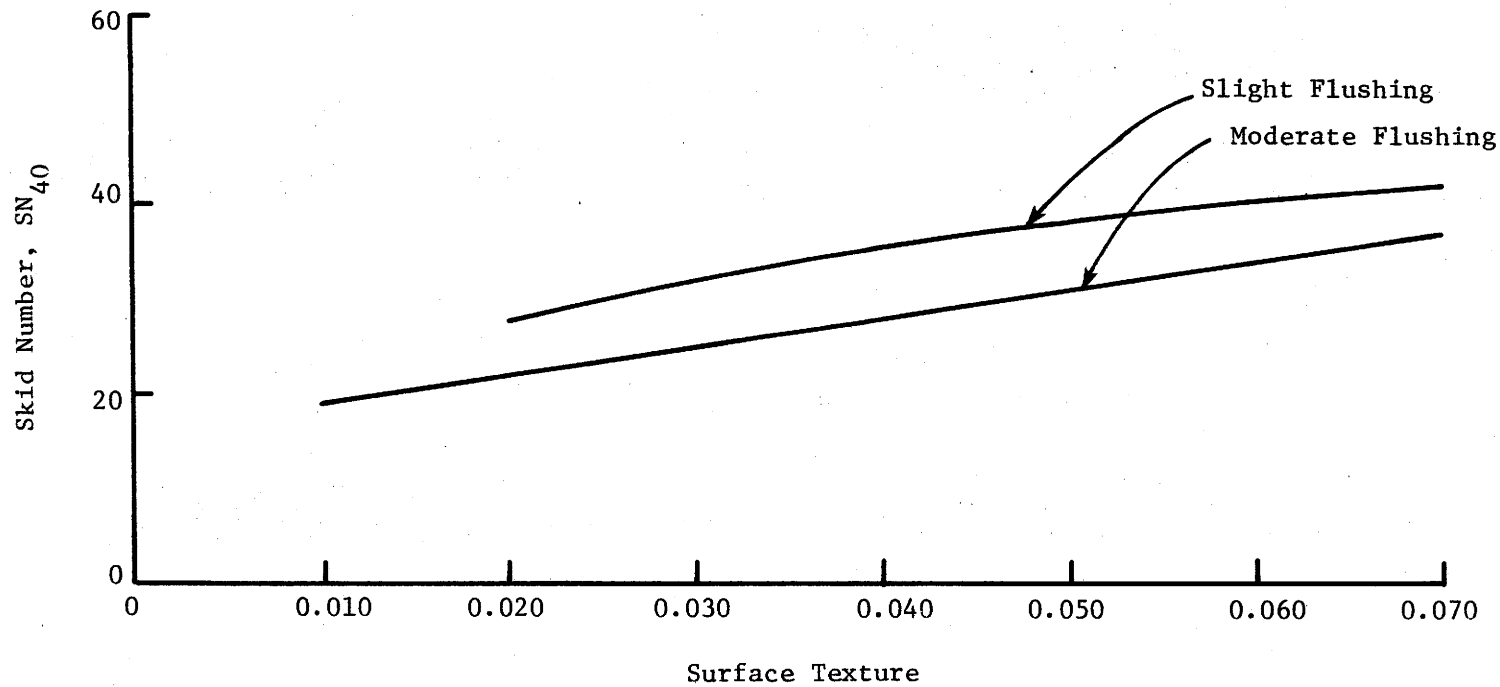

Figure 21. Skid Number Versus Surface Texture - Limestone Rock Asphalt Seal Coats for Slight and Moderate Flushing

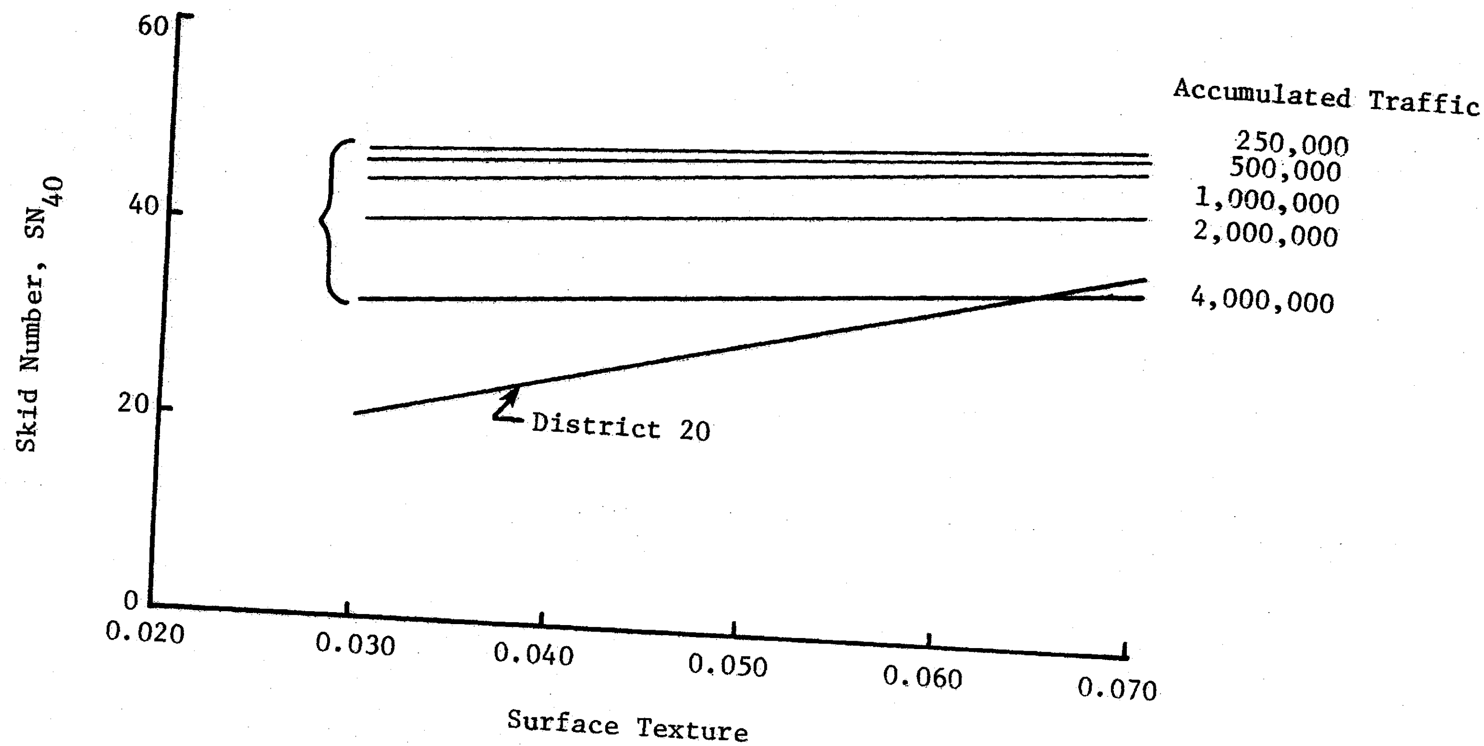

Figure 22. Skid Number versus Surface Texture for Various Levels of Accumulated Traffic Limestone Rock Asphalt Seal Coats in District 20 and 22

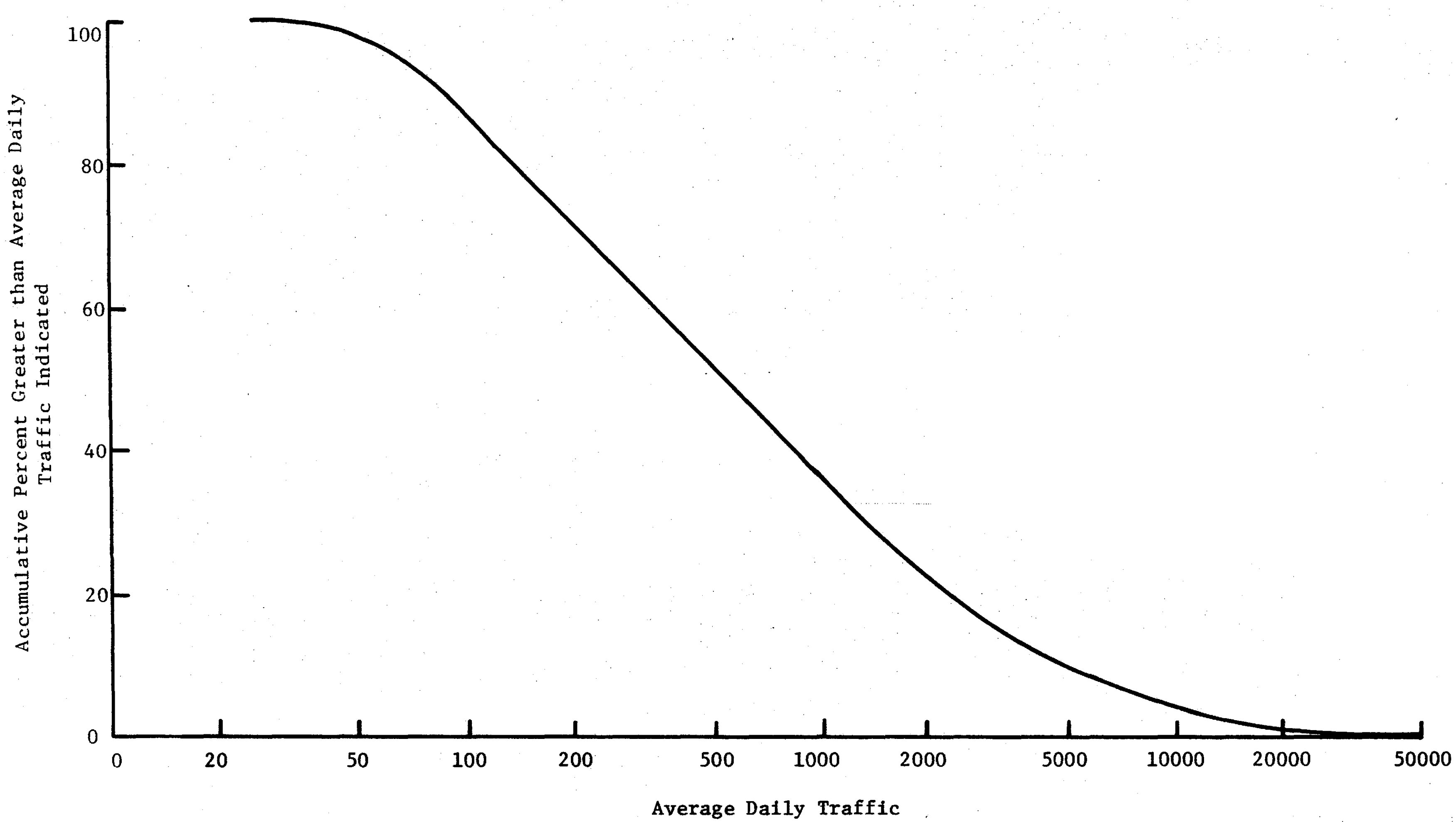

Figure 23. **Rural and Urban Road Mileage for Various Average Daily Traffic Volumes**

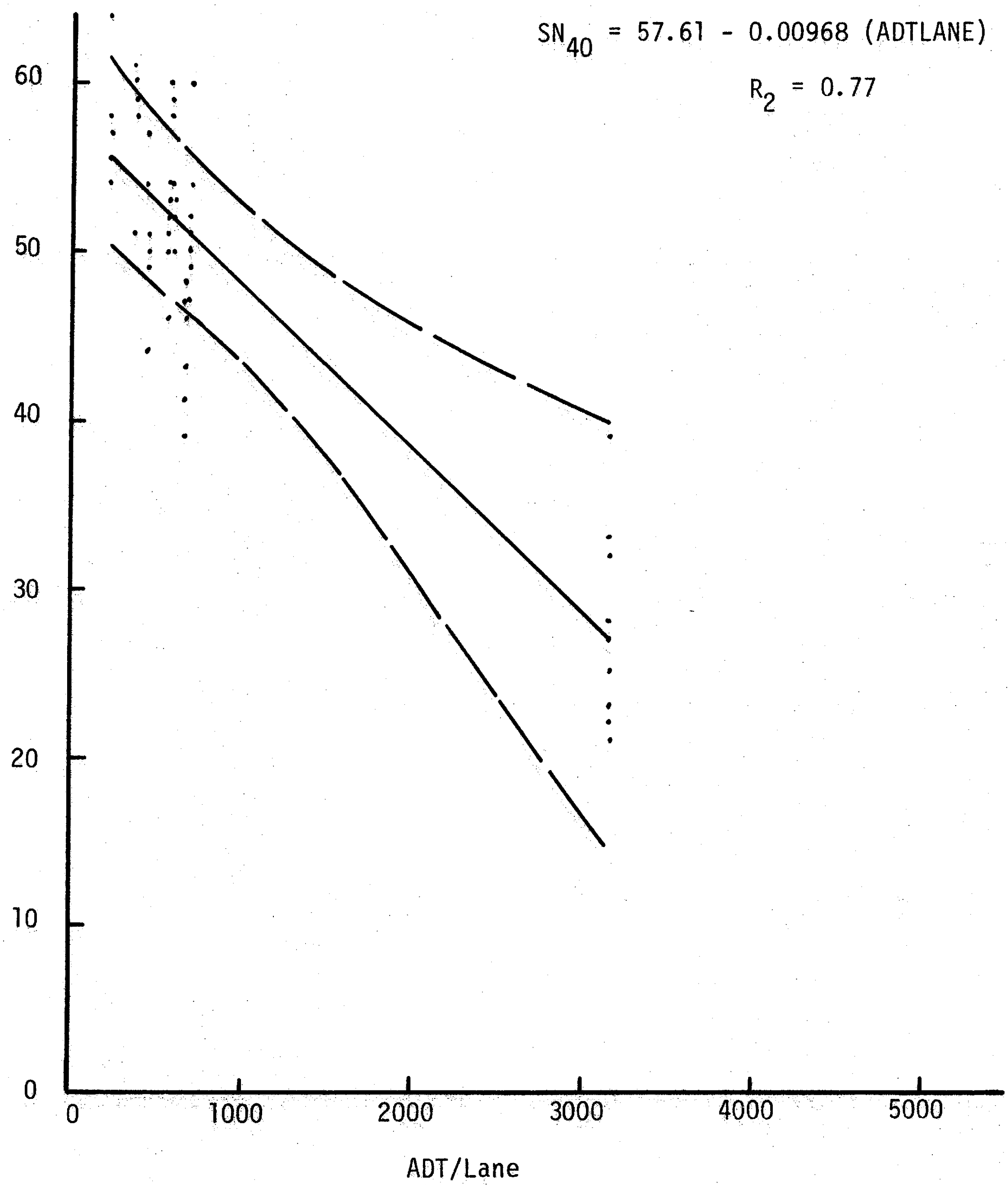

Figure 24. Skid Number versus ADT/Lane for Limestone Rock Asphalt Type CMOD Cold Mixes in District 22 with 90 % Confidence Bands for the Regression Equation.

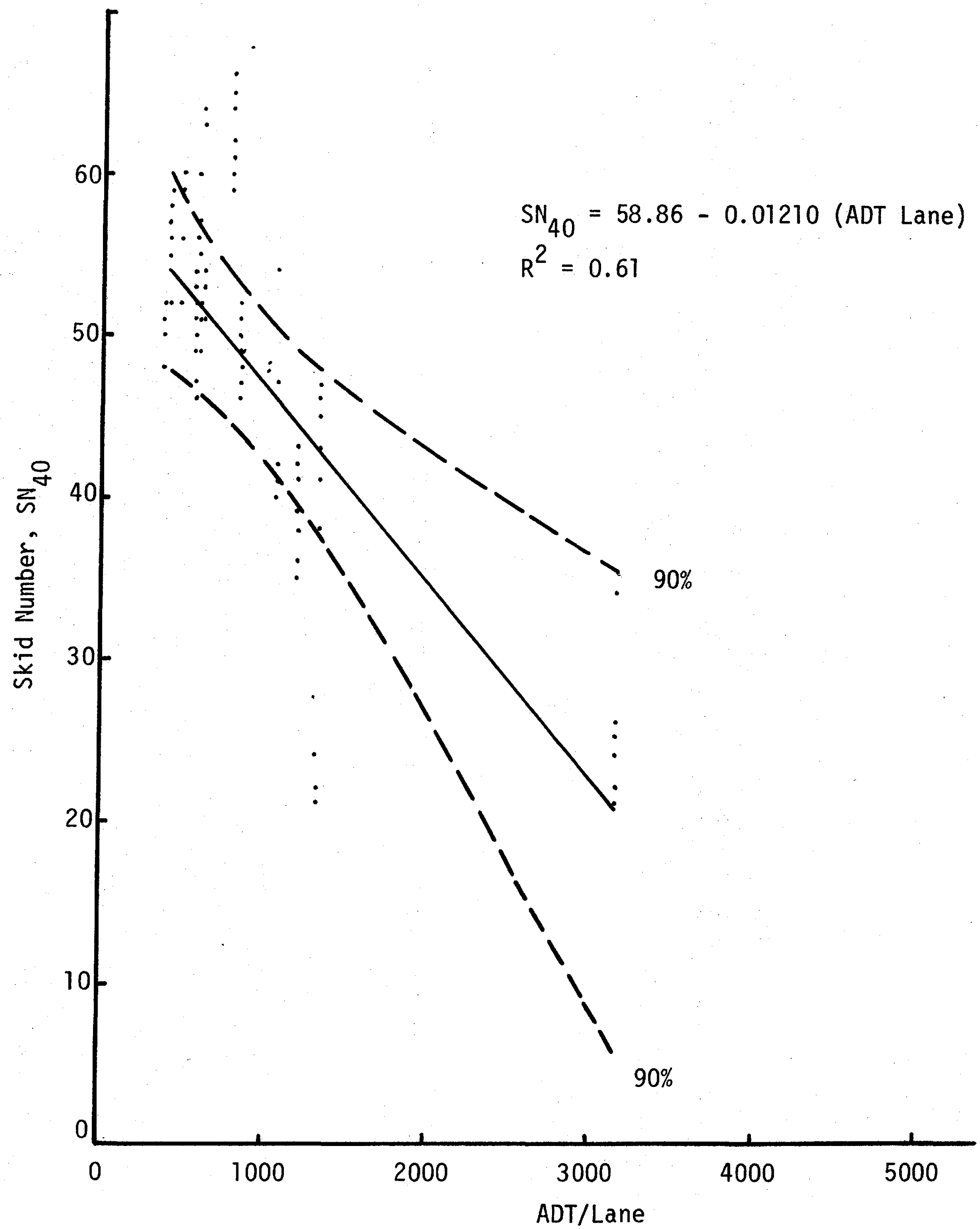

Figure 25. Skid Number versus ADT/Lane for Limestone Rock Asphalt Type C Cold Mixes in District 22 with 90 Percent Confidence Bands for the Regression Equation.

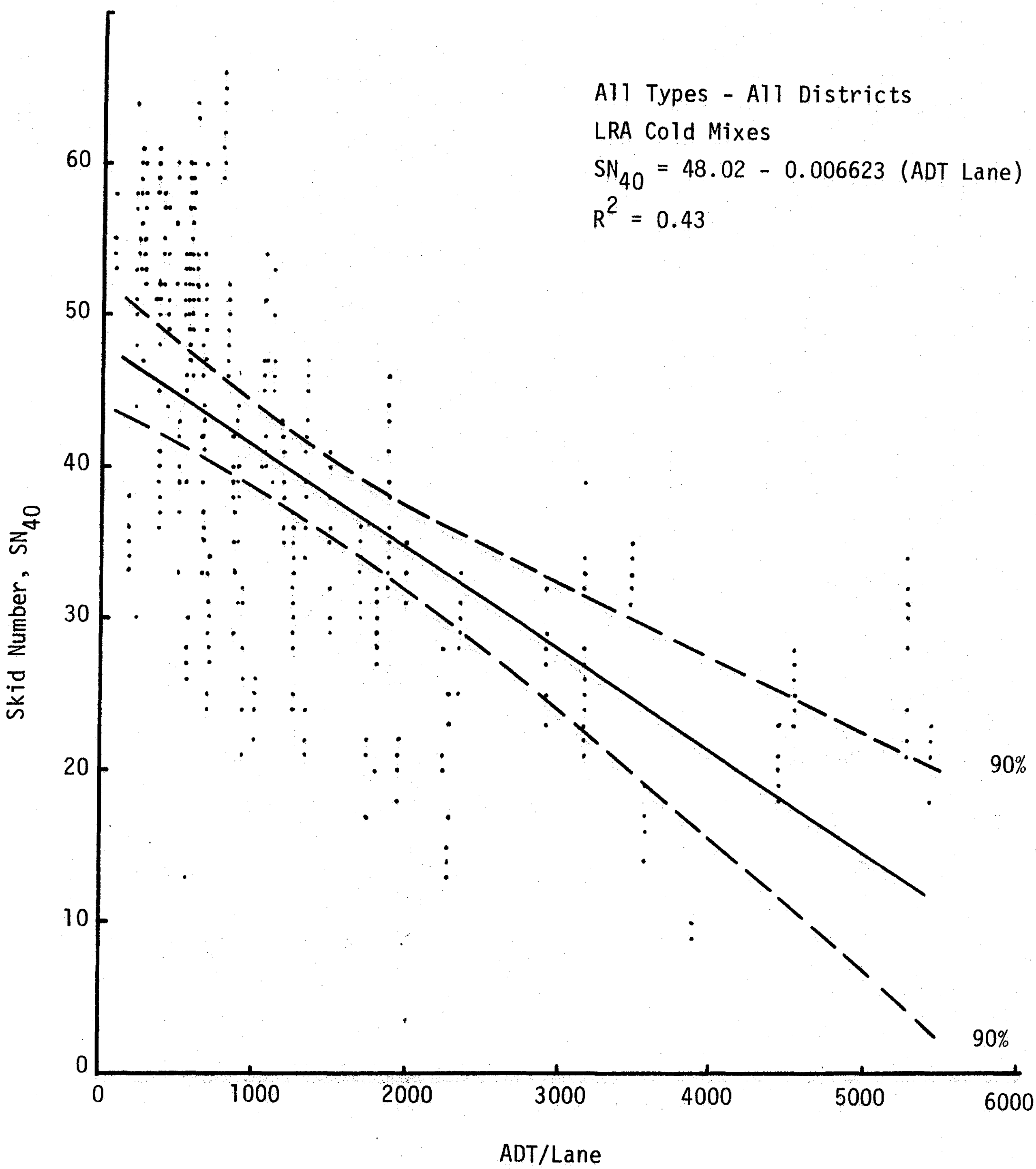

Figure 26. Skid Number versus ADT/Lane for "Good" to "Average" Limestone Rock Asphalt Cold Mixes with 90 Percent Confidence Bands for the Regression Equation.

are shown as the dashed curves. These confidence bands indicate the range of mean skid number to be expected with a 90 percent confidence (28, 29). Use of confidence bands with regression equations safeguard against making inferences which do not account for the variability in the data used to generate the equations. Figure 24 indicates what can be considered near optimal conditions and using the lower 90 percent curve that an average skid number of 35 can be expected for an ADT/Lane value of 1700 or less. Use of the regression equation alone indicates that an ADT/Lane of 2300 or less results in an expected skid number of 35. Figure 25 represents the Type C cold mixes in District 22 which also performed well with respect to skid resistance. Again using the lower 90 percent curve, an average skid number of 35 can be expected for an ADT/Lane value of about 1500 or less. The limiting ADT/Lane level by use of the regression equation alone is approximately 2000 or less. Thus by using these two figures, an average skid number of 35 or greater can be expected for ADT/Lane levels ranging from 2500 to 2000 or less with 90 percent confidence. These values of ADT/Lane represent about the "best" that can be expected with respect to skid number.

Figure 26 is a regression plot representing data for all cold mix types in the three districts. It is felt this case represents a "good" to "average" skid resistance condition for the pavement sections in this grouping are various kinds of Type C mixes which are primarily located in District 22. Thus the regression equation and corresponding confidence bands represent a number of pavement sections which exhibited good skid performance. Using the lower 90 percent confidence band, an average skid number of 35 can be expected for an

ADT/Lane value of 1550 or less. The limiting ADT/Lane level by use of the regression equation alone is approximately 2000 or less.

The three regression models had R^2 values ranging from 0.77 to 0.43. Thus, 77 to 43 percent of the observed variation in the skid numbers was explained by ADT/Lane - the independent variable. Considering that R^2 values of this size were achieved with only one independent variable, the models are felt to be reasonable and useful.

The standard deviation of these three regression models is also of interest. These values represent the standard deviation of the dependent variable (SN_{40}) for any value of the independent variable (ADT/Lane). This is sometimes referred to as the root mean square error (RMSE). The RMSE ranged from a high of 9.7 skid numbers to a low of 4.8 with the higher RMSE value associated with the lower R^2.

The F values calculated for these models ranged from a high of 400 to a low of 172. These F values strongly indicate that the hypothesis stating the regression coefficient for ADT/Lane is not zero be accepted. This is another way of verifying that a statistical relationship between SN_{40} and ADT/Lane exists.

Caution should be used if making conclusions based on results shown in Figures 24 and 26. This occurs because age is not considered in the regression equations and was not a significant independent variable in the vast majority of the models attempted. It is reasonable that any given pavement surface may be able to sustain high traffic levels with "safe" skid resistance for a short time but not over its full life. Thus, the age of the surface should be considered. The average age for the Type C and CMOD cold mixes (Figures 24 and 25) was about eight years, and all cold mix types combined (Figure 26) about six years. Fortunately, these average ages exceed the normal survival time for similar Texas pavement surfaces (based on published data developed by the authors). If the expected survival times are to exceed the average age for the cold mixes, then conclusions drawn from the models about the maximum ADT/Lane which would provide acceptable skid numbers may be invalid.

All of the regression equations developed in this study can only in a general way represent actual data trends. The more data used to develop such equations generally enhances the validity of the equations. In this study a number of the equations are based on data obtained from relatively few pavement sections and thus improvement could be made if more data are made available. If additional data do not become available at a future date then those equations presented in this report will suffice.

Seal Coats

Many of the same factors which affected the skid resistance of limestone rock asphalt cold mixes also affect limestone rock asphalt seal coats. The primary factors studied are: effects due to different districts, specification types, amount of flushing, age, surface texture, ADT/Lane and accumulated traffic.

The analysis follows the same steps as was done for cold mixes. This includes an examination of general statistics and regression modeling for subgroups of seal coat data. Additional skid data will also be summarized to help compare limestone rock asphalt seal coats to other surface types and levels of traffic.

Table 27 shows the eleven different data groups and the number of pavement sections contained in each. A total of 50 pavement sections

Table 27. Grouping of Limestone Rock Asphalt Seal Coat Data

Group Number and Description	Number of Pavement Sections in Group
1. All LRA Seal Coats - All Districts	58
2. LRA Seal Coats - District 20	11
3. LRA Seal Coats - District 21	19
4. LRA Seal Coats - District 22	15
5. LRA Seal Coats Without Flushing	10
6. LRA Seal Coats With Slight Flushing	17
7. LRA Seal Coats With Moderate Flushing	16
8. LRA Seal Coats - None to Slight Flushing	27
9. LRA Seal Coats - None to Slight Flushing District 22	11
10. LRA Seal Coats - Item 304 Type PB Grade 4	13
11. LRA Seal Coats - Item 302 Type B Grade 4	7

surfaced with limestone rock asphalt seal coats were evaluated with fewer numbers of pavement sections being used in the remianing data groups.

A total of twelve separate variables were considered in examining skid number trends for limestone rock asphalt seal coats. These variables were the same as considered for cold mixes but excluded the following: bitumen in minus No. 10 fraction, percent white rock and percent bitumen in white rock. The variables of age, surface texture, accumulated traffic and ADT/Lane were selected for primary study. Of the remaining eight variables (material retained 5/8 inch sieve through percent average bitumen), none proved to be a significant indicator of skid resistance. The general statistics for the eight variables deleted from further study are shown in Table B-6.

General Statistics. Table 28 is a summary of the means obtained for each data group. More detailed tables containing this information can be found in Table B-3. The means shown in the tables are for the following basic variables (same as used for limestone rock asphalt cold mixes): skid number, age, average daily traffic per lane (ADT/Lane), accumulated traffic and surface texture (inner wheelpath). How these individual variables were obtained was previously discussed.

Comparing mean skid numbers for the eleven data groupings, seal coats, without flushing has the highest value at 48.9. The next highest data grouping is District 22 seals with none to slight flushing. The lowest mean skid numbers are shown for seals in District 20 and seals with moderate flushing at 26.5 and 26.8, respectively, the remaining data groups fall between these two extremes. Additionally

Table 28. Summarized Means for Various Groupings of Limestone Rock Asphalt Seal Coats

Data Grouping	Means				
	SN_{40}	Age	ADT/lane	Accumulated Traffic	Surface Texture
All LRA Seal Coats	34.7	4.0	1,415	2,304,500	0.054
District 20	26.5	4.5	1,267	1,770,000	0.044
District 21	36.1	4.0	975	906,300	0.051
District 22	46.9	3.7	995	1,277,100	0.065
Without Flushing	48.9	4.1	866	550,500	0.075
With Slight Flushing	40.5	4.0	969	1,112,400	0.061
With Moderate Flushing	26.8	4.1	1,263	1,838,600	0.035
None to Slight Flushing	43.6	4.0	931	904,300	0.067
None to Slight Flushing - District 22	48.4	3.3	947	978,200	0.067
Item 304, Type PB Grade 4	35.6	2.2	1,432	942,800	0.051
Item 302, Type B Grade 4	42.1	3.4	1,012	1,189,900	0.062

the overall mean skid number for all pavement sections surveyed in all districts is 34.7. This value is about five numbers less than for all cold mixes surveyed in the study.

A comparison of the three districts shows that seal coats in District 20 exhibit the lowest skid number and District 22 the highest with the difference being slightly over twenty skid numbers. The same trend can be seen more graphically in Figure 18 which is a plot of skid number versus cumulative frequency for the three districts. The mean ages for Districts 20 and 22 are approximately the same but the ADT/Lane for District 20 is about twenty-seven percent greater than that reported for District 22. Additionally, the surface texture is shown to be approximately one-third less for District 20 when compared to District 22. Possibly the single most important factor contributing to the low mean skid number observed for District 20 is that nine of the eleven pavement sections surveyed exhibited the distress manifestation of moderate flushing. A graphical representation of this trend can be seen in Figure 19. The data used to produce these means may be biased in that the number of pavement sections in each of the three districts is not uniform. For example, the majority (9 out of 16) of the moderately flushed sections were located in District 20 which has the lowest overall mean skid number of the three districts comapred. The difference in ADT/Lane between the three data groups is a maximum of about 400 vehicles per day - a relatively small difference. As would be expected the surface texture steadily decreases with increasing flushing. Overall, it appears that flushing of limestone rock asphalt seal coats can significantly reduce skid resistance.

The data groups for all sections, all districts and District 22 with none to slight flushing are also of interest. By eliminating pavement sections with moderate or severe flushing the mean skid numbers are increased by six skid numbers for all districts combined and about two skid numbers for District 22. Thus, if limestone rock asphalt seal coats are constructed and maintained in such a way as to preclude moderate or severe flushing, then the skid resistance of these surface types will in most cases be increased.

A comparison of two of the specifications used by the SDHPT for limestone rock asphalt seal coats is presented. The two seal coat specifications examined are: Item 304, Type PB, Grade 4 and Item 302, Type B, Grade 4. The data contained in Table 28 indicates Item 302, Type B, Grade 4 exhibit superior skid performance when compared to the other specification type. No conclusions should be drawn from these data because the severity of flushing for the two groups of data vary. Thirty-eight percent of the Item 304, Type PB, Grade 4 pavement sections had moderate flushing while the Item 302, Type B, Grade 4 pavement sections had only 14 percent. As was previously discussed, moderate flushing in the wheelpaths can significantly influence skid resistance.

To further examine the differences in skid number which may exist between the major types of limestone rock asphalt seal coats a separation of "high traffic" and "low traffic" levels was made as was done for the cold mixes. The resulting data is shown in Table 29. The goal was to see if the skid numbers for the seal coats in the three districts studied varied significantly with traffic.

For District 20 the mean skid number at the high and low traffic levels is consistently low - averaging about 26.0. These mean values are influenced by the moderate flushing present on the pavement sections

Table 29. Effect of High/Low Average Daily Traffic Per Lane on LRA Seal Coats in Districts 20, 21, and 22

High Traffic Level
(≥ 1500 ADT/lane)

District	Mean			Number of Sections
	SN_{40}	Age	ADT/Lane	
20	22.2	3.8	2130	4
21	34.8	1.6	2234	5
22	37.3	3.3	2167	3

Low Traffic Level
(< 1500 ADT/lane)

District	Mean			Number of Sections
	SN_{40}	Age	ADT/Lane	
20	28.9	4.9	774	7
21	36.5	4.9	525	14
22	49.7	3.8	676	11

studied in this district. For District 21 the same trend occurs but the overall mean skid number is higher than reported for District 20 and is about 35.0. Of special note is the age of the five sections used to compute the high traffic level statistics for District 21. This age is only 1.6 years which is significantly less than that reported for all districts, all traffic levels. Finally, the mean skid numbers for the two traffic levels in District 22 do vary by about twelve skid numbers. This tends to show that increased traffic can be expected to decrease skid resistance for limestone rock asphalt seal costs in this district; although firm conclusions must be carefully made due to the fact that the statistics computed are based on very small sample sizes.

Additional skid information available about other pavement surface types in Districts 20 and 21 was previously shown in Tables 23 and 24. Table 23 indicates an overall mean skid number of 35.9 for all types of seal coats in District 20 and 33.7 for District 21. Thus, District 21 limestone rock asphalt seal coats, based on the sections in the study, compare favorably to the district wide average - actually about two skid numbers higher. The District 20 limestone rock asphalt seal coats, which have an overall mean of 26.5 based on the study sections, do not compare favorably with the district wide average for all seal coats. The limestone rock asphalt seals are approximately nine skid numbers less.

Table 30 shows a rearrangement of the data shown in Tables 23 and 24 and indicates the influence of high and low traffic levels on hot mix asphalt concrete and seal coats. For all seal coats in District 20 and 21 a drop of about four skid numbers is shown when the mean ADT

Table 30. Effect of High/Low Average Daily Traffic on HMAC and Surface Treatment/Seal Coat Surfaces in Districts 20 and 21 (Based on Available SDHPT Skid Summaries)

High Traffic Level
(≥ 3000 ADT)

District	Type Surface	Mean			Number of Sections*
		SN_{40}	Age	ADT	
20	HMAC	33.2	4.2	10,102	84
21	HMAC	27.0	5.7	9,724	173
20	ST/SC	34.1	4.1	6,307	38
21	ST/SC	30.4	3.1	6,240	42

Low Traffic Level
(< 3000 ADT)

District	Type Surface	Mean			Number of Sections*
		SN_{40}	Age	ADT	
20	HMAC	34.5	5.6	1,987	31
21	HMAC	30.7	6.9	1,670	48
20	ST/SC	36.7	5.4	988	277
21	ST/SC	34.0	5.4	743	275

*Refers to the number of construction sections used to produce the mean values.

increases from a range of 700 - 1,000 to 6,200 - 7,000 vehicles per day. This decrease in skid number is slightly more than observed for District 20; although, the ADT for all seal coat types was higher which can account for the variation.

Regression Analysis. Extensive regression modeling was accomplished (similar to that done for the cold mixes) to examine the existence of any significant correlations between skid number and other variables in the data groupings as shown in Table 27. Skid number was used as the dependent variable and the principal independent variables were age, ADT/Lane, accumulated traffic and surface texture (inner wheelpath). Table B-4 contains a summary of all consistent regression models for the various groupings of data. Table 31 contains the "best" regression models selected from Table B-4. The criteria used to select the models were the same as used for the limestone rock asphalt cold mixes.

From the models with the highest R^2 values in each of the eleven data groupings in Table 31, surface texture is the single best estimator of skid number appearing as the single independent variable twice. For models with two independent variables, the combination of surface texture and accumulated traffic appears six times. Singularly or in combination the variable of age, ADT/Lane and accumulative traffic compose the remaining models. The R^2 for all seventeen models range from a high of 0.79 to a low of 0.25 with the logarithm transformed models providing the best overall fit of the data in most cases. Figures 20 through 22 show how the regression equations can be used to represent the relationships between skid number and the independent variables.

Figure 20 is a plot of three regression equations for limestone rock asphalt seal coats in all three districts, District 21 and District

TABLE 31. "Best" Regression Models for Various Groupings of Limestone Rock Asphalt Seal Coats

Group Number and Description	"Best Regression Model and R^2
1. All LRA Seal Coats - All Three Districts (20, 21, 22)	$SN_{40} = 602.56\ (SURTEX)^{0.258}(ACCTRAF)^{-0.151}$ $R^2 = 0.45$ $SN_{40} = 588.84\ (ACCTRAF)^{-0.210}$ $R^2 = 0.25$
2. LRA Seal Coats - District 20	$SN_{40} = 6.88 + 452.14\ (SURTEX)$ $R^2 = 0.54$
3. LRA Seal Coats - District 21	$SN_{40} = 1318.25\ (SURTEX)^{0.279}(ADTLANE)^{-0.212}$ $R^2 = 0.63$ $SN_{40} = 1000.00\ (ACCTRAF)^{-0.259}$ $R^2 = 0.31$
4. LRA Seal Coats - District 22	$SN_{40} = 45.96 + 100.08(SURTEX) - 0.00000420\ (ACCTRAF)$ $R^2 = 0.70$ $SN_{40} = 52.23 - 0.00000339\ (ACCTRAF)$ $R^2 = 0.41$ $SN_{40} = 56.47 - 0.00950\ (ADTLANE)$ $R^2 = 0.42$
5. LRA Seal Coats Without Flushing	$SN_{40} = 56.55 - 0.727\ (AGE) - 0.00000831\ (ACCTRAF)$ $R^2 = 0.40$
6. LRA Seal Coats With Slight Flushing	$SN_{40} = 380.19\ (SURTEX)^{0.265}(ACCTRAF)^{-0.112}$ $R^2 = 0.43$ $SN_{40} = 104.71(SURTEX)^{0.340}$ $R^2 = 0.32$
7. LRA Seal Coats With Moderate Flushing	$SN_{40} = 16.20 + 295.10\ (SURTEX)$ $R^2 = 0.35$
8. LRA Seal Coats - None to Slight Flushing	$SN_{40} = 457.09\ (SURTEX)^{0.188}(ACCTRAF)^{-0.138}$ $R^2 = 0.42$
9. LRA Seal Coats - None to Slight Flushing District 22	$SN_{40} = 48.28 + 93.11(SURTEX) - 0.00000631\ (ACCTRAF)$ $R^2 = 0.57$

TABLE 31. Continued

Group Number and Description	"Best" Regression Model and R^2
10. LRA Seal Coats - Item 304, Type PB,	$SN_{40} = 54.95\ (AGE)^{-0.649}$ $R^2 = 0.31$
11. LRA Seal Coats - Item 302, Type B, Grade 4	$SN_{40} = 2884.03\ (ACCTRAF)^{-0.333}$ $R^2 = 0.79$

22 with the models being logarithm transformed. At the lower accumulated traffic levels the difference between the District 21 and District 22 curves is about sixteen skid numbers. This difference remains fairly constant for the full range of traffic studied. The curve shown for all three districts combined falls between the two extremes as one would expect. For the District 21 case, the skid number drops 14 units going from an accumulated traffic level of 500,000 to 4,000,000. For the same range of traffic, the skid number drops 17 units for the District 22 case. Thus, the skid numbers for District 22 seal coats deteriorate at a faster rate with respect to accumulated traffic than do the seal coats in District 21. This is offset by the fact that District 22 seals start at a much higher skid number than the seals studied in District 21.

Figure 21 is a plot of skid number and surface texture for pavement sections in the study which exhibited slight and moderate flushing. This figure plainly shows that for the same amount of surface texture the estimated skid number will be higher for sections with slight flushing as opposed to those with moderate flushing. Once again the importance of minimizing flushing on this kind of pavement surface is demonstrated.

Figure 22 is a plot of skid number versus surface texture for various levels of accumulated traffic. The exception to this is the District 20 regression equation which does not allow the level of accumulated traffic to be varied. The trend shown in this figure is that accumulated traffic must approach 4,000,000 vehicles in District 22 to approach the low skid numbers for the District 20 pavement sections. Recall that poor skid resistance observed in District 20 can be primarily attributed to the moderate flushing observed on nine of the eleven pavement sections surveyed.

One of the primary goals of this section on limestone rock asphalt seal coats is represented as Figures 27 and 28. As was similarly stated for the cold mixes, this goal is to determine allowable maximum traffic levels which will provide for "safe" levels of skid resistance.

Figure 27 is a regression plot of skid number versus accumulated traffic for District 22 seal coats. Figure 28 is the same kind of plot for District 22 seal except ADT/Lane is substituted for accumulated traffic. The data used to generate the regression lines in these two figures are considered to be representative of "good" performing limestone rock asphalt seal coats. Using the lower 90 percent confidence band, a skid number of 35 or greater can be expected for an accumulated traffic value of 3,300,000 vehicles or less (Figure 27) or an ADT/Lane value of approximately 1600 per day lane or less (Figure 28). These values become 5,000,000 vehicles or less (Figure 27) or an ADT/Lane level of 2200 or less (Figure 28) if only the regression equation is used without the use of the confidence bands.

It is important to note that three of the fifteen pavement sections used to generate Figures 27 and 28 exhibited the distress manifestation of moderate flushing. It is reasonable to believe that the allowable traffic limits would be higher if the models were based on data from pavement sections with flushing conditions no greater than slight.

The two regression models had R^2 values of 0.42 and 0.41. Thus, 42 to 41 percent of the observed variation in the skid numbers was explained by the one independent variable (the higher R^2 associated with ADT/Lane and the lower with accumulated traffic). The RMSE ranged from a low of 7.8 skid numbers to a high of 7.9 for the independent variables of ADT/Lane and accumulated traffic, respectively. The F values ranged from 91 to 86 thus indicating that a statistical relationship exists between skid number and accumulated traffic and between skid number and ADT/Lane.

The same precaution stated for cold mixes also applies to the results shown in Figures 27 and 28. This occurs because age is not directly considered in the regression equations and was not a significant variable in the majority of the models attempted. The average age for District 22 seal coats (Figures 27 and 28) was about four years. This average age is slightly less than the normal survival time for similar Texas pavement surfaces (based on unpublished data developed by the author). If expected survival times are to exceed the average for the seal coats, then conclusions drawn from these models about the maximum ADT/Lane which would provide acceptable skid numbers may be invalid.

RESOURCE UTILIZATION

Limestone rock asphalt is a valuable natural resource with which Texans have surfaced many miles of streets and highways. The establishment of an average daily traffic limit above which limestone rock asphalt products should not be used as a surfacing material will limit the use of this resource. In an attempt to define the magnitude of this restriction, data indicating the rural and urban road mileage for various average daily traffic volumes were obtained from the Texas State Department of Highways and Public Transportation files (30) and are summarized on Figure 23. Traffic distributions assumed in calculating ADT/Lane data are shown on Table 32. For multilane facilities; however, ADT/Lane traffic was first calculated for the outside or travel

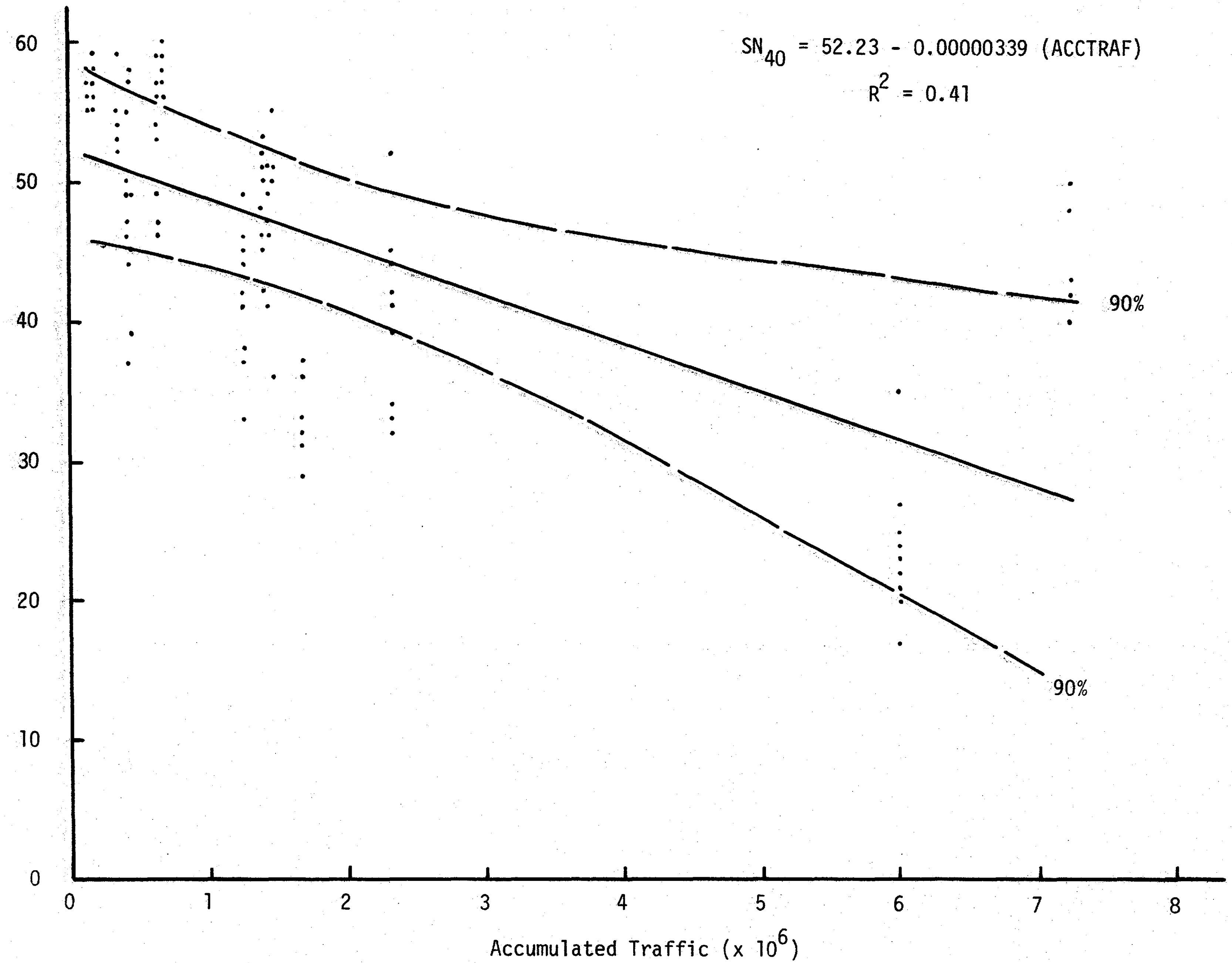

Figure 27. Skid Number versus Accumulated Traffic for Limestone Rock Asphalt Seal Coats in District 22 with 90 Percent Confidence Bands for the Regression Equation.

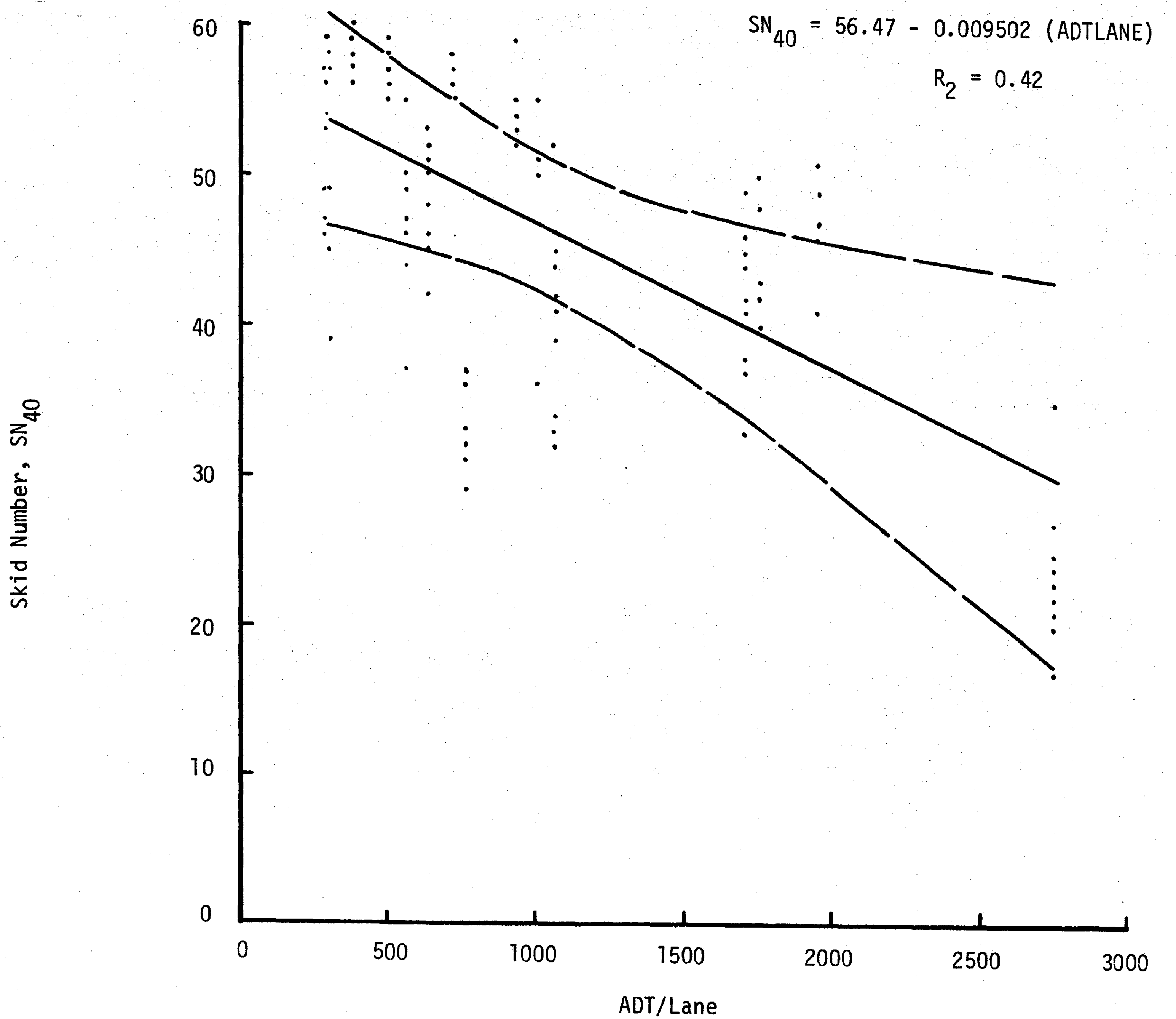

Figure 28. Skid Number versus ADT/Lane for Limestone Rock Asphalt Seal Coats in District 22 with 90 Percent Confidence Bands for the Regression Equation.

Table 32: Assumed Traffic Distributions

Location of Roadway	Number of Lanes	Frontage Roads	Traffic Distribution, Percent of Total ADT		
			Outside Lanes (Travel Lanes)	Inside Lanes (Passing Lanes)	Frontage Roads *
RURAL	2	No	50		
	4	No	42.5	7.5	
	4	Yes	42.1	7.4	1
	6	Yes	24.5	14.7, 9.8	1
URBAN	2	No	50		
	4	No	30	20	
	4	Yes	24	16	10
	6	Yes	16	12, 12	10
	8	Yes	12	10, 10, 8	10

* One side of roadway.

lane. All inside lanes of this facility were assigned traffic volumes equal to their outside lanes and mileages accumulated. This was considered a valid assumption as surface rehabilitation of multilane facilities is normally performed across the entire roadway.

If the use of limestone rock asphalt products for surface courses is limited to 2,000 vehicles per day per lane or less, Figure 23 indicates that 20.5 percent of the total system lane miles would be restricted from using these products. However, a significant portion of these lane miles are the inside lanes of multilane facilities which in actual fact have ADT/Lane less than 2000. It is estimated that if these lane miles were not included, the 20.5 percent would become about 15 percent. In addition, present practice and local material availability have dictated the use of other types of materials on these high traffic facilities. This statement is verified by the inability of the research team to locate test sections on high traffic volume facilities in the state.

From the above discussions it is apparent that rock asphalt products will not be suitable surfacing materials for a small percentage of the state's highways. This statement appears to reduce the utilization of this valuable natural resource; however, this study may open new markets as definitive data are now presented to indicate under what conditions limestone rock asphalt products can be used successfully.

CONCLUSIONS

1. Previous research studies conducted by the Texas SDHPT and the Texas Transportation Institute have defined typical engineering properties of asphalt concrete and seal coats made with a variety

of aggregates. Data collected in this study defined certain engineering properties of LRA materials. Comparisons of these data indicated the following:

a. The load carrying capability of fully cured limestone rock asphalt cold mixes is similar to that of asphalt concrete. This statement is based on field deflection testing and laboratory testing of field cores. However, field data indicated greater amounts of alligator cracking associated with limestone rock asphalt concrete. (This may be influenced by the fact that limestone rock asphalt overlays are generally thinner than those with asphalt concrete.)

b. Hveem and Marshall stability values for limestone rock asphalt cold mix are within the range normally obtained for asphalt concrete.

c. The air void content of in-service limestone rock asphalt cold mixes is higher than that normally experienced for asphalt concrete.

d. Limestone rock asphalt cold mixes exhibit a greater tendency to ravel than asphalt concrete. This tendency did not appear to be detrimental to performance of the pavements and is probably a mixture characteristic occurring during or soon after construction rather than progressing throughout the life of the pavement.

e. Surfaces constructed with limestone rock asphalt cold mixes have less flushing than asphalt concrete surfaces.

f. Pavement Rating Score for the 106 limestone rock asphalt surfaced pavements is 79 while an average of 83 was obtained on 245 randomly selected pavements in Texas.

2. Statistical evaluation of Skid SN 40 data using multiple regression techniques shows a reliable relationship between SN 40 and ADT/Lane for both LRA cold mixes and seal coats. A reliable relationship between SN 40 and accumulated traffic on seal coats was also shown.

3. The sections studied in District 22 exhibited the best overall skid performance. This is attributed to good construction techniques and the fact that poor performing A and B mixes are not used. The District 22 data as shown in Figures 24 through 28 indicate the best performance that can reasonably be expected. Under these conditions the regression analysis shows that SN 40 values of 35 or greater were achieved on approximately 95% of the sections when:

ADT/LANE	is less than 1,500 for cold mixes
ADT/LANE	is less than 1,600 for seal coats
ACCUMULATED Traffic/LANE	is less than 3,300,000 for seal coats

Regression analysis also shows that SN 40 values of 35 or greater were achieved on approximately 50% of the sections when:

ADT/LANE	is less than 2,000 for cold mixes
ADT/LANE	is less than 2,200 for seal coats
ACCUMULATED Traffic/LANE	is less than 5,000,000 for seal coats

4. Flushing of limestone rock asphalt seal coats can significantly decrease skid number. (Figure 21.)

5. Type A and B mixes exhibit lower skid numbers than Type C and CC mixtures. Regression analysis indicates that Type C and CC mixtures may exhibit higher skid numbers with low traffic levels than Type A

and B mixes but the rate of loss of skid number with increasing traffic appears to be higher for the Type C and CC mixes.

6. Within the limits of the data evaluated, the percent flux oil, percent water, percent bitumen, bitumen in minus No. 10 fraction and percent white rock did not appear to be significant variables in predicting skid performance of limestone rock asphalt cold mixtures. They may have significant influence on other performance factors.
7. Climate cannot as yet be definitely eliminated as a factor controlling skid properties of the surfaces studied.
8. The report makes an assessment of resource utilization and concludes that rock asphalt products can be utilized as a surfacing material on all but a small percentage of the states highways. While this statement appears to reduce the utilization of this valuable natural resource; other definitive engineering data are contained in the report which may open new markets as conditions are defined under which limestone rock asphalt products can be successfully utilized.

RECOMMENDATIONS

1. The use of limestone rock asphalt as a surfacing material on the State Highway system should be considered a satisfacotry alternative up to a design average daily traffic per lane of 2000. This is based on good construction techniques and recognizing that local district experience may dictate the use of other values.
2. Existing Type A and B limestone rock asphalt cold mixtures should not be used for surface courses. Gradations and mixture designs other than those presently specified should be investigated.

3. Consideration should be given to developing improved mixture design methods and field construction techniques.
4. Proper methods for placing limestone rock asphalt cold mixes should be well documented and training films prepared.

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APPENDIX A

Figure A-1. General Information Form

District No. ______County No. _____Highway_____From MP_____To MP_____Section No. _____

HISTORY: Year surface placed _________________ Type of Surface _____________________

Supporting Structure:

Construction Problems:

Performance:

DISTRESS:

DISCUSSION:

FUTURE MAINTENANCE:

CORES:

TRAFFIC: _______________ADT No. of Lanes ____________Accumulative Traffic___________

Figure A-2
CARD NO. 1

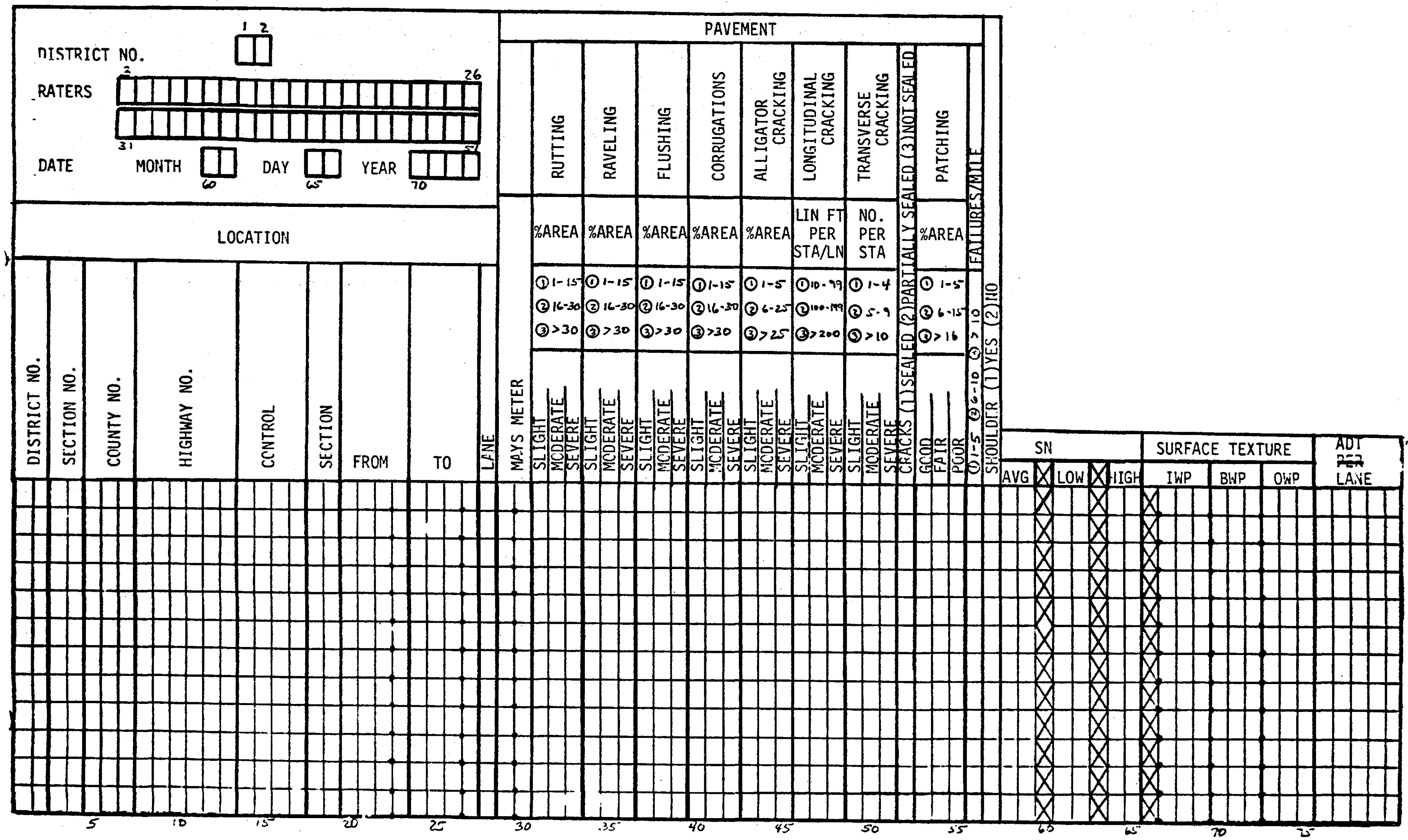
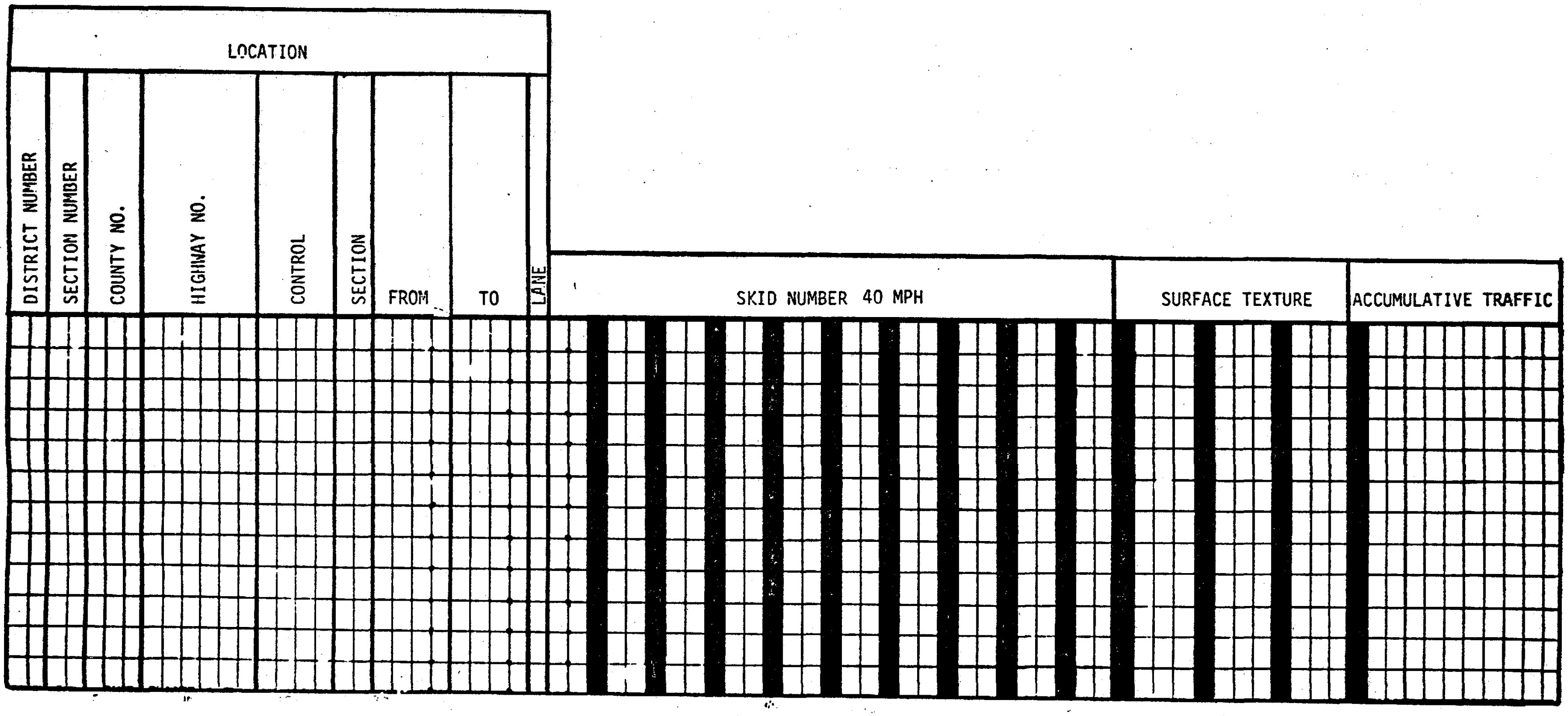


Figure A-3
CARD NO. 2



CARD NO. 3 - **Figure A-4**
PAVEMENT SECTION

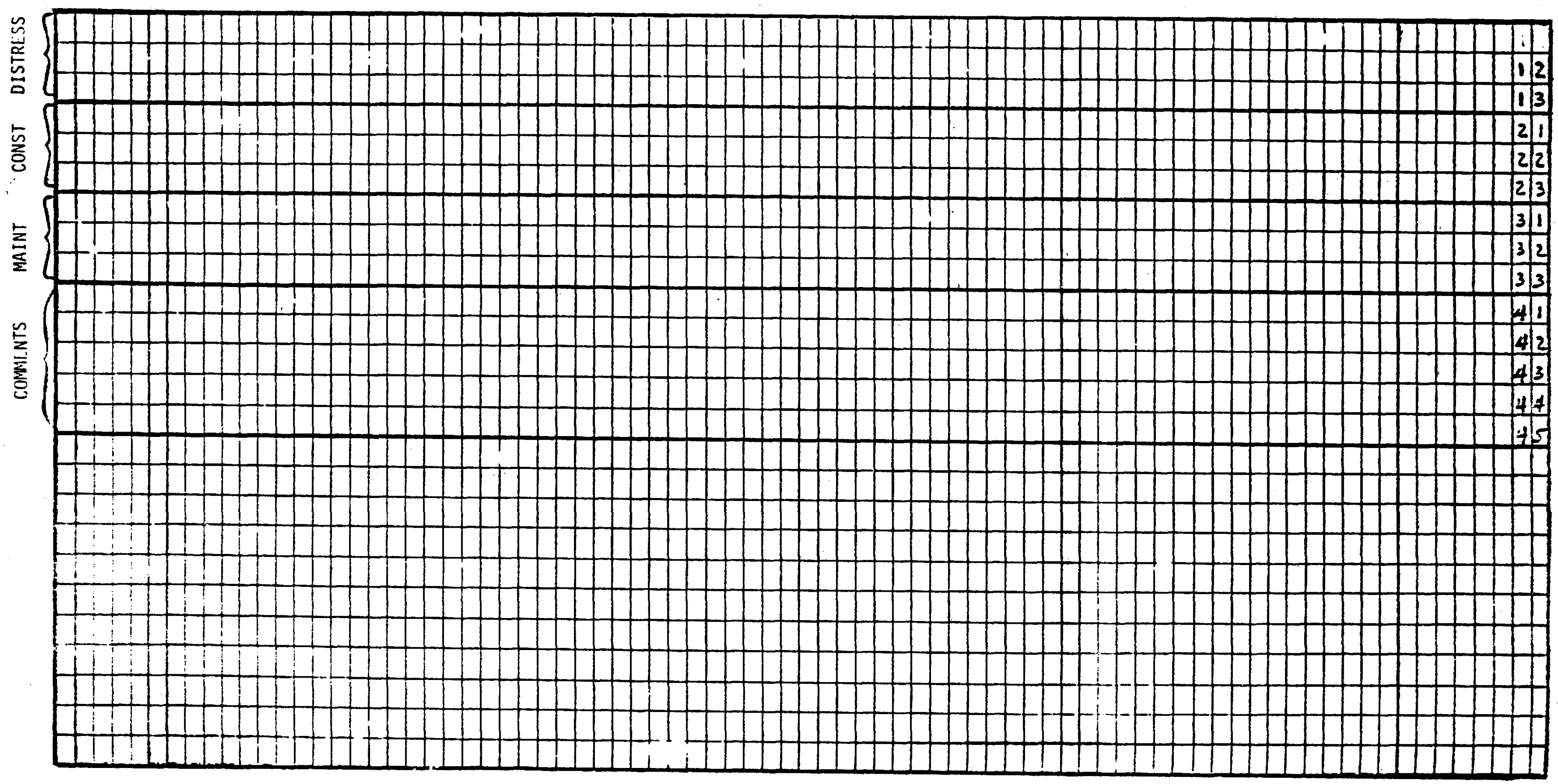
DISTRICT NO.	SECTION NO.	LAYER NO. 1					LAYER NO. 2					LAYER NO. 3					LAYER NO. 4					LAYER NO. 5					LAYER NO. 6					PAVEMENT RATING SCORE	SERVICEABILITY INDEX	SURFACE CURVATURE INDEX
		LAYER DESIGNATION	TYPE OF MATERIAL	GRADE	THICKNESS	YEAR PLACED	LAYER DESIGNATION	TYPE OF MATERIAL	GRADE	THICKNESS	YEAR PLACED	LAYER DESIGNATION	TYPE OF MATERIAL	GRADE	THICKNESS	YEAR PLACED	LAYER DESIGNATION	TYPE OF MATERIAL	GRADE	THICKNESS	YEAR PLACED	LAYER DESIGNATION	TYPE OF MATERIAL	GRADE	THICKNESS	YEAR PLACED	LAYER DESIGNATION	TYPE OF MATERIAL	GRADE	THICKNESS	YEAR PLACED			

CARD NO. 4 Figure A-5

DISTRICT NO.	
SECTION NO.	
TYPE OF MATERIAL	ITEM
	TYPE
	GRADE
SOURCE OF MATERIAL	
CONSTRUCTION	
MIXTURE PROPERTIES	% FLUX OIL
	% WATER ADDED
	AVG. BIT.
	BIT. PASS NO. 10
	% WHITE ROCK
	BIT. WHITE ROCK
	AVG. HVEEM STAB.
AGGREGATE GRADATION — % RETAINED ON SIEVES	1"
	3/4"
	5/8"
	1/2"
	3/8"
	1/4"
	No. 4
	No. 20
	No. 40
AGGREGATE GRADATION	PASS NO. 10
FIELD CORE DATA — LAYER NUMBER	LAYER DES.
	THICKNESS
	LAYER DES.
	THICKNESS
	LAYER DES.
	THICKNESS
	LAYER DES.
	THICKNESS
	LAYER DES.
	THICKNESS
FIELD CORE DATA — LABORATORY TESTS	RESILIENT AVG. MODULUS X 10^3 PSI
	AVG. SPECIFIC GRAVITY
	AVG. AIR VOIDS

Figure A-6

CARDS NO. 5 TO 18



APPENDIX B

Table B-1. General Statistical Summary of Limestone Rock Asphalt Cold Mix Data Groups

Type of Pavement Surface: LRA Cold Mixtures District (No. of Sections): 1(2), 10(1), 13(1), 15(1), 19(1), 20(13), 21(14), 22(32)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid Number_{40}	534	39.0	12.8	9.0	66.0	32.8
Age	58	6.2	3.6	1.0	16.0	57.4
Surface Texture (Inner Wheelpath)	58	0.029	0.015	0.0	0.088	52.9
Accumulated Traffic	65	3,028,300	3,237,600	180,000	14,760,000	106.9
ADT/Lane	65	1414	1268	100	5421	89.7

Type of Pavement Surface: LRA Cold Mixtures - Type A District (No. of Sections): 20(4), 21(8)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid Number_{40}	88	24.7	6.1	9.0	35.0	24.9
Age	12	4.8	1.8	2.0	8.0	37.1
Surface Texture (Inner Wheelpath)	12	0.021	0.007	0.010	0.034	35.2
Accumulated Traffic	12	3,833,833	2,950,363	655,000	11,440,000	77.0
ADT/Lane	12	2434	1584	850	5500	65.1

Table B-1. Continued

Type of Pavement Surface: LRA Cold Mixtures - Type B
District (No. of Sections): 20(4), 21(1)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	42	32.6	5.2	23.0	42.0	16.0
Age	5	5.2	0.8	4.0	6.0	16.1
Surface Texture (Inner Wheelpath)	5	0.032	0.010	0.020	0.045	35.0
Accumulated Traffic	5	3,994,600	2,536,542	2,300,000	8,400,000	63.5
ADT/Lane	5	2311	1572	1350	5100	68.0

Type of Pavement Surface: LRA Cold Mixtures - Type C
District (No. of Sections): 20(2), 21(1), 22(13)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	136	45.0	11.6	21.0	66.0	25.8
Age	16	7.4	3.4	1.0	13.0	46.3
Surface Texture (Inner Wheelpath)	16	0.039	0.020	0.0	0.088	51.5
Accumulated Traffic	16	3,036,188	3,483,172	246,000	14,100,000	114.7
ADT/Lane	16	1098	988	375	4480	90.0

Table B-1. Continued

Type of Pavement Surface: LRA Cold Mixtures - Type D District (No. of Sections): 20(3), 22(2)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	45	37.3	11.8	21.0	61.0	31.6
Age	5	7.8	3.6	4.0	12.0	45.7
Surface Texture (Inner Wheelpath)	5	0.020	0.013	0.003	0.032	62.2
Accumulated Traffic	5	4,765,600	5,831,085	1,300,000	15,040,000	122.4
ADT/Lane	5	2095	2396	305	6150	114.4

Type of Pavement Surface: LRA Cold Mixtures Without Moderate or Severe Raveling District (No. of Sections): 20(10), 21(11), 22(30)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	426	39.7	12.4	9.0	64.0	31.3
Age	51	5.9	3.6	1.0	16.0	60.1
Surface Texture (Inner Wheelpath)	51	0.028	0.014	0.0	0.065	50.0
Accumulated Traffic	51	2,928,569	3,358,770	140,000	15,040,000	114.7
ADT/Lane	51	1496	1400	200	6150	93.6

Table B-1. Continued

Type of Pavment Surface: LRA Cold Mixtures With Moderate or Severe Raveling District (No. of Sections): 20(3), 21(2), 22(2)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	58	42.3	14.4	18.0	66.0	33.9
Age	7	8.4	3.0	4.0	12.0	36.2
Surface Texture (Inner Wheelpath)	7	0.037	0.023	0.018	0.088	62.3
Accumulated Traffic	6	3,495,667	3,963,810	1,046,000	11,440,000	113.4
ADT/Lane	7	1301	1889	100	5500	145.2

Type of Pavement Surface: LRA Cold Mixtures - Type C District: 22						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	114	47.0	11.2	21.0	66.0	23.8
Age	13	7.8	3.4	1.0	13.0	43.2
Surface Texture (Inner Wheelpath)	13	0.040	0.022	0.0	0.088	54.1
Accumulated Traffic	13	3,479,462	3,730,340	270,000	14,100,000	107.2
ADT/Lane	13	1183	1083	375	4480	91.5

Table B-1. Continued

Type of Pavement Surface: LRA Cold Mixtures - Type CMOD District: 22						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	72	49.7	9.9	21.0	64.0	20.0
Age	8	8.2	2.7	4.0	13.0	32.9
Surface Texture (Inner Wheelpath)	8	0.024	0.005	0.019	0.032	20.1
Accumulated Traffic	8	3,171,250	3,949,244	490,000	12,590,000	124.5
ADT/Lane	8	1084	1389	200	4480	128.2

Type of Pavement Surface: LRA Cold Mixtures - Type CC District: 22						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	61	43.3	9.1	24.0	60.0	21.1
Age	7	3.7	5.4	1.0	16.0	146.4
Surface Texture (Inner Wheelpath)	7	0.028	0.020	0.009	0.065	69.0
Accumulated Traffic	7	626,429	669,283	140,000	1,900,000	106.8
ADT/Lane	7	734	585	280	1990	79.7

Table B-1. Continued

Type of Pavement Surface: LRA Cold Mixtures - Type CCMOD District: 22						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	18	46.3	4.2	39.0	55.0	9.0
Age	2	1.0	0.0	1.0	1.0	0.0
Surface Texture (Inner Wheelpath)	2	0.030	0.021	0.016	0.045	67.2
Accumulated Traffic	2	285,000	35,255	260,000	310,000	12.4
ADT/Lane	2	1112	145	1010	1215	13.0

Type of Pavement Surface: LRA Cold Mixtures - Types C, D, CC, CMOD, CCMOD District: 22						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	283	46.9	10.2	21.0	66.0	21.8
Age	32	6.8	4.3	1.0	16.0	63.0
Surface Texture (Inner Wheelpath)	32	0.032	0.018	0.0	0.088	57.8
Accumulated Traffic	32	2,461,188	3,267,938	140,000	14,100,000	132.8
ADT/Lane	32	1007	1007	200	4480	100.0

Table B-1. Continued

Type of Pavement Surface: LRA Cold Mixtures - Types D, CMOD, CC, CCMOD District: 20(3), 22(19)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	196	44.5	10.8	21.0	64.0	24.3
Age	22	6.0	4.5	1.0	16.0	74.2
Surface Texture (Inner Wheelpath)	22	0.025	0.013	0.003	0.065	53.3
Accumulated Traffic	22	2,461,500	3,851,356	140,000	15,040,000	156.5
ADT/Lane	22	1205	1451	200	6150	120.4

Type of Pavement Surface: LRA Cold Mixtures Without Moderate or Severe Raveling - Type C District (No. of Sections): 20(1), 21(1), 22(12)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	118	44.1	11.3	21.0	64.0	25.7
Age	14	6.9	3.4	1.0	13.0	48.5
Surface Texture (Inner Wheelpath)	14	0.036	0.016	0	0.065	44.8
Accumulated Traffic	14	3,098,500	3,726,954	246,000	14,100,000	120.3
ADT/Lane	14	1160	1045	375	4480	90.1

Table B-1. Continued

Type of Pavement Surface: LRA Cold Mixtures - Type A District: 20						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variaiton (%)
Skid $Number_{40}$	36	27.9	4.8	18.0	35.0	17.1
Age	4	5.2	1.0	4.0	6.0	18.2
Surface Texture (Inner Wheelpath)	4	0.026	0.007	0.018	0.034	25.5
Accumulated Traffic	4	5,257,000	4,301,502	1,688,000	11,440,000	81.8
ADT/Lane	4	2832	1954	1250	5500	69.0

Type of Pavment Surface: LRA Cold Mixtures - Types A, B District: 20						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	69	30.1	5.7	18.0	42.0	18.9
Age	8	5.1	0.8	4.0	6.0	16.3
Surface Texture (Inner Wheelpath)	8	0.031	0.009	0.018	0.045	29.6
Accumulated Traffic	8	4,637,625	3,470,339	1,688,000	11,440,000	74.8
ADT/Lane	8	2626	1750	1250	5500	66.6

Table B-1. Continued

Type of Pavement Surface: LRA Cold Mixtures - Types A, B, C, D District: 20						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	114	30.5	5.8	18.0	43.0	19.2
Age	13	5.5	1.7	4.0	10.0	30.5
Surface Texture (Inner Wheelpath)	13	0.030	0.011	0.003	0.045	38.1
Accumulated Traffic	13	4,679,154	4,291,911	1,200,000	15,040,000	91.7
ADT/Lane	13	2473	1889	550	6150	76.4

Type of Pavement Surface: LRA Cold Mixtures - Type A District: 21						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	52	22.4	6.0	9.0	34.0	26.7
Age	8	4.5	2.1	2.0	8.0	46.0
Surface Texture (Inner Wheelpath)	8	0.018	0.006	0.010	0.027	35.1
Accumulated Traffic	8	3,122,250	2,003,208	655,000	6,980,000	64.2
ADT/Lane	8	2235	1473	850	4300	65.9

Table B-1. Continued

Type of Pavement Surface: LRA Cold Mixtures - Types A, B District: 21						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	61	24.0	6.9	9.0	36.0	28.6
Age	9	4.7	2.0	2.0	8.0	42.9
Surface Texture (Inner Wheelpath)	9	0.019	0.006	0.010	0.027	32.7
Accumulated Traffic	9	3,208,667	1,891,679	655,000	6,980,000	59.0
ADT/Lane	9	2195	1383	850	4300	63.0

Type of Pavement Surface: LRA Cold Mixtures - Types A, B, C District: 21						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	65	25.1	7.8	9.0	44.0	31.3
Age	10	4.5	2.0	2.0	8.0	43.5
Surface Texture (Inner Wheelpath)	10	0.019	0.006	0.010	0.027	31.0
Accumulated Traffic	10	2,912,400	2,014,593	246,000	6,980,000	69.2
ADT/Lane	10	2047	1386	715	4300	67.7

Table B-2. Summary of All Consistent Regression Models for Limestone Rock Asphalt Cold Mixes

Model Number	Type of Pavement Surface	District	Model Transformation	Regression Coefficients					R^2	Total Degrees of Freedom	Number of Independent Variables in Model
				Inter-cept	Age	Surface Texture	Accumulated Traffic	ADT/ Lane			
1	All LRA Cold Mixes	20,21,22	---	48.14				-5.65E-03	0.41	478	1
2	"	"	---	40.78		231.83		-5.27E-03	0.49	478	2
3	"	"	$\log_{10}$	2.47				-2.96E-01	0.51	469	1
4	"	"	"	2.67		1.46E-01		-2.87E-01	0.56	469	2
5	LRA Cold Mixes - Type A	20,21	---	30.23				-2.33E-03	0.36	87	1
6	"	"	---	21.09		410.74		-2.30E-03	0.58	87	2
7	"	"	$\log_{10}$	2.22				-2.55E-01	0.34	87	1
8	"	"	"	2.98		4.00E-01		-2.82E-01	0.58	87	2
9	LRA Cold Mixes - Type B	20,21	---	39.38				-2.83E-03	0.62	41	1
10	"	"	$\log_{10}$	2.44				-2.81E-01	0.67	41	1
11	LRA Cold Mixes - Type C	20,21,22	---	53.09				-7.20E-03	0.37	135	1
12	"	"	---	43.70		209.07		-6.11E-03	0.49	135	2
13	"	"	$\log_{10}$	2.51				-2.95E-01	0.42	126	1
14	"	"	"	2.73		1.80E-01		-2.81E-01	0.48	126	2
15	LRA Cold Mixes - Type D	20,22	$\log_{10}$	2.26				-2.29E-01	0.70	44	1

Table B-2. Continued

Model Number	Type of Pavement Surface	District	Model Transformation	Regression Coefficients					R^2	Total Degrees of Freedom	Number of Independent Variables in Model
				Inter-cept	Age	Surface Texture	Accumulated Traffic	ADT/ Lane			
16	LRA Cold Mixture Without Moderate or Severe Raveling	20,21,22	---	48.19				-5.18E-03	0.42	425	1
17	"	"	$\log_{10}$	2.50				-3.06E-01	0.53	416	1
18	"	"	"	2.69		1.28E-01		-3.02E-01	0.57	416	2
19	LRA Cold Mixtures With Moderate or Severe Raveling	20,21,22	---	23.73		460.97			0.56	52	1
20	"	"	---	32.09		369.10		-3.21E-03	0.70	52	2
21	"	"	$\log_{10}$	2.47		5.94E-01			0.61	52	1
22	"	"	"	3.41		5.44E-01	-1.60E-01		0.71	52	2
23	LRA Cold Mixes - Type C	22	---	56.73				-8.13E-03	0.59	113	1
24	"	"	---	47.30		202.64		-6.95E-03	0.72	113	2
25	"	"	$\log_{10}$	2.61				-3.19E-01	0.71	104	1
26	LRA Cold Mixes - Type CMOD	22	---	56.87				-6.66E-03	0.77	71	1
27	"	"	---	47.96		376.74		-6.83E-03	0.80	71	2
28	"	"	$\log_{10}$	2.42				-2.59E-01	0.74	71	1

Table B-2. Continued

Model Number	Type of Pavement Surface	District	Model Transformation	Regression Coefficients					R^2	Total Degrees of Freedom	Number of Independent Variables in Model
				Inter-cept	Age	Surface Texture	Accumulated Traffic	ADT/ Lane			
29	LRA Cold Mixes - Types C, D, CC, CMOD, CCMOD	22	---	53.66				-6.70E-03	0.43	282	1
30	"	"	$\log_{10}$	2.32				-2.27E-01	0.44	273	1
31	"	"	"	2.59		1.43E-01		-2.45E-01	0.54	273	2
32	LRA Cold Mixes - Types D, CMOD, CC, CCMOD	20,22	---	50.23				-4.77E-03	0.39	195	1
33	"	"	$\log_{10}$	2.30				-2.31E-01	0.52	195	1
34	LRA Cold Mixes Without Moderate or Severe Raveling Type C	20,21,22	---	52.62				-7.18E-03	0.43	117	1
35	"	"	$\log_{10}$	2.56				-3.10E-01	0.51	108	1
36	LRA Cold Mixes - Type A	20	---	8.52		733.17			0.83	35	1
37	"	"	---	40.00	-1.10			-2.22E-03	0.84	35	2
38	"	"	$\log_{10}$	2.54		6.93E-01			0.85	35	1
39	LRA Cold Mixes - Types A, B	20	---	13.55		542.17			0.67	68	1
40	"	"	---	24.48		311.96		-1.46E-03	0.73	68	2

Table B-2. Continued

Model Number	Type of Pavement Surface	District	Model Transformation	Regression Coefficients					R^2	Total Degrees of Freedom	Number of Independent Variables in Model
				Inter cept	Age	Surface Texture	Accumulated Traffic	ADT/ Lane			
41	LRA Cold Mixes - Types A, B	20	$\log_{10}$	2.36		5.80E-01			0.75	68	1
42	"	"	"	2.45		3.82E-01		-1.16E-01	0.78	68	2
43	LRA Cold Mixes - Types A, B, C, D	20	---	35.37				-1.95E-03	0.37	113	1
44	"	"	$\log_{10}$	2.05				-1.76E-01	0.41	113	1
45	LRA Cold Mixes - Type A	21	---	29.24				-3.28E-03	0.60	51	1
46	"	"	---	22.05		490.37		-4.31E-03	0.79	51	2
47	"	"	$\log_{10}$	2.49				-3.59E-01	0.61	51	1
48	"	"	"	3.46		4.00E-01		-4.43E-01	0.79	51	2
49	LRA Cold Mixes - Types A, B	21	---	31.13				-3.45E-03	0.43	60	1
50	"	"	$\log_{10}$	2.46				-3.40E-01	0.42	60	1
51	"	"	"	3.56		4.52E-01		-4.36E-01	0.59	60	2
52	LRA Cold Mixes - Types A, B, C	21	---	32.99				-4.01E-03	0.44	64	1
53	"	"	---	22.22		675.87		-5.21E-03	0.64	64	2
54	"	"	$\log_{10}$	2.58				-3.75E-01	0.47	64	1
55	"	"	"	3.64		4.73E-01		-4.51E-01	0.65	64	2

Table B-3. General Statistical Summary of Limestone Rock Asphalt Seal Coat Data Groups

Type of Pavement Surface: LRA Seal Coats
District (No. of Sections): 1(4), 10(2), 16(4), 20(12), 21(21), 22(15)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	493	34.7	14.2	12.0	70.0	40.8
Age	44	4.0	3.2	0.0	21.0	80.1
Surface Texture (Inner Wheelpath)	44	0.054	0.036	0.0	0.156	67.4
Accumulated Traffic	58	2,304,500	3,050,900	68,000	19,107,000	132.4
ADT/Lane	58	1415	1336	70	8605	94.4

Type of Pavement Surface: LRA Seal Coats
District: 20

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	95	26.5	8.9	15.0	48.0	33.5
Age	11	4.5	2.0	3.0	10.0	45.3
Surface Texture (Inner Wheelpath)	11	0.044	0.015	0.027	0.072	34.5
Accumulated Traffic	11	1,770,000	1,460,514	350,000	5,600,000	82.5
ADT/Lane	11	1267	750	530	2680	59.2

Table B-3. Continued

Type of Pavement Surface: LRA Seal Coats

District 21

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	161	36.1	15.5	12.0	70.0	43.0
Age	19	4.0	4.4	0.0	21.0	109.3
Surface Texture (Inner Wheelpath)	19	0.051	0.044	0.0	0.156	86.5
Accumulated Traffic	19	906,316	953,109	68,000	4,011,000	105.2
ADT/Lane	19	975	973	70	4070	99.8

Type of Pavement Surface: LRA Seal Coats

District: 22

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	127	46.8	10.2	17.0	60.0	21.7
Age	14	3.7	2.1	1.0	6.0	57.3
Surface Texture (Inner Wheelpath)	14	0.065	0.035	0.008	0.115	53.8
Accumulated Traffic	15	1,706,300	2,046,400	130,000	7,255,000	119.9
ADT/Lane	15	1019	691	284	2745	67.8

Table B-3. Continued

Type of Pavement Surface: LRA Seal Coats Without Flushing District (No. of Sections): 20(1), 21(5), 22(4)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation(%)
Skid Number$_{40}$	88	48.9	9.2	30.0	61.0	18.8
Age	10	4.1	6.2	0.0	21.0	150.5
Surface Texture (Inner Wheelpath)	10	0.075	0.035	0.010	0.108	47.2
Accumulated Traffic	10	550,500	345,427	120,000	1,100,000	62.7
ADT/Lane	10	866	568	400	1750	65.6

Type of Pavement Surface: LRA Seal Coats With Slight Flushing District (No. of Sections): 20(1), 21(9), 22(7)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid Number$_{40}$	150	40.5	13.1	15.0	70.0	32.2
Age	17	4.0	2.2	1.0	10.0	54.5
Surface Texture (Inner Wheelpath)	17	0.061	0.037	0.016	0.156	60.7
Accumulated Traffic	17	1,112,412	1,013,454	68,000	4,011,000	91.1
ADT/Lane	17	969	960	70	4070	99.0

Table B-3. Continued

Type of Pavement Surface: LRA Seal Coats With Moderate Flushing

District (No. of Sections): 20(9), 21(4), 22(3)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	130	26.8	11.2	13.0	59.0	41.9
Age	16	4.1	1.3	2.0	6.0	30.5
Surface Texture (Inner Wheelpath)	16	0.035	0.024	0.0	0.083	68.9
Accumulated Traffic	16	1,838,562	1,709,814	240,000	5,970,000	93.0
ADT/Lane	16	1263	872	140	2870	69.0

Type of Pavement Surface: LRA Seal Coats None to Slight Flushing

District (No. of Sections): 20(2), 21(14), 22(11)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	238	43.6	12.5	15.0	70.0	28.6
Age	27	4.0	4.0	0.0	21.0	99.4
Surface Texture (Inner Wheelpath)	27	0.067	0.037	0.010	0.156	54.9
Accumulated Traffic	27	904,296	865,922	68,000	4,011,000	95.8
ADT/Lane	27	931	825	70	4070	88.6

Table B-3. Continued

Type of Pavement Surface: LRA Seal Coats - None To Slight Flushing District: 22						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	97	48.4	8.4	29.0	60.0	17.5
Age	11	3.3	2.1	1.0	6.0	65.7
Surface Texture (Inner Wheelpath)	11	0.067	0.035	0.010	0.115	51.7
Accumulated Traffic	11	978,182	738,794	120,000	2,400,000	75.5
ADT/Lane	11	947	492	400	2000	52.0

Type of Pavement Surface: LRA Seal Coats - Item 304 Type PB Grade 4 District (No. of Sections): 20(4), 21(6), 22(3)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	114	35.6	12.8	13.0	57.0	36.0
Age	13	2.2	1.2	0.0	5.0	52.3
Surface Texture (Inner Wheelpath)	13	0.051	0.031	0.010	0.108	60.8
Accumulated Traffic	13	942,846	667,809	263,000	2,4000,000	70.8
ADT/Lane	13	1432	725	425	2680	50.6

Table B-3. Continued

Type of Pavement Surface: LRA Seal Coats - Item 302 Type B Grade 4 District: 21						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Skid $Number_{40}$	60	42.1	17.9	15.0	70.0	42.4
Age	7	3.4	0.5	3.0	4.0	15.6
Surface Texture (Inner Wheelpath)	7	0.062	0.056	0.0	0.156	89.7
Accumulated Traffic	7	1,189,857	1,417,000	68,000	4,011,000	119.1
ADT/Lane	7	1012	1411	70	4070	139.4

Table B-4. Summary of All Consistent Regression Models for Limestone Rock Asphalt Seal Coats

Model Number	Type of Pavement Surface	District	Model Transformation	Regression Coefficients					R^2	Total Degrees of Freedom	Number of Independent Variables in Model
				Inter-cept	Age	Surface Texture	Accumulated Traffic	ADT/ Lane			
1	LRA Seal Coats	20,21,22	---	43.37			-5.08E-06		0.20	376	1
2	"	"	---	23.78		247.01			0.36	376	1
3	"	"	---	45.08			-3.55E-06	-3.40E-03	0.21	376	2
4	"	"	---	30.77		221.64		-5.23E-03	0.45	376	2
6	"	"	$\log_{10}$	2.77			-2.10E-01		0.25	368	1
7	"	"	"	1.99		3.33E-01			0.33	353	1
8	"	"	"	2.78		2.58E-01	-1.51E-01		0.45	353	2
9	LRA Seal Coats	20	---	6.88		452.14			0.54	94	1
10	"	"	$\log_{10}$	2.34		6.80E-01			0.48	94	1
11	LRA Seal Coats	21	---	42.76			-7.79E-06		0.22	160	1
12	"	"	---	25.70		195.65			0.29	160	1
13	"	"	---	31.20		195.39		-5.65E-03	0.42	160	2
14	"	"	$\log_{10}$	3.00			-2.59E-01		0.31	152	1
15	"	"	"	2.01		3.45E-01			0.41	137	1
16	"	"	"	3.12		2.79E-01	-2.12E-01		0.63	137	2

Table B-4 Continued

Model Number	Type of Pavement Surface	District	Model Transformation	Inter-cept	Age	Surface Texture	Accumulated Traffic	ADT/ Lane	R^2	Total Degrees of Freedom	Number of Independent Variables in Model
	LRA Seal Coats	22	---	56.88				-9.84E-03	0.45	120	
17	"	"	---	54.10			-5.54E-06		0.63	120	1
18	"	"	---	45.96		100.08	-4.20E-06		0.70	120	2
19	"	"	$\log_{10}$	2.72			-1.80E-01		0.54	120	1
20	"	"	"	2.83			-1.38E-01	-1.23E-01	0.60	120	2
21	"	"	"	2.59		1.14E-01	-1.33E-01		0.63	120	2
22	"	"	"	2.43	-1.34E-01	1.08E-01		-1.96E-01	0.68	120	3
23	LRA Seal Coats Without Flushing	20,21,22	---	52.61	-8.85E-01				0.32	87	1
24	"	"	---	56.55	-7.27E-01		-8.31E-06		0.40	87	2
25	"	"	---	53.05	-8.98E-01	70.66			0.44	87	3
28	LRA Seal Coats with Slight Flush.	20,21,22	---	47.61			-6.43E-06		0.24	149	1
29	"	"	---	40.13		102.82	-5.35E-06		0.31	149	2
30	"	"	$\log_{10}$	2.53			-1.63E-01		0.26	149	1
31	"	"	"	2.02		3.40E-01			0.32	149	1
32	"	"	"	2.58		2.65E-01	-1.12E-01		0.43	149	2

Table B-4. Continued

Model Number	Type of Pavement Surface	District	Model Transformation	Regression Coefficients: Intercept	Age	Surface Texture	Accumulated Traffic	ADT/ Lane	R^2	Total Degrees of Freedom	Number of Independent Variables in Model
33	LRA Seal Coats With Moderate Flushing	20,21,22	---	33.64				-5.31E-03	0.17	129	1
34	"	"	---	16.20		295.10			0.35	129	1
35	"	"	$\log_{10}$	1.88				-1.63E-01	0.14	129	1
36	"	"	"	1.72		2.20E-01			0.19	123	1
37	LRA Seal Coats None to Slight Flushing	20,21,22	---	50.49			-7.63E-06		0.27	237	1
38	"	"	---	52.13	-5.03E-01		-7.20E-06		0.30	237	2
39	"	"	---	42.42		104.79	-6.37E-06		0.36	237	2
40	"	"	$\log_{10}$	2.62			-1.74E-01		0.29	229	1
41	"	"	"	2.55	-5.56E-02		-1.56E-01		0.30	229	2
42	"	"	"	2.66		1.88E-01	-1.38E-01		0.42	229	2
43	LRA Seal Coats None to Slight Flushing	22	---	56.14			-8.03E-06		0.46	96	1
44	"	"	---	48.28		93.11	-6.31E-06		0.57	96	2
45	"	"	$\log_{10}$	2.38			-1.21E-01		0.42	96	1
46	"	"	"	2.38		5.35E-02	-1.09E-01		0.45	96	2
47	"	"	"	2.29	-1.16E-01	7.06E-02		-1.62E-01	0.48	96	3

Table B-4. Continued

Model Number	Type of Pavement Surface	District	Model Transformation	Regression Coefficients					R^2	Total Degrees of Freedom	Number of Independent Variables in Model
				Inter-cept	Age	Surface Texture	Accumulated Traffic	ADT/ Lane			
48	LRA Seal Coats Item 304, Type PB Grade 4	20,21,22	---	48.61	-5.75				0.25	113	1
49	"	"	---	39.83	-4.16	103.32			0.29	113	2
50	"	"	---	42.90	-3.92	115.88		-2.97E-03	0.31	113	3
51	"	"	$\log_{10}$	1.74	-6.49E-01				0.31	105	1
52	"	"	"	2.00	-6.43E-01			-8.40E-02	0.33	105	2
53	LRA Seal Coats Item 302, Type B Grade 4	21	---	53.69			-1.01E-05		0.57	59	1
54	"	"	---	108.13	-15.10		-1.21E-05		0.73	59	2
55	"	"	$\log_{10}$	2.40				-3.08E-01	0.74	59	1
56	"	"	"	3.46			-3.33E-01		0.79	53	1

Table B-5. General Statistical Summary of Limestone Rock Asphalt Cold Mix Data for Eleven Variables

Type of Pavement Surface: LRA Cold Mixes District (No. of Sections): 20 (13), 21 (13), 22 (32)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	13	8.4	3.1	0.0	12.0	37.3
Retained 1/2" sieve	33	0.9	5.2	0.0	30.0	574.4
Retained 3/8" sieve	48	9.2	12.3	0.0	32.0	132.5
Retained No. 4 sieve	49	47.5	9.6	7.0	57.0	20.3
Passing No. 10 sieve	49	34.9	5.5	28.0	46.0	15.7
% Flux Oil	49	3.0	0.2	2.6	3.2	6.6
% Water	49	2.1	0.5	0.3	2.5	21.2
% Average Bitumen	49	5.9	0.3	5.5	6.9	4.8
Bit. Pass No. 10	48	6.3	0.4	5.4	7.3	6.2
% White Rock	48	26.6	2.2	22.0	31.0	8.4
Bit. White Rock	48	0.3	0.1	0.1	0.4	30.0

Table B-5. Continued

Type of Pavement Surface: LRA Cold Mixes - Type A District (No. of Sections): 20 (4), 21 (8)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	12	9.1	1.9	6.0	12.0	21.2
Retained 1/2" sieve	1	30.0	0.0	30.0	30.0	0.0
Retained 3/8" sieve	11	30.5	1.2	29.0	32.0	4.0
Retained No. 4 sieve	12	56.1	1.2	53.0	57.0	2.2
Passing No. 10 sieve	12	31.0	1.2	30.0	33.0	3.9
% Flux Oil	12	2.7	0.1	2.6	2.9	4.0
% Water	12	2.1	0.5	0.8	2.5	21.5
% Average Bitumen	12	6.0	0.4	5.6	6.9	5.9
Bit. Pass No. 10	12	6.4	0.4	5.7	7.3	6.7
% White Rock	12	25.4	2.3	22.0	28.0	9.0
Bit. White Rock	12	0.3	0.1	0.1	0.4	34.0

Table B-5. Continued

Type of Pavement Surface: LRA Cold Mixes - Type B District (No. of Sections): 20(3), 21(1)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	-	-	-	-	-	-
Retained 1/2" sieve	-	-	-	-	-	-
Retained 3/8" sieve	4	10.0	1.4	9.0	12.0	14.1
Retained No. 4 sieve	4	52.8	1.0	52.0	54.0	1.8
Passing No. 10 sieve	4	31.0	0.8	30.0	32.0	2.6
% Flux Oil	4	2.8	0.2	2.6	3.0	5.8
% Water	4	2.1	0.4	1.7	2.5	18.2
% Average Bitumen	4	5.8	0.4	5.5	6.3	6.5
Bit. Pass No. 10	4	6.4	0.5	5.9	7.2	8.4
% White Rock	4	26.2	1.0	25.0	27.0	3.6
Bit. White Rock	4	0.3	0.1	0.2	0.4	43.6

Table B-5. Continued

Type of Pavement Surface: LRA Cold Mixes - Type C District (No. of Sections): 20 (2), 21 (1), 22 (13)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	-	-	-	-	-	-
Retained 1/2" sieve	-	-	-	-	-	-
Retained 3/8" sieve	14	1.0	0.4	0.0	2.0	39.2
Retained No. 4 sieve	14	46.5	2.4	44.0	50.0	5.2
Passing No. 10 sieve	14	30.9	2.1	28.0	37.0	6.8
% Flux Oil	14	3.0	0.1	2.8	3.2	4.4
% Water	14	2.1	0.6	0.3	2.5	30.1
% Average Bitumen	14	5.8	0.2	5.5	6.0	3.2
Bit. Pass No. 10	14	6.1	0.3	5.4	6.7	5.6
% White Rock	14	26.9	1.7	25.0	30.0	6.2
Bit. White Rock	14	0.3	0.1	0.1	0.4	33.8

Table B-5. Continued

Type of Pavement Surface: LRA Cold Mixes - Type D District (No. of Sections): 22 (2)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	-	----	---	---	---	---
Retained 1/2" sieve	-	----	---	---	---	---
Retained 3/8" sieve	-	----	---	---	---	---
Retained No. 4 sieve	2	7.5	0.7	7.0	8.0	9.4
Passing No. 10 sieve	2	41.5	2.1	40.0	43.0	5.1
% Flux Oil	2	3.2	0.0	3.2	3.2	0.0
% Water	2	1.8	0.1	1.8	1.9	3.8
% Average Bitumen	2	6.3	0.1	6.2	6.4	2.2
Bitumen Passing No. 10	2	6.8	0.1	6.7	6.8	1.0
% White Rock	2	24.0	1.4	23.0	25.0	5.9
% Bitumen White Rock	2	0.2	0.1	0.1	0.3	47.1

Table B-5. Continued

Type of Pavement Surface: LRA Cold Mixes - Type CMOD District (No. of Sections): 22 (8)						
Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	-	----	---	---	---	---
Retained 1/2" sieve	-	----	---	---	---	---
Retained 3/8"sieve	8	0.9	0.4	0.0	1.0	40.4
Retained No. 4 sieve	8	46.1	1.2	44.0	48.0	2.7
Passing No. 10 sieve	8	40.0	2.4	37.0	45.0	6.1
% Flux Oil	8	3.0	0.1	2.9	3.2	3.1
% Water	8	2.1	0.4	1.4	2.5	17.1
% Average Bitumen	8	5.9	0.3	5.5	6.5	5.5
Bitumen Passing No. 10	8	6.3	0.4	5.7	6.9	6.6
% White Rock	8	26.2	2.4	22.0	29.0	9.0
Bitumen White Rock	8	0.2	0.0	0.2	0.3	10.6

Table B-5. Continued

Type of Pavement Surface: LRA Cold Mixes - Type CC

District (No. of Sections): 22 (7)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	-	----	---	---	---	----
Retained 1/2" sieve	-	----	---	---	---	----
Retained 3/8" sieve	7	3.4	4.4	1.0	13.0	127.0
Retained No. 4 sieve	7	44.9	3.6	37.0	48.0	8.1
Passing No. 10 sieve	7	41.4	2.1	40.0	46.0	5.0
% Flux Oil	7	3.1	0.1	3.0	3.2	3.4
% Water	7	2.4	0.2	2.0	2.5	10.4
% Average Bitumen	7	5.8	0.1	5.6	6.0	2.4
Bitumen Passing No. 10	6	6.1	0.2	6.0	6.3	2.5
% White Rock	6	28.8	0.8	28.0	30.0	2.6
Bitumen White Rock	6	0.3	0.0	0.3	0.4	6.8

Table B-5. Continued

Type of Pavement Surface: LRA Cold Mixes - Type CCMOD

District (No. of Sections): 22 (2)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	-	----	---	---	---	---
Retained 1/2" sieve	-	----	---	---	---	---
Retained 3/8" sieve	2	11.5	2.1	10.0	13.0	18.4
Retained No. 4 sieve	2	47.0	0.0	47.0	47.0	0.0
Passing No. 10 sieve	2	45.5	0.7	45.0	46.0	1.6
% Flux Oil	2	3.0	0.0	3.0	3.0	0.0
% Water	2	2.0	0.1	1.9	2.0	3.6
% Average Bitumen	2	5.8	0.0	5.8	5.8	0.0
Bitumen Passing No. 10	2	6.0	0.1	6.0	6.1	1.2
% White Rock	2	30.5	0.7	30.0	31.0	2.3
Bitumen White Rock	2	0.3	0.0	0.3	0.4	12.9

Table B-6. General Statistical Summary of Limestone Rock Asphalt Seal Coat Data for Eight Variables.

Type of Pavement Surface: LRA Seal Coats

District (No. of Sections): 20 (11), 21 (19), 22 (14)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	16	1.1	0.7	0.0	2.0	63.9
Retained 1/2" sieve	25	6.4	5.9	0.0	16.0	92.5
Retained 3/8" sieve	35	33.3	14.4	1.0	61.0	43.2
Retained No. 4 sieve	37	94.0	16.1	4.0	98.0	17.1
Passing No. 10 sieve	38	1.1	0.3	1.0	3.0	30.8
% Flux Oil	29	0.6	0.2	0.5	1.4	27.7
% Water	29	1.0	0.1	0.7	1.7	14.1
% Average Bitumen	38	5.4	0.4	4.7	6.8	7.6

Table B-6. Continued

Type of Pavement Surface: LRA Seal Coats

District (No. of Sections): 20 (11)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	6	1.8	0.4	1.0	2.0	22.3
Retained 1/2" sieve	9	7.3	5.8	0.0	16.0	79.5
Retained 3/8' sieve	8	29.2	1.0	28.0	30.0	3.5
Retained No. 4 sieve	9	98.0	0.0	98.0	98.0	0.0
Passing No. 10 Sieve	9	1.0	0.0	1.0	1.0	0.0
% Flux Oil	8	0.6	0.0	0.6	0.6	0.0
% Water	8	1.0	0.0	1.0	1.0	0.0
% Average Bitumen	9	5.4	0.1	5.3	5.6	1.8

Table B-6. Continued

Type of Pavement Surface: LRA Seal Coats

District (No. of Sections): 21 (19)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	1	1.0	0.0	1.0	1.0	0.0
Retained 1/2" sieve	4	4.0	6.0	1.0	13.0	150.0
Retained 3/8" sieve	15	23.5	10.3	1.0	38.0	43.8
Retained No. 4 sieve	16	88.8	23.9	4.0	98.0	26.9
Passing No. 10 sieve	17	1.1	0.5	1.0	3.0	43.4
% Flux Oil	9	0.7	0.3	0.5	1.4	41.8
% Water	9	1.1	0.2	1.0	1.7	21.6
% Average Bitumen	17	5.6	0.4	4.7	6.8	7.9

Table B-6. Continued

Type of Pavement Surface: LRA Seal Coats

District (No. of Sections): 22 (14)

Variable	N	Mean	Standard Deviation	Lowest Value	Highest Value	Coefficient of Variation (%)
Retained 5/8" sieve	9	0.7	0.5	0.0	1.0	75.0
Retained 1/2" sieve	12	6.5	6.3	0.0	14.0	96.3
Retained 3/8" sieve	12	48.2	10.8	28.0	61.0	22.5
Retained No. 4 sieve	12	98.0	0.0	98.0	98.0	0.0
Passing No. 10 sieve	12	1.0	0.0	1.0	1.0	0.0
% Flux Oil	12	0.5	0.0	0.5	0.6	8.6
% Water	12	1.0	0.1	0.7	1.0	8.9
% Average Bitumen	12	5.1	0.3	4.7	5.6	6.4