MACRO-TEXTURE, FRICTION, CROSS SLOPE AND WHEEL TRACK DEPRESSION MEASUREMENTS ON 41 TYPICAL TEXAS HIGHWAY PAVEMENTS

by

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DISCLAIMER

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

ABSTRACT

The role of macro-texture in imparting friction capabilities to pavement surfaces is of major concern to researchers. Macro-texture is but one of the many variables affecting the interaction at the tire-pavement interface; however, at present its relative importance is questioned.

Friction tests obtained at 20, 40, and 60 mph with the Texas Highway Department research skid trailer, and macro-texture tests utilizing four different methods were conducted on forty-one pavement surfaces. These surfaces exhibited widely different friction levels, friction-speed gradients, drainage capabilities, mineralogical properties, and texture classifications.

Macro-texture values obtained with the four methods are compared. The effects of macro-texture types and magnitudes on friction numbers and friction-speed gradients are analyzed. Statistical analyses and typical plots are given. Brief descriptions of several macro-texture measurement methods which have or are being used by various agencies in the United States and other countries are presented.

For the treaded tire and 0.020-inch water film thicknesses used in this study, macro-texture was found to have little effect on friction level, but did appreciably influence the percent decrease in friction with speed.

Pavement cross slope and wheel track depression measurements were taken. Cross slope values are compared with recommended AASHO guidelines. On the average, cross slopes on the Texas pavements included in this study were found to be flatter than those recommended by AASHO. Based on measurements made on the various pavements included in this study, wheel track depression or pavement rutting is not a serious problem.

IMPLEMENTATION

A working knowledge of the basic design parameters and service requirements coupled with an appreciation for the relative importance of the many factors which may alter driver control of an automotive vehicle in any and all driving conditions is necessary for the engineer to fully appreciate the questions raised by this study. It is evident from the research reported herein that the findings have application in proper selection of paving materials and pavement mix designs commensurate with acceptable pavement friction characteristics and service demands.

The importance of friction-speed gradients is emphasized as an implementable facet of the findings. It must be assumed, human nature being what it is, that there will be those drivers who, for many and various reasons, will contribute to the hazards of the general driving public. Selected changes in design and construction specifications may assure an adequate margin of safety to offset considerably the potential hazards of such drivers.

Improvements in cross slope may form a part of the normal maintenance operations, especially in the primary system where engineering judgement dictates a structural improvement of the pavement. Similarly on secondary roads, the application of plant mixed paving mixtures allows improvement in cross slope. The economy of such application can be justified on highways with high skidding accident rates and/or highways that have radical surface texture differences along and across the pavement. These do not lend themselves to successful maintenance with chip seals.

KEY WORDS

Friction, skid resistance, skid number, water film thickness, gradient, percentage gradient, macro-texture, profilograph, texture-meter, modified sand patch, putty impression, micro-texture, internal drainage, surface type, correlation coefficient, coefficient of determination, regression line, cross slope, wheel track depression, and rutting.

OBJECTIVES

The phase of the research reported herein had four objectives as summarized below:

1. Analyze and compare different methods for measuring pavement surface macro-texture. Both volumetric and mechanical roughness detector methods were used for assessing macro-texture levels.

2. Determine effects of macro-texture types and magnitudes on friction numbers and friction-speed gradients of various pavement surface types.

3. Survey the normal range of macro-texture existing on Texas pavements for use in a subsequent study of the effects of variable macro-texture on water depth buildup for various levels of pavement cross slopes and rainfall intensities.

4. Measure normal range of cross slopes and wheel track depressions existing on Texas pavements. Cross slope comparisons with recommended guidelines were to be made. These are also for use in a subsequent study of the effects of variable cross slopes on water depth buildup for various levels of pavement macro-textures and rainfall intensities.

INTRODUCTION

Friction properties of pavement surfaces have become factors of major importance to the overall traffic safety problem. Although friction measurements of the tire-pavement combination are considered acceptable for evaluating the skid resistant properties of pavement surfaces, attempts are being made to characterize the skid resistant properties in qualitative manners, such as macro-texture, drainage characteristics of the surface and aggregate size, shape, micro-texture and mineralogy. The majority of these qualitative tests are not convenient survey measures; however, a basic understanding of the relative effects of the measured factors on pavement friction is a necessity in order to more fully understand the interaction at the tire-pavement interface and thus enable the designer to understand the need for these desirable properties in the pavement surface.

Several researchers have indicated that the type and magnitude of texture is an important characteristic of pavement surfaces with respect to friction properties (12, 13, 22, 23). Pavement surface texture refers to the distribution and the geometrical configuration of the individual surface aggregates. There is not sufficient agreement among the various researchers to adopt a standard nomenclature for discussing textural parameters. However, general practice today favors the use of the terms macroscopic texture (macro-texture) which refers to that part of the pavement surface as a whole or the large scale texture caused by the size and shape of the surface aggregate, and microscopic texture (micro-texture) which refers to the fine-scaled roughness contributed by individual small asperities on the individual aggregate particles.

The researchers have conflicting claims on the relative merits of macro- and micro-texture. Some contend that a high level of macro-texture is essential to provide the pavement drainage at high speeds (24), whereas, micro-texture is the main texture contributor for a given friction level. Still others believe that a combination of both macro- and micro-texture is most desirable (13, 21).

Kummer and Meyer (13) proposed the classification shown in Figure 1, which delineates the two roughness types that affect the friction of pavement surfaces. Although five surface types are classified, only three levels of macro-texture, i.e., smooth fine, and coarse, are identified since types 2 and 3 and types 4 and 5 respectively are the same as far as macro-texture is concerned. Thus a given level of macro-texture as measured by the majority of existing test methods does not appear to adequately assess the degree of roundness of grittiness the individual aggregates possess. It is the authors' opinions that this fact is the main contributor to the low coefficients of correlation between friction parameters and macro-texture obtained in this study.

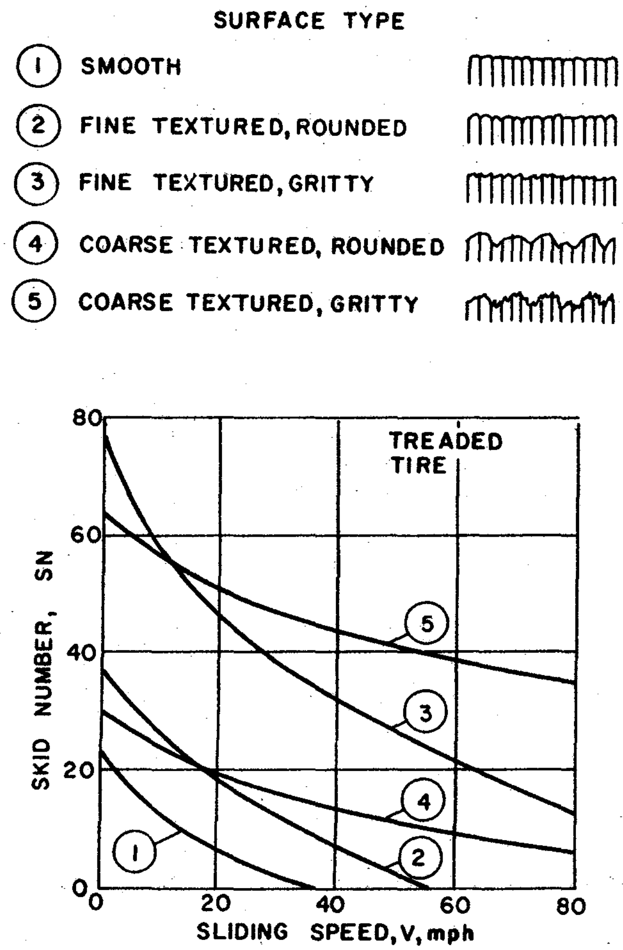


Figure 1. Classification of pavement surfaces according to their friction and drainage properties (13).

Macro- and micro-texture, respectively, provide for gross surface drainage and subsequent puncturing of the water film. Another factor which acts in combination with macro- and micro-texture is internal drainage of the pavement surface itself. Goodwin (19), Hutchinson (20), and Gallaway (21), among others, have postulated that high void content surfaces, porous pavements, or visicular aggregates would provide internal escape paths for water under a tire and thus lessen hydro-dynamic pressure build up. This would result in better tire gripping capability and increased traction, particularly at higher speeds, while decreasing the need of macro-texture for providing initial, gross drainage. Research directed toward measuring dynamic drainage capabilities of pavement surfaces is in the development stage (20). It is the authors' opinions that the combined effects of macro- and micro-texture and internal drainage largely determine the friction levels of pavement surfaces. In this paper only the effects of macro-texture are examined.

Various agencies in the United States and other countries are engaged in developing methods for measuring pavement surface macro-texture in order to more fully evaluate its role in vehicle braking, cornering, and accelerating manuevers. Brief descriptions of several macro-texture measurement methods which have or are being used are given below. Descriptions of four additional methods used in this research are reserved for the body of the report.

Sand Patch Method

A known volume of fine dry sand is spread over a circular area until flush with the aggregate tips of the pavement surface. The area of the patch is determined from an average of a number of measurements. The average texture depth, obtained by the ratio of the volume to the area, is considered to be a measure of surface texture (1).

NASA Grease Method

This method is similar in principle to the sand patch method. A selected volume of grease is applied to the pavement surface between parallel lines of masking tape and then positioned into the surface voids with an aluminum squeegee faced with rubber having a hardness approximately equivalent to that of tire tread rubber. An average texture depth of the surface is obtained by dividing the volume of grease by the area covered by the grease (2).

Drainage Meter

This method utilizes a transparent cylinder about 5 inches in diameter and 12 inches in height with a rubber ring glued to the bottom face. The cylinder is placed on the pavement and loaded so that the rubber ring will drape over the aggregate particles similar to a tread element. Water is poured in the cylinder and the time required for a known volume of water to escape between the rubber ring and the pavement surface is measured. The water in the cylinder can be under atmospheric or increased pressure. Short durations of time or high rates of flow are associated with above average texture depths and/or high permeability of the pavement material (3).

Foil Piercing Method

A piece of aluminum foil is placed on the pavement and given an impact by a rubber-tipped rod released from a pre-determined height. An imprint of the surface texture is engraved in the foil by the impact. Some piercings of the foil are caused by the sharper-tipped aggregates particles. The density or number of piercings per square inch is found by counting the punctures on the foil or on a photo-negative made of the foil. High puncture densities are generally found to be associated with high skid numbers. It is conceivable that this method also measures micro-texture to a certain degree (4).

Linear Traverse Method

This method employs a motorized lathe and a stereo microscope with the shaft of a potentiometer attached to the microscope focusing shaft. The potentiometer is fixed to the body of the microscope so that the only movement possible is in the potentiometer shaft. A low constant voltage is fed into the potentiometer; the output is fed through an amplifier to a strip chart recorder.

In operation, the sample with the surface to be studied is placed in the lathe, and the equipment is referenced both vertically and horizontally. The sample is moved transversely under the microscope, and the operator keeps the microscope in constant focus on the surface of the sample. Focusing on the varying surface elevation results in corresponding changes in the potentiometer output voltage. The end result is an amplified tracing of the surface texture of the sample (5).

Stereophotographic Method

Stereo pairs of photographs are taken by a specially designed camera in which a single lens is used. The pair of photographs is obtained by moving the lens laterally a fixed amount in a plane parallel to the pavement surface. Measurements of the parralax between the two photographs are made on a stereocomparator. Records of the surface profile are obtained by measuring the relative heights of successive points at 0.025cm intervals along lines on the surface with the aid of a parallax bar.

The micrometer readings of the parallax are converted into binary form on punched tape by gearing a combination of optical and mechanical digitisers to the micrometer. By selecting, amplifying, integrating, and decoding through appropriate electronic units adjacent to the stereo comparator, the output in a binary form is obtained on paper tape for analysis on a computer. The computer provides printouts of tape readings in tabular form and plots of the tape readings with a certain horizontal to vertical scale ratio. Surface textures or roughness of the order of 0.01 inch can be shown on the plot.

One way of assessing the surface profile is by the profile ratio, a ratio of the length of the profile to the length of the straight baseline. High profile ratios are generally associated with low percentages of reduction in skid resistance with increase in speed (6).

Casting or Molding Method

A casting material such as a low melting metal or plaster is used with a form to obtain a negative of the pavement surface. A positive is then made from the negative. The surface of the positive is painted and is immediately wiped with a sponge. This removes the paint from the top of the surface areas and gives a measure of contrast. Detail studies of the surface textures are then conducted in the laboratory. One study involves drawing magnified shadow images of the cross-sectional profiles projected onto a paper screen. Measurements of the drainage area per unit length of the pavement surface are made from these silhouettes (7).

Impression Method

A negative impression of the road surface is made by pouring a volume of RTV silicone rubber inside a mold taped to the pavement or a pavement core. After the rubber has hardened, the sample is then removed from the surface. Cross sections from the specimen are then sliced on a meat slicer for measurement of surface voids, surface void distribution, asperity, and a typical surface profile. The composite of these measurements is then used as the measure of surface roughness (8).

Centrifuge Kerosene Equivalent (CKE) Method

This method provides a value for the surface texture and particle shape characteristics of the aggregates used for seal coats. A sample consists of 100 grams of the washed and dried aggregates passing a No. 3 sieve and retaining on a No. 4 sieve. This sample is saturated in kerosene for ten minutes and centrifuged for two minutes at 400 times gravity. The sample is weighed to the nearest 0.1 gram and is submerged in SAE-10 lubricating oil, raised immediately and is allowed to drain. The difference in weights after centrifuging and after draining represents a surface factor for the sample. This factor, after a specific gravity correction, is designated K_s. The range of K_s values for mineral aggregates is from 1.1 to 3.0, the high values being associated with high angularity and high surface roughness (9).

Wear and Roughness Meter Method

This method measures mean wear height and mean roughness and provides a plot of the surface profile from which the maximum depth and distribution of peaks of the surface can be observed.

The instrument is contained in a light-tight case with an internal support frame. Within the case, a horizontal array of identical sensing plungers is mounted in such a manner as to permit movement in the vertical direction only. The top surfaces of the plungers have a mirror finished surface inclined at 45 degrees to the vertical axis. A light from a tublar lamp is collimated by a parabolic mirror and deflected by a small 45 degree mirror through a horizontal slit. The light beam is then reflected by the top surfaces of the plungers toward a photocell which is as long as the stack of plungers and is inclined at an angle so as to magnify the width of the collimated beam from the plunger by a factor of ten.

When the points of the plungers are in contact with a smooth, flat surface, the light is projected by the plunger tops as a parallel band with smooth edges on the photocell. When the plungers contact a rough or textured surface, the light pattern at the photocell reproduces the surface profilê with a magnification of ten. A relative maximum roughness meter reading is obtained when testing on the smooth, flat surface, and a lower maximum reading is obtained on a textured surface. The difference between the two maxima is the roughness of the textured surface (10).

<u>Mineralogical Studies and Profilograph Method</u>

In this combined mineralogical studies and texture measuring method, a thorough knowledge of the polish susceptibility of various aggregates is acquired. In addition, both macro- and micro-roughness are evaluated in light of aggregate wearing characteristics under traffic.

A qualified geologist conducts petrographic analyses of aggregate samples from the rock quarries supplying aggregates for pavements. Based on these analyses, various road surfaces are selected for testing purposes. Texture measurements are made using the profilograph, and skid tests are conducted. Cored specimens are visually described and microscopically examined to obtain a variety of information related to the surface characteristics. These data include aggregate type, percent exposed aggregate, roughness, harshness, particle geometry, polish, and microscopic identification of minerals. The surface profiles are analyzed and compared with skid test results to evaluate the importance of large scale roughness. Qualitative evaluation of the role of microroughness of the aggregates on skid resistance is made from microscopic observations of thin sections obtained from the surfaces of the cores (11).

Photo-Interpretation Method

In the photo-interpretation method, skid numbers are obtained from values of various pavement surface texture parameters. Color stereophotographs of approximately 6-inch square sections of the pavement surface are obtained by a means described previously in the Stereophotographic Method. The transparencies are viewed through a micro-stereoscope and also through a standard microscope with a 3x linear magnification.

The texture elements of the pavement surface are visibly classified and subjectively rated according to the established severity rating for each of seven parameters. The parameters include the height, width, angularity, density, and the fine texture of the projections, and also the fine texture and cavities found in the background surface.

A tabulated relationship established between the severity of each of the seven parameters and friction weights is used to estimate the skid number of the pavement surface. The basis used in establishing the relationship was mainly trial and error. However, the investigators reported a correlation coefficient of 0.9 between the skid numbers obtained from skid tests and the photo-interpreted skid numbers (12).

TEST EQUIPMENT

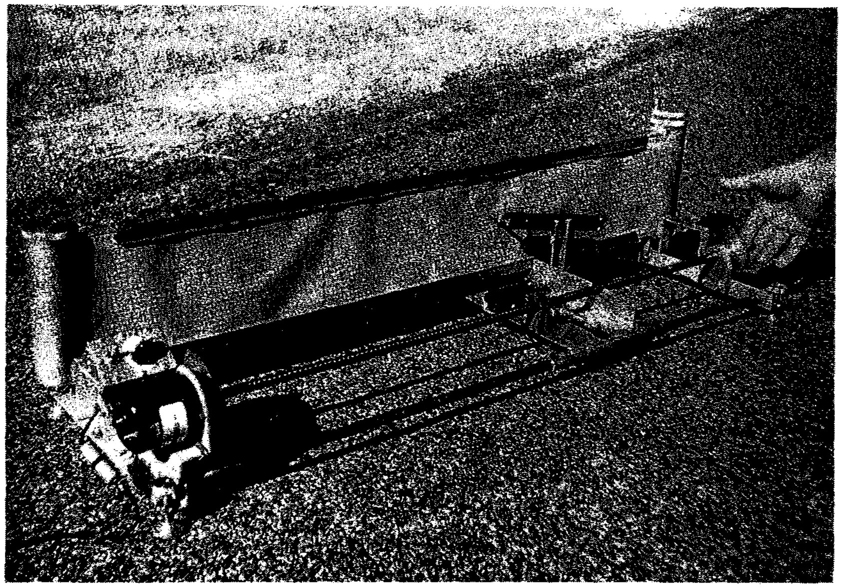
Skid Test Trailer

The friction measurements reported herein were obtained with the Texas Highway Department research skid trailer which conforms substantially to ASTM standards and utilizes E-17 treaded tires inflated to 24 psi. The drag forces were measured with strain gages and the self-watering system utilized a centrifugal pump which applied a water film approximately 0.020-inches in thickness to the pavement surface. The development and calibration of the trailer may be reviewed in a departmental research report published earlier by the Texas Highway Department (14). Figure 2 depicts the trailer under test conditions.

Macro-Texture Measurements

Four methods were used to obtain five measures of macro-texture. Equipment used for these are shown in Figure 3. Two measures of average peak height and two measures of average texture depth were obtained and these measurements were reduced to equivalent units. Also, one measure of accumulative peak height was obtained. A tabulation of the methods is contained in Table 1 and brief descriptions of each method follows:

Figure 2. Texas Highway Department Research Skid Trailer.



a. Profilograph

b. Texturemeter

Figure 3. Equipment Used for Macro-Texture Tests.

c. Modified Sand Patch

d. Putty Impression

Figure 3. Continued.

Table 1. Methods Used for Macro-Texture Texts

METHOD	MEASURE	UNITS
Profilograph	Average Peak Height	inch
Profilograph	Accumulative Peak Height	inch
Texturemeter	Average Peak Height	inch
Modified Sand Patch	Average Texture Depth	inch
Putty Impression	Average Texture Depth	inch

Profilograph

The instrument used for this test was developed by the Texas Highway Department (15). It is designed to scribe a magnified profile of the surface texture as a probe is drawn across the surface. That is, the probe is placed on the pavement surface and as the probe is drawn over the surface irregularities, the vertical movement of the probe is magnified through a linkage system. The probe and linkage system are attached to a carriage which is forced to move in a horizontal manner parallel to the pavement surface by a framework with adjustable legs. The vertical and horizontal movement results in a duplicated (but magnified) texture profile which is scribed on a chart. Average peak height can then be determined. Also, the upward vertical excursions are recorded on a counter of which the counter reading, at any time, is the cumulative vertical peak heights of the texture through the length traversed by the probe.

Texturemeter

The instrument, developed at the Texas Transportation Institute (16) and used previously for macro-texture tests (17), consists essentially of a series of evenly spaced, parallel rods mounted in a frame. The rods can be moved vertically, independently of one another, against spring pressure. At either end of the series of moveable rods is a fixed rod rigidly attached to the frame. Each movable rod is pierced by a hole through which passes a taut string, one end of which is fixed to the frame and the other to the spring loaded stem of a 0.001-inch dial gage mounted on the frame. When the instrument is in use, the rods are held in a vertical position with their ends resting against the pavement surface. If the surface is smooth, the string will form a straight line and the dial will read zero. Any irregularities in the surface will cause the string to form a zig-zag line and will result in a dial reading; the coarser the pavement texture, the larger the dial reading. Average peak height can be calculated from the dial reading. The readings given by an instrument of this kind are affected by the size and spacing of the rods and the distance spanned by these rods. For the texturemeter used, the rods are spaced at 5/8-inch, and the instrument spans a distance of 10 inches between fixed supports.

Modified Sand Patch

This method was modified slightly from that developed by the British (1). Equipment consist of 1) a 6.15 inches by 4.60 inches rectangular metal plate, 1/8-inch thick with a 4.35 inches by 2.90 inches center hole, and a 2-inch wide, 1/16-inch thick collar or free board, 2) 100 grams of a fine grained sand, and 3) a 4-inch long straight edge. The technique involves determining the increased volume of sand required to fill the metal plate cavity when placed on the test surface as compared to the volume required to fill the cavity on a non-textured surface. If the plate is placed on a textured surface, the bottom of the plate will rest on the upper aggregate asperities. The more irregular the surface texture, the larger the resulting weight of sand required to fill the cavity. The average texture depth is defined as the ratio of the increased volume of sand to the area of the patch.

Putty Impression

This method was initially developed as a means of providing surface texture correction factors for nuclear density measurements (18). Equipment consists of 1) a 6-inch diameter by 1-inch thick metal plate with a 4-inch diameter, 1/16-inch deep recess machined into one side, and 2) a 15.90-gram ball of silicone putty. When placed on a smooth surface, 15.90 grams of putty will smooth out to a 4-inch diameter circle, 1/16-inch deep, thus completely filling the recess.

The silicone putty is formed into an approximate sphere and placed on the pavement surface. The recess in the plate is centered over the putty and the plate is pressed down in firm contact with the road surface. The more irregular the surface texture (the higher the macro-texture) the smaller the resulting putty diameter because more material is required to fill the surface texture. Average texture depth, based on volume per unit area, is calculated from an average of four diameter measurements.

Table 2. Skid Number and Macro-Texture Values

Surface Type	Number Tested	Range Skid Number, 40 mph	Range Macro-Texture, inches
Hot Mix Asphalt Concrete	21	29-59	0.01 - 0.04
Portland Cement Concrete	9	36-45	0.01 - 0.04
Surface Treatment	9	29-65	0.02 - 0.07
Seal Coat	2	18-27	0.00 - 0.01

Cross Slope and Wheel Track Depression Measurements

The equipment for measuring pavement slope and wheel track depression is shown in Figures 4 and 5. A 1-3/4-inch by 4-inch by 12-feet long aluminum box channel marked at one foot increments was used.

For the cross slope measurements, a bubble level was attached to the channel. The channel was leveled transversely to the direction of travel and the difference in elevation from the inside to the outside of the lane was measured directly with a ruler. The average cross slope, expressed in inch per foot and foot per foot across the total width of the lane was computed.

The channel was placed flush with the pavement surface for wheel track depression measurements. A ruler was used to measure directly the inter and outer wheel track depressions.

Summary data, classified as to service category, are presented in Table 3, along with recommended AASHO guidelines (25).

Figure 4. Cross Slope Measurements.

Figure 5. Wheel Track Depression Measurements.

TABLE 3. CROSS SLOPE AND WHEEL TRACK DEPRESSION SUMMARY DATA

Service Category	Number of Surfaces Tested	Field Measurements				
		Average Rate of Cross Slope			Wheel Track Depression	
		Inch per Foot	Inch per Foot	Foot per Foot	Inside Wheel Track, Inch	Outside Wheel Track, Inch
<u>Interstate</u> (IH) Marked Routes	11	.15	5/32	.013	1/64	1/64
<u>Federal</u> (US) Marked Routes	9	.15	5/32	.013	3/64	7/64
<u>State</u> (St) Marked Routes	7	.18	3/16	.015	3/64	5/64
<u>Farm</u> (FM) Marked Routes	9	.22	7/32	.018	1/8	5/32
Test Surfaces Texas A&M Annex	5	.14	9/64	.011	0	0

Service Category	Number Of Surfaces Tested	AASHO Recommendations [25]			Field Measurements		
		Range in Rate of Cross Slope			Range in Rate of Cross Slope		
		Inch per Foot	Inch per Foot	Foot per Foot	Inch per Foot	Inch per Foot	Foot per Foot
<u>Interstate</u> (IH) Marked Routes	11	.125-.250 [1]	1/8-1/4 [1]	.01-.02 [1]	.10-.19	3/32-3/16	.008-.016
<u>Federal</u> (US) Marked Routes	9	.125-.250 [1]	1/8-1/4 [1]	.01-.02 [1]	.09-.23	3/32-15/64	.008-.019
<u>State</u> (St) Marked Routes	7	.187-.375 [2]	3/16-3/8 [2]	.015-.03 [2]	.06-.33	1/16-21/64	.005-.027
<u>Farm</u> (FM) Marked Routes	9	.187-.375 [2]	3/16-3/8 [2]	.015-.03 [2]	.15-.28	5/32-9/32	.013-.023
Test Surfaces Texas A&M Annex	5				.11-.18	7/64-3/16	.009-.015

1 High surface type, AASHO classification.

2 Intermediate surface type, AASHO classification.

SURFACE TYPES

Forty-one pavement surfaces were tested including 21 hot mix asphalt concrete surfaces, 9 portland cement concrete surfaces, 9 surface treatments, and 2 seal coats. The term "surface" as used in this paper is defined as a section of pavement on which the wearing course is essentially identical over the entire length under study. These test surfaces were selected with regard to level of service, degree of polish, and traffic volume. In addition, it was planned for the test sample to include at least ten surfaces from each major service category of the Texas Highway System. The array of surface types selected included the various mineralogical types and aggregate size configurations commonly used in Texas. Tests were also made on new surface designs, which are not widely used at present, but for which increased use is envisioned for the future. Information for the surfaces is contained in Table 4. Skid number speed curves are shown in Figures 6, 7, and 8. Differences in skid numbers found on the 41 pavements are evident from these data.

The surfaces were classified with respect to the type of coarse aggregate contained therein. Lightweight aggregate infers an expanded clay or shale.

Table 4. Classification of Test Surfaces

Surface Classification	Surface Type	Number Tested
Hot Mix Asphalt Concrete	Lignite Boiler Slag Aggregate	3
	Rounded Siliceous Gravel	4
	Crushed Limestone Aggregate	4
	Crushed Siliceous Gravel	4
	Crushed Sandstone Aggregate	3
	Lightweight Aggregate	3
Portland Cement Concrete	Rounded Siliceous Gravel	5
	Crushed Limestone Aggregate	3
	Rounded Siliceous Gravel & Crushed Sandstone Aggregate Mixture	1
Surface Treatment and Seal Coat	Rounded Siliceous Gravel	2
	Crushed Limestone Aggregate	4
	Lightweight Aggregate	3
	Flush Seal	2

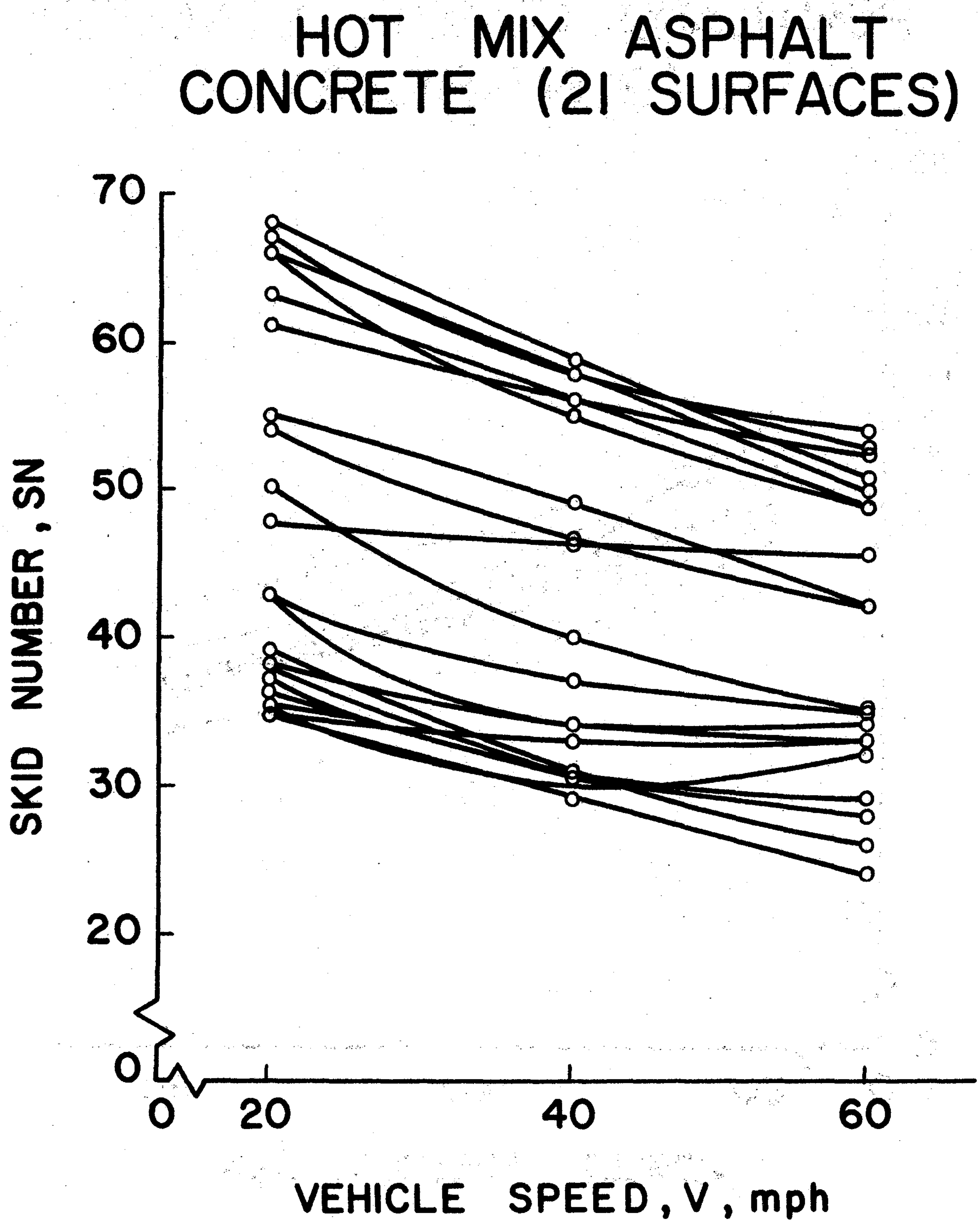


Figure 6. Skid Number-Speed Relationships for Hot-Mix Asphalt Concrete Surfaces.

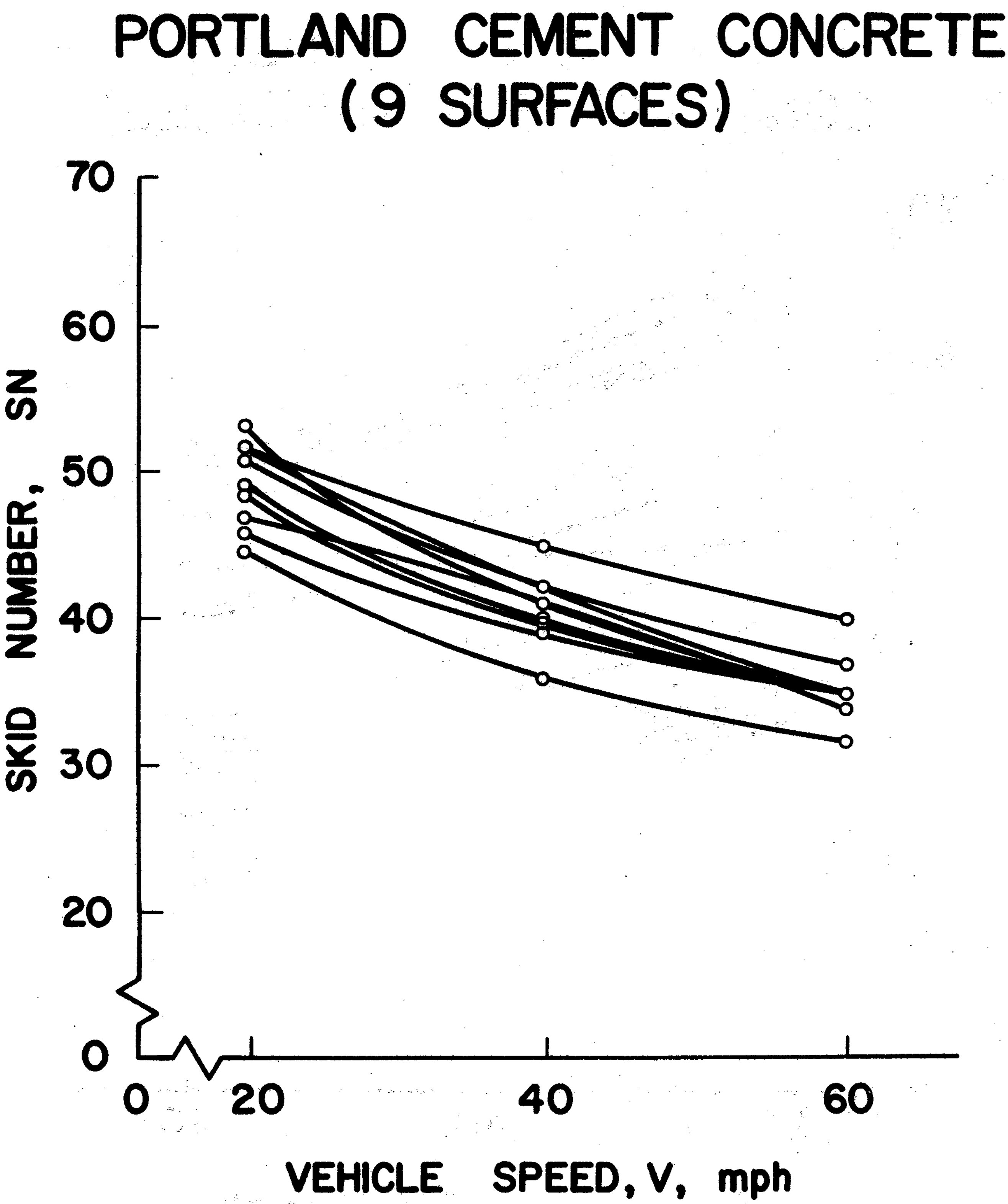


Figure 7. Skid Number-Speed Relationships for Portland Cement Concrete Surfaces.

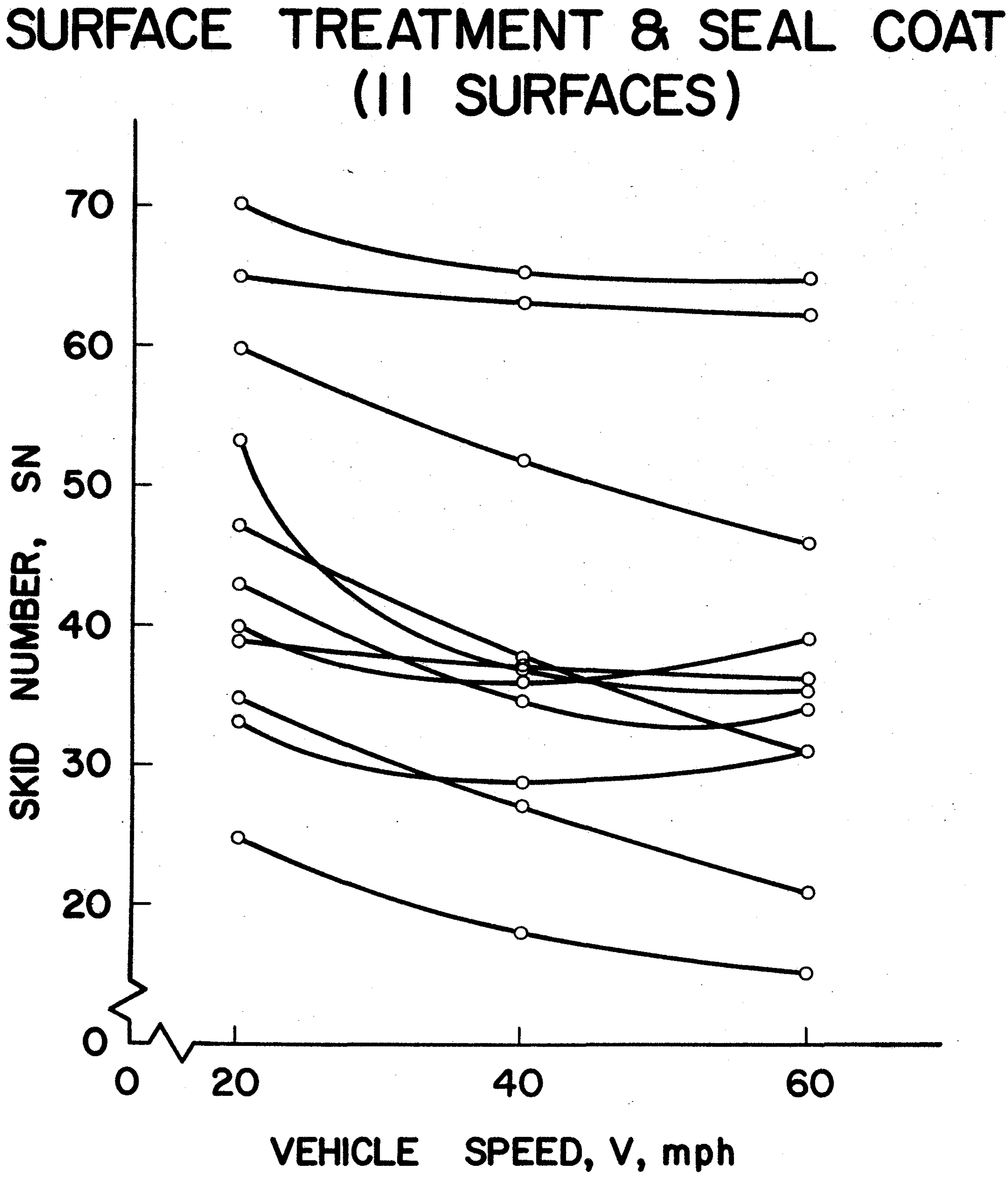


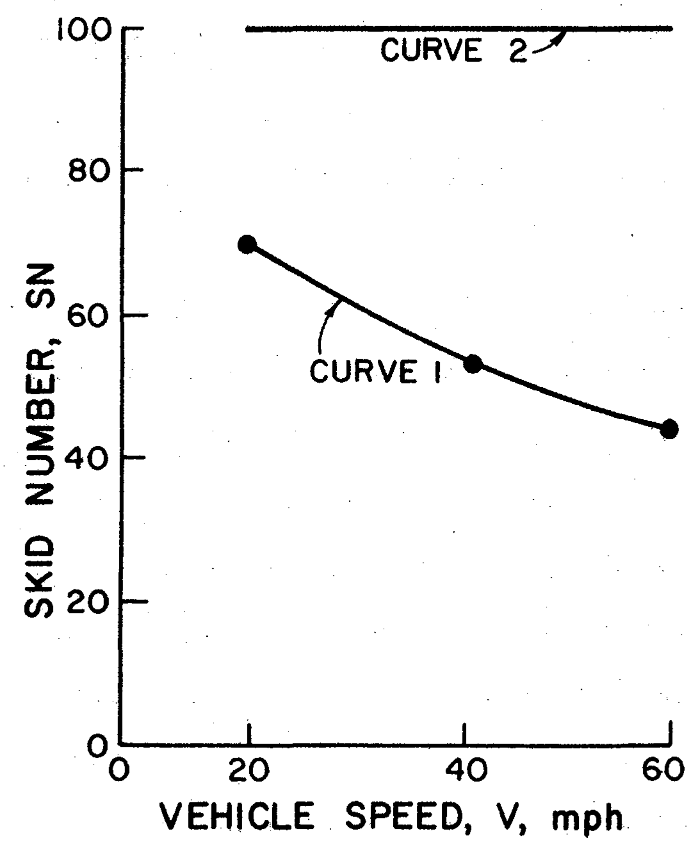
Figure 8. Skid Number-Speed Relationships for Surface Treatments and Seal Coats.

TEST PROCEDURE

A series of 20, 40, and 60 mph skid tests was conducted at four locations on each test surface. Ten texture measurements were taken at each location for a total of forty measurements per surface. All measurements were made in the outer wheel path.

Average skid numbers at 20, 40, and 60 mph respectively with appropriate temperature corrections were calculated for each test surface. In addition, for use in subsequent comparisons, average skid numbers between 20 and 60 mph were calculated. Provided abrupt slope changes in the skid number-speed curve do not occur, the average skid number is very nearly equal to the skid number at 40 mph. Calculations appear in Figure 9.

Gradients (denoted by G) of the skid number speed curve between 20 and 60 mph and between 20 and 40 mph were calculated. These have been used in previous reports. In addition, in order to reflect the relative position of the curve, percentage gradients were calculated. Curves of a given gradient positioned low on the graph would have higher percentage gradients than curves with the same gradient positioned high on the graph. Thus, percentage gradient is defined as the percentage of the gradient, obtained under test conditions, to a theoretical gradient if the skid number at the higher speed were zero. Calculations appear in Figure 10.



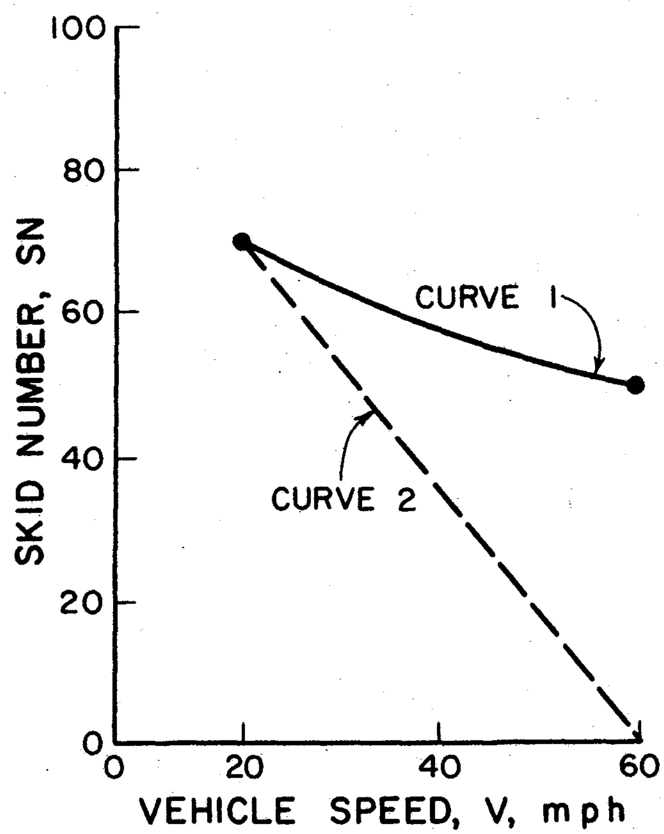
AVERAGE SKID NUMBER $A_V SN$ =

$$\frac{\text{AREA UNDER CURVE 1 } (A_1)}{\text{AREA UNDER CURVE 2 } (A_2)} \times 100$$

$$A_V SN_{20-60} \approx SN_{40}$$

NOTE: A_2 IS CONSTANT = 4000 UNITS

Figure 9. Average Skid Number Calculation.



$$\text{GRADIENT (G)} = \frac{SN_{20} - SN_{60}}{40}$$

$$\text{GRADIENT }(G_2) = \frac{SN_{20} - 0}{40}$$

$$\text{PERCENTAGE GRADIENT (PG)} = \frac{G}{G_2} \times 100 = \frac{SN_{20} - SN_{60}}{SN_{20}} \times 100$$

Figure 10. Gradient and Percentage Gradient Calculations.

DISCUSSION OF RESULTS

Macro-texture, friction, cross slope, and wheel track depression values for the surfaces with regard to service category and surface type are given in Tables 5 and 6 respectively. Values for each surface are contained in Appendix A. Aggregate type, average daily traffic and construction date for each surface are contained in Appendix B.

Statistical analyses were conducted to determine correlation coefficients, coefficients of determination, and regression lines for the comparisons established in this study. Results are contained in Tables 7-10.

Comparison of Macro-Texture Test Methods

Statistical correlation of the five macro-texture measures obtained on the 41 surfaces are given in Table 7. The relationships indicate a fairly high degree of correlation. A typical plot of one relationship is given in Figure 11. The most diverse data scatter was obtained at the extremities of the texture levels.

Comparison of Skid Number and Macro-Texture

Statistical correlation of skid numbers with macro-texture measures obtained on the 41 surfaces are contained in Table 8. Correlation coefficients were extremely low for all speed levels, but the relative magnitudes increased with higher speeds. Textures obtained with the profilograph consistantly

TABLE 5. SUMMARY VALUES WITH REGARD TO SERVICE CATEGORY

Service Category	Number of Surfaces Tested	Macro-Texture: Profilograph Average Peak Height (inches)*	Macro-Texture: Profilograph Accumulative Peak Height (inches)	Macro-Texture: Texture Meter Average Peak Height (inches)*	Macro-Texture: Modified Sand Patch Average Texture Depth (in)*	Macro-Texture: Putty Impression Average Texture Depth (in)*	Friction: Skid Number 20 MPH	Friction: Skid Number 40 MPH	Friction: Skid Number 60 MPH	Friction: Gradient 20-60 MPH	Friction: Percentage Gradient 20-60 MPH	Cross Slope in./ft.	Cross Slope in./ft.	Cross Slope ft./ft.	Wheel Track Depression Inside in.	Wheel Track Depression Outside in.
Interstate (IH) Marked Routes	11	.0213	.329	.0116	.0284	.0230	49	41	36	.32	26	.15	5/32	.013	1/64	1/64
Federal (US) Marked Routes	9	.0204	.373	.0130	.0205	.0200	51	45	42	.21	17	.15	5/32	.013	3/64	7/64
State (St) Marked Routes	7	.0215	.395	.0160	.0263	.0215	48	39	35	.31	25	.18	3/16	.015	3/64	5/64
Farm (FM) Marked Routes	9	.0377	1.752	.0309	.0638	.0454	55	48	46	.21	15	.22	7/32	.018	1/8	5/32
Test Surfaces Texas A&M Annex	5	.0184	.346	.0134	.0174	.0170	55	47	41	.33	26	.14	9/64	.011	0	0

*These are comparable values even though the descriptive terms differ.

TABLE 6. SUMMARY VALUES WITH REGARD TO SURFACE TYPE

Surface Type	Number of Surfaces Tested	Macro-Texture: Profilograph Average Peak Height (inches)*	Macro-Texture: Profilograph Accumulative Peak Height (inches)	Macro-Texture: Texture Meter Average Peak Height (inches)*	Macro-Texture: Modified Sand Patch Average Texture Depth (in)*	Macro-Texture: Putty Impression Average Texture Depth (in)*	Friction: Skid Number 20 MPH	Friction: Skid Number 40 MPH	Friction: Skid Number 60 MPH	Friction: Gradient 20-60 MPH	Friction: Percentage Gradient 20-60 MPH	Cross Slope*** in./ft.	Cross Slope*** in./ft.	Cross Slope*** ft./ft	Wheel Track Depression*** Inside in.	Wheel Track Depression*** Outside in.
Lignite Boiler Slag Hot Mix Asphalt Concrete	3	.0184	.023	.0021	.0078	.0079	47	41	37	.24	21	.14	9/64	.012	3/64	5/64
Rounded Siliceous Gravel Hot Mix Asphalt Concrete	4	.0252	.741	.0215	.0317	.0276	44**	39**	37**	.18**	16**	.13	9/64	.011	3/32	7/64
Crushed Limestone Aggregate Hot Mix Asphalt Concrete	4	.0177	.308	.0123	.0205	.0175	49**	40**	36**	.31**	26**	.15	9/64	.012	3/16	1/32
Crushed Siliceous Gravel Hot Mix Asphalt Concrete	4	.0227	.589	.0179	.0308	.0276	47**	41**	39**	.21**	18**	.14	9/64	.012	1/32	7/64
Crushed Sandstone Aggregate Hot Mix Asphalt Concrete	3	.0215	.299	.0142	.0159	.0212	68	60	56	.29	17	.19	3/16	.016	0	1/32
Open Graded Lightweight Aggregate Hot Mix Asphalt Concrete	3	.0262	1.107	.0264	.0406	.0324	64	55	49	.38	23	.21	13/64	.017	7/32	13/64
Hot Mix Asphalt Concrete	Ave. 21	.0219	.516	.0159	.0250	.0226	52	45	42	.26	20	.16	5/32	.013	3/32	3/32
Rounded Siliceous Gravel Portland Cement Concrete	5	.0210	.239	.0095	.0230	.0202	52	44	39	.35	26	.12	1/8	.010	0	0
Crushed Limestone Aggregate Portland Cement Concrete	3	.0188	.128	.0074	.0195	.0170	51	42	36	.37	29	.14	13/32	.011	0	0
Crushed Sandstone & Rounded River Gravel Portland Cement Concrete	1	.0203	.355	.0140	.0535	.0308	52	49	38	.35	27	.18	3/16	.015	0	0
Portland Cement Concrete	Ave. 9	.0202	.215	.0093	.0252	.0203	52	43	38	.36	27	.14	15/64	.011	0	0
Rounded Siliceous Gravel Surface Treatment	2	.0463	2.527	.0425	.0794	.0464	42	39	40	.06	5	.21	7/32	.018	2/32	13/64
Crushed Limestone Aggregate Surface Treatment	4	.0267	.879	.0226	.0569	.0450	46	37	35	.30	24	.20	13/64	.016	9/64	9/64
Lightweight Aggregate Surface Treatment	3	.0425	1.943	.0295	.0649	.0470	67	62	60	.19	11	.25	1/4	.021	1/32	3/64
Surface Treatment	Ave. 9	.0363	1.600	.0293	.0646	.0460	52	46	44	.21	15	.22	7/32	.018	3/32	1/8
Flushed Seals	2	.0154	.035	.0094	.0049	.0030	33	25	21	.29	36	.21	13/64	.017	1/32	3/32
Flushed Seals	Ave. 2	.0154	.035	.0094	.0049	.0030	33	25	21	.29	36	.21	13/64	.017	1/32	7/32

* These are comparable values even though the descriptive terms differ.
** One test section at Annex included which increases the average.
*** Test surfaces at Annex Excluded.

TABLE 7. STATISTICAL CORRELATION OF MACRO-TEXTURE TEST METHODS

No.	Variables Y	X	Regression Line	Correlation Coefficient	Coefficient of Determination	Standard Deviation
1	TDS	TDP	Y = -0.00 + 1.41 X	.93	.86	.009
2	TDS	APHP	Y = 0.02 + 0.03 X	.86	.74	.012
3	TDS	PHP	Y = -0.01 + 1.80 X	.81	.66	.014
4	TDS	PHTM	Y = 0.00 + 1.75 X	.86	.74	.012
5	TDP	APHP	Y = 0.02 + 0.02 X	.78	.61	.009
6	TDP	PHP	Y = -0.00 + 1.11 X	.77	.59	.010
7	TDP	PHTM	Y = 0.01 + 1.08 X	.81	.65	.009
8	APHP	PHP	Y = -1.01 + 68.64 X	.92	.85	.306
9	APHP	PHTM	Y = -0.42 + 63.30 X	.92	.85	.307
10	PHP	PHTM	Y = 0.01 + 0.76 X	.83	.68	.006

TDS = Average texture depth, sand method.

TDP = Average texture depth, putty method.

APHP = Accumulative peak height, profilograph method.

PHP = Average peak height, profilograph method.

PHTM = Average peak height, texturemeter method.

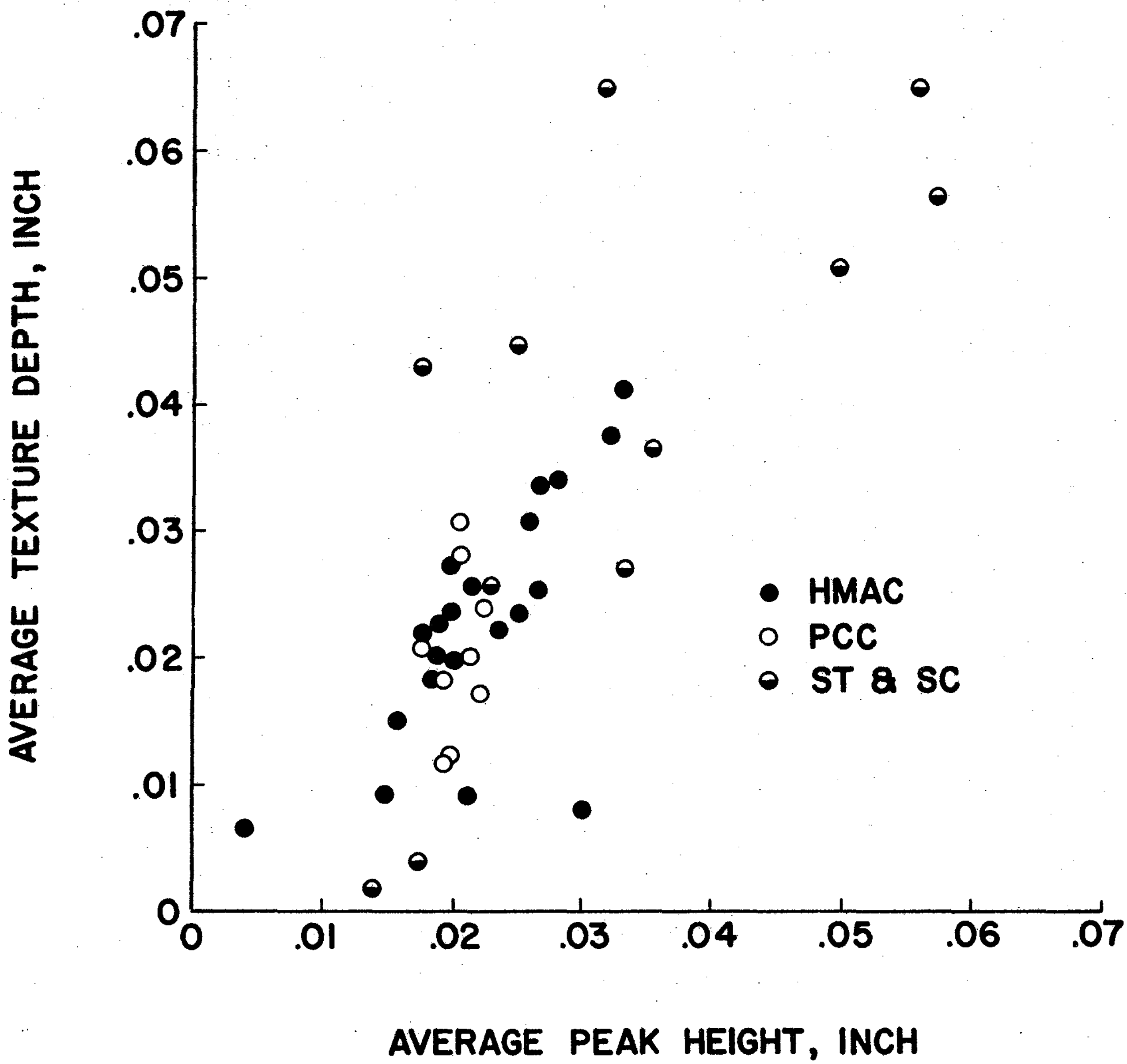


Figure 11. Comparison of Macro-Texture Tests, Putty Impression Versus Profilograph Methods.

TABLE 8. STATISTICAL CORRELATION OF SKID NUMBER AND MACRO-TEXTURE

No.	Variables Y	X	Regression Line	Correlation Coefficient	Coefficient of Determination	Standard Deviation
1	SN_{20}	TDS	Y = 48.35 + 13.18 X	.03	.00	11.79
2	SN_{20}	TDP	Y = 45.09 + 140.37 X	.18	.03	11.60
3	SN_{20}	APHP	Y = 47.54 + 1.87 X	.12	.02	11.70
4	SN_{20}	PHP	Y = 44.23 + 186.81 X	.17	.03	11.63
5	SN_{20}	PHTM	Y = 47.56 + 71.59 X	.07	.00	11.77
6	SN_{40}	TDS	Y = 40.09 + 46.58 X	.10	.01	11.26
7	SN_{40}	TDP	Y = 37.01 + 175.08 X	.24	.06	10.99
8	SN_{40}	APHP	Y = 39.17 + 3.67 X	.25	.06	10.94
9	SN_{40}	PHP	Y = 33.87 + 317.44 X	.30	.09	10.81
10	SN_{40}	PHTM	Y = 38.51 + 181.39 X	.18	.03	11.12
11	SN_{60}	TDS	Y = 34.37 + 110.84 X	.24	.06	10.43
12	SN_{60}	TDP	Y = 31.44 + 250.00 X	.35	.13	10.04
13	SN_{60}	APHP	Y = 34.26 + 5.63 X	.41	.17	9.79
14	SN_{60}	PHP	Y = 26.36 + 477.12 X	.47	.22	9.49
15	SN_{60}	PHTM	Y = 32.73 + 307.97 X	.33	.11	10.15
16	ASN	TDS	Y = 40.74 + 49.63 X	.10	.01	11.03
17	ASN	TDP	Y = 37.65 + 179.60 X	.25	.06	10.75
18	ASN	APHP	Y = 39.97 + 3.60 X	.25	.06	10.73
19	ASN	PHP	Y = 34.64 + 316.77 X	.30	.09	10.58
20	ASN	PHTM	Y = 39.26 + 181.42 X	.19	.03	10.90

SN = Skid number, suffix indicating speed in mph.

ASN = Average skid number between 20 and 60 mph.

TDS = Average texture depth, sand method.

TDP = Average texture depth, putty method.

APHP = Accumulative peak height, profilograph method.

PHP = Average peak height, profilograph method.

PHTM = Average peak height, texturemeter method.

correlated better with skid numbers. A typical plot of one relationship is given in Figure 12. A slight trend is noticeable.

Comparison of Gradient and Macro-Texture

Statistical correlation of friction-speed gradients obtained from 20-40 mph and from 20-60 mph with macro-texture measures obtained on the 41 surfaces are listed in Table 9. Correlation coefficients were fairly low, particularly for the logrithmic relationships. Gradient computations from 20-60 mph resulted in higher coefficients than those from 20-40 mph. Also, the "mechanical roughness detector" instruments (profilograph and texturemeter) gave higher coefficients than the "volumetric" measures (putty and sand). A typical plot is shown in Figure 13.

Comparison of Percentage Gradient and Macro-Texture

Statistical correlation of friction-speed percentage gradients obtained from 20-40 mph and from 20-60 mph with macro-texture measures obtained on the 41 surfaces are listed in Table 10. Relative trends were the same as those for corresponding gradient comparisons; however, magnitudes in each case were greater, indicating better correlation. Again, as was evident from the gradient comparisons presented previously, macro-texture effects on friction increase with higher speeds. A typical plot is given in Figure 14.

Comparison of Gradient and Skid Number

Friction-speed gradients and average skid numbers from

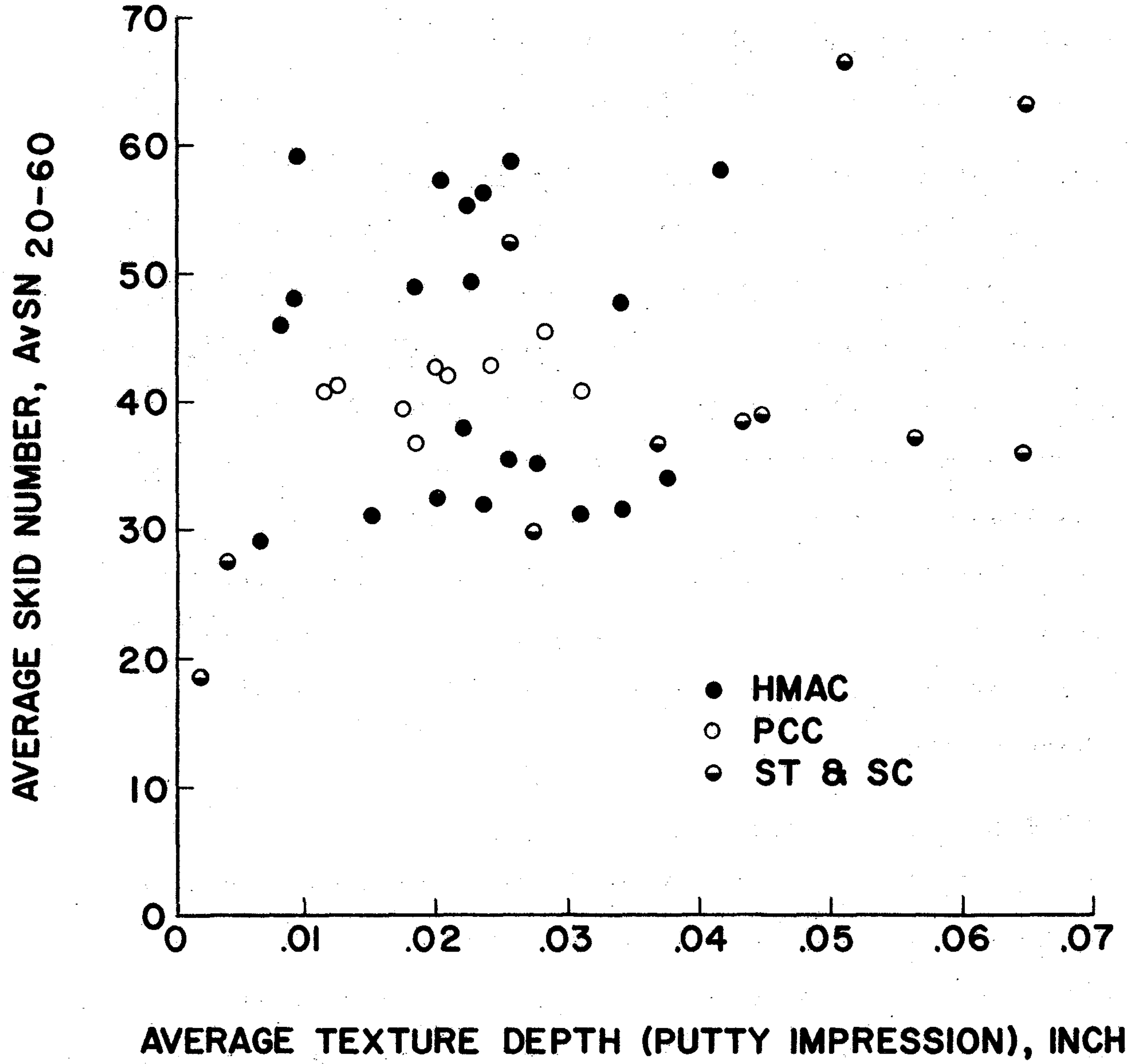


Figure 12. Average Skid Number Versus Macro-Texture.

TABLE 9. STATISTICAL CORRELATION OF GRADIENT AND MACRO-TEXTURE

No.	Variables Y	X	Regression Line	Correlation Coefficient	Coefficient of Determination	Standard Deviation
1	G_{20-40}	TDS	Y = 0.41 - 1.67 X	-.27	.07	.140
2	G_{20-40}	TDP	Y = 0.40 - 1.74 X	-.18	.03	.143
3	G_{20-40}	APHP	Y = 0.42 - 0.09 X	-.48	.23	.127
4	G_{20-40}	PHP	Y = 0.52 - 6.53 X	-.47	.22	.128
5	G_{20-40}	PHTM	Y = 0.45 - 5.50 X	-.43	.19	.131
6	G_{20-40}	ln TDS	Y = 0.31 - 0.01 ln X	-.08	.01	.145
7	G_{20-40}	ln TDP	Y = 0.27 - 0.02 ln X	-.11	.01	.145
8	G_{20-40}	ln APHP	Y = 0.33 - 0.02 ln X	-.24	.06	.141
9	G_{20-40}	ln PHP	Y = -0.09 - 0.12 ln X	-.35	.13	.136
10	G_{20-40}	ln PHTM	Y = 0.32 - 0.01 ln X	-.07	.01	.145
11	G_{20-60}	TDS	Y = 0.35 - 2.44 X	-.44	.20	.115
12	G_{20-60}	TDP	Y = 0.34 - 2.75 X	-.33	.11	.121
13	G_{20-60}	APHP	Y = 0.33 - 0.09 X	-.57	.33	.105
14	G_{20-60}	PHP	Y = 0.45 - 7.24 X	-.59	.35	.103
15	G_{20-60}	PHTM	Y = 0.37 - 5.91 X	-.53	.28	.109
16	G_{20-60}	ln TDS	Y = 0.15 - 0.03 ln X	-.22	.05	.125
17	G_{20-60}	ln TDP	Y = 0.12 - 0.04 ln X	-.23	.05	.125
18	G_{20-60}	ln APHP	Y = 0.24 - 0.03 ln X	-.33	.11	.121
19	G_{20-60}	ln PHP	Y = -0.27 - 0.14 ln X	-.48	.23	.112
20	G_{20-60}	ln PHTM	Y = 0.21 - 0.01 ln X	-.15	.02	.127

G = Gradient (slope) of the friction-speed curve, suffix indicating speed range in mph.

TDS = Average texture depth, sand method.

TDP = Average texture depth, putty method.

APHP = Accumulative peak height, profilograph method.

PHP = Average peak height, profilograph method.

PHTM = Average peak height, texturemeter method.

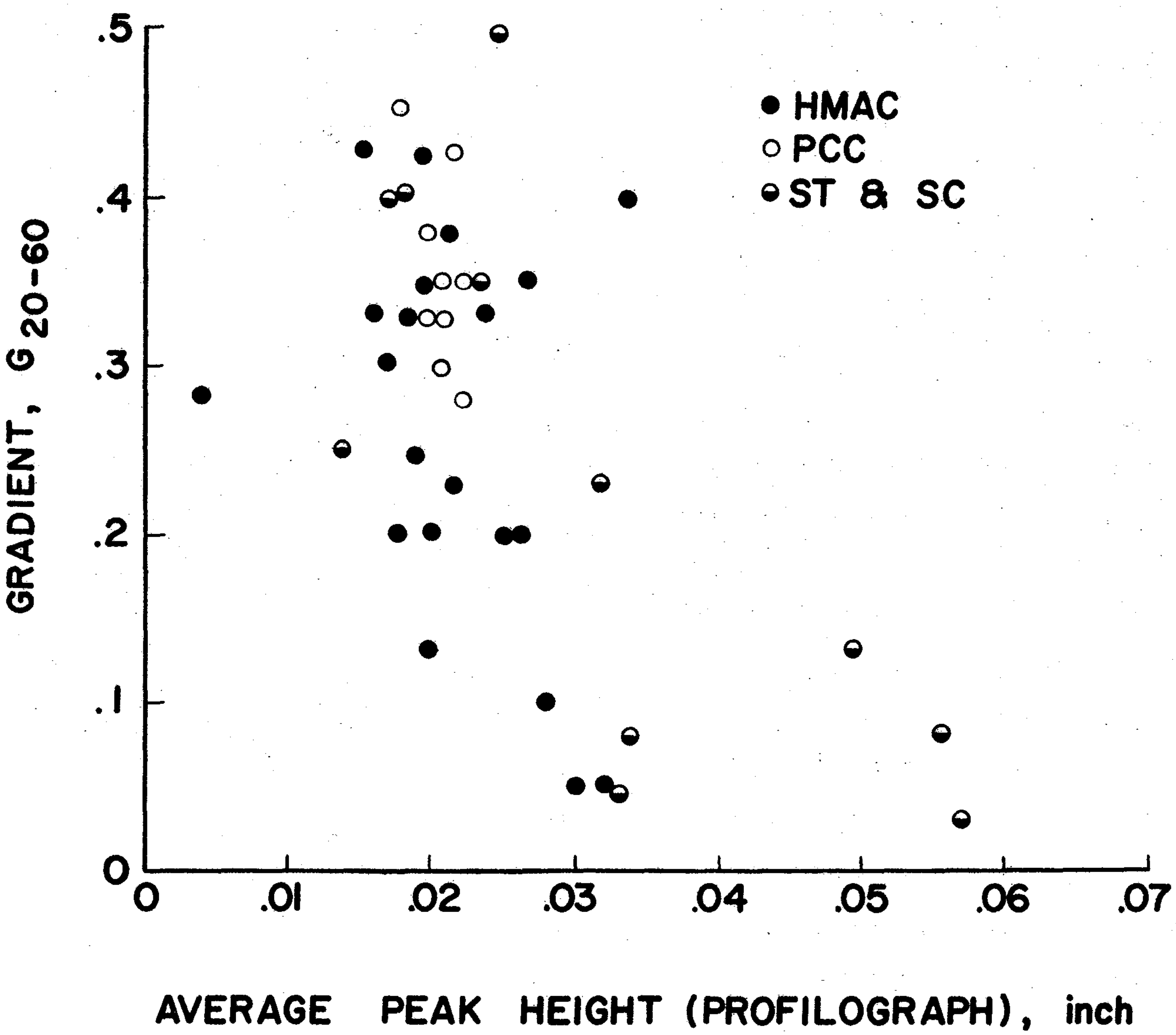


Figure 13. Gradient Versus Macro-Texture.

TABLE 10. STATISTICAL CORRELATION OF PERCENTAGE GRADIENT AND MACRO-TEXTURE

No.	Variables Y	X	Regression Line	Correlation Coefficient	Coefficient of Determination	Standard Deviation
1	PG_{20-40}	TDS	Y = 17.7 - 81.0 X	-.31	.09	5.77
2	PG_{20-40}	TDP	Y = 18.3 - 122.3 X	-.31	.09	5.77
3	PG_{20-40}	APHP	Y = 17.9 - 4.2 X	-.54	.30	5.09
4	PG_{20-40}	PHP	Y = 22.9 - 321.4 X	-.56	.31	5.04
5	PG_{20-40}	PHTM	Y = 19.3 - 249.0 X	-.47	.22	5.36
6	PG_{20-40}	ln TDS	Y = 9.6 - 1.5 ln X	-.21	.05	5.93
7	PG_{20-40}	ln TDP	Y = 3.1 - 3.1 ln X	-.37	.14	5.63
8	PG_{20-40}	ln APHP	Y = 13.0 - 1.9 ln X	-.45	.20	5.42
9	PG_{20-40}	ln PHP	Y = -10.7 - 6.8 ln X	-.49	.24	5.31
10	PG_{20-40}	ln PHTM	Y = 12.1 - 0.7 ln X	-.14	.02	6.01
11	PG_{20-60}	TDS	Y = 29.6 - 225.1 X	-.53	.28	8.44
12	PG_{20-60}	TDP	Y = 30.1 - 301.7 X	-.46	.21	8.80
13	PG_{20-60}	APHP	Y = 28.0 - 8.7 X	-.69	.47	7.21
14	PG_{20-60}	PHP	Y = 38.8 - 680.3 X	-.72	.52	6.88
15	PG_{20-60}	PHTM	Y = 31.5 - 545.7 X	-.63	.39	7.74
16	PG_{20-60}	ln TDS	Y = 7.2 - 4.0 ln X	-.36	.13	9.27
17	PG_{20-60}	ln TDP	Y = 2.6 - 6.5 ln X	-.47	.22	8.75
18	PG_{20-60}	ln APHP	Y = 17.9 - 3.8 ln X	-.56	.31	8.23
19	PG_{20-60}	ln PHP	Y = -33.7 - 14.7 ln X	-.64	.41	7.60
20	PG_{20-60}	ln PHTM	Y = 14.2 - 1.8 ln X	-.24	.06	9.65

PG = Percentage gradient of the friction-speed curve, suffix indicating speed range in mph.

TDS = Average texture depth, sand method.

TDP = Average texture depth, putty method.

APHP = Accumulative peak height, profilograph method.

PHP = Average peak height, profilograph method.

PHTM = Average peak height, texturemeter method.

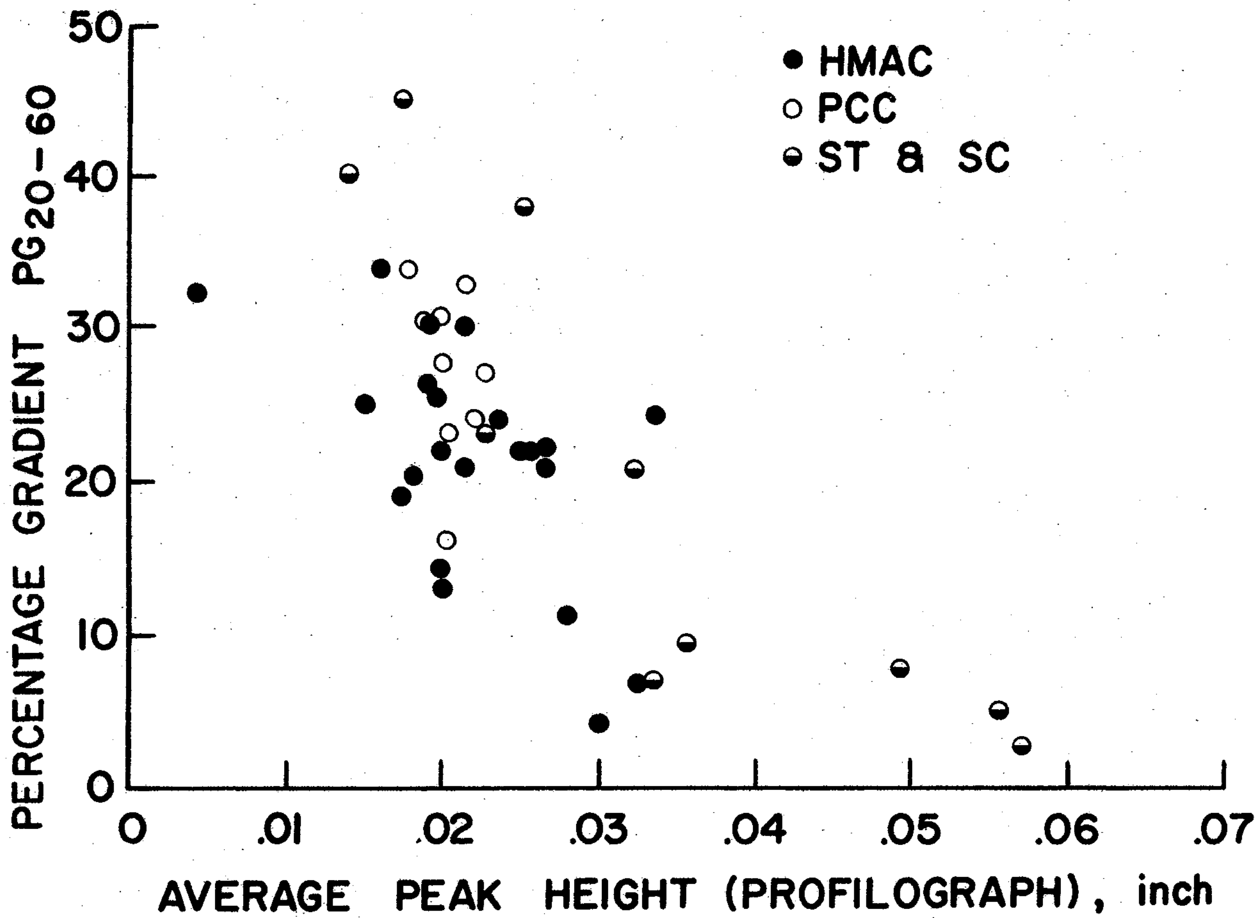


Figure 14. Percentage Gradient Versus Macro-Texture.

20-60 mph for the 41 pavements are plotted in Figure 15. A relationship did not exist.

Pavement Cross Slope

It appears to be evident from the data presented that, of those pavements included in this study, an increase in cross slope is desirable. This may be due, in part at least, to improved designs and construction procedures. The use of paved shoulders on two-lane highways may generally reduce the subsidance of the outside one third of a traffic lane, such subsidance being caused in the past by less construction compaction at the pavement edge and subsequently greater permanent deformation in service.

Where highly compacted shoulders are added to existing two-lane facilities without reconstruction of the traveled roadway, permanent deformation could be occurring at higher rates on the traveled lanes and thus in time cross slope could be lost. Whatever the reason for the existing mild cross slopes, some improvement in this area appears warranted.

Only in widely scattered instances were wheel path depressions found to be of any concern. In some areas of the state on the secondary road system there is some evidence of rutting or depressions in the wheel path. Excessive localized depressions are usually due to structural weaknesses in the subgrade. Such instances of permanent deformation were excluded from this study. Only those depressions, apparently caused by consolidation due to traffic loads, were included.

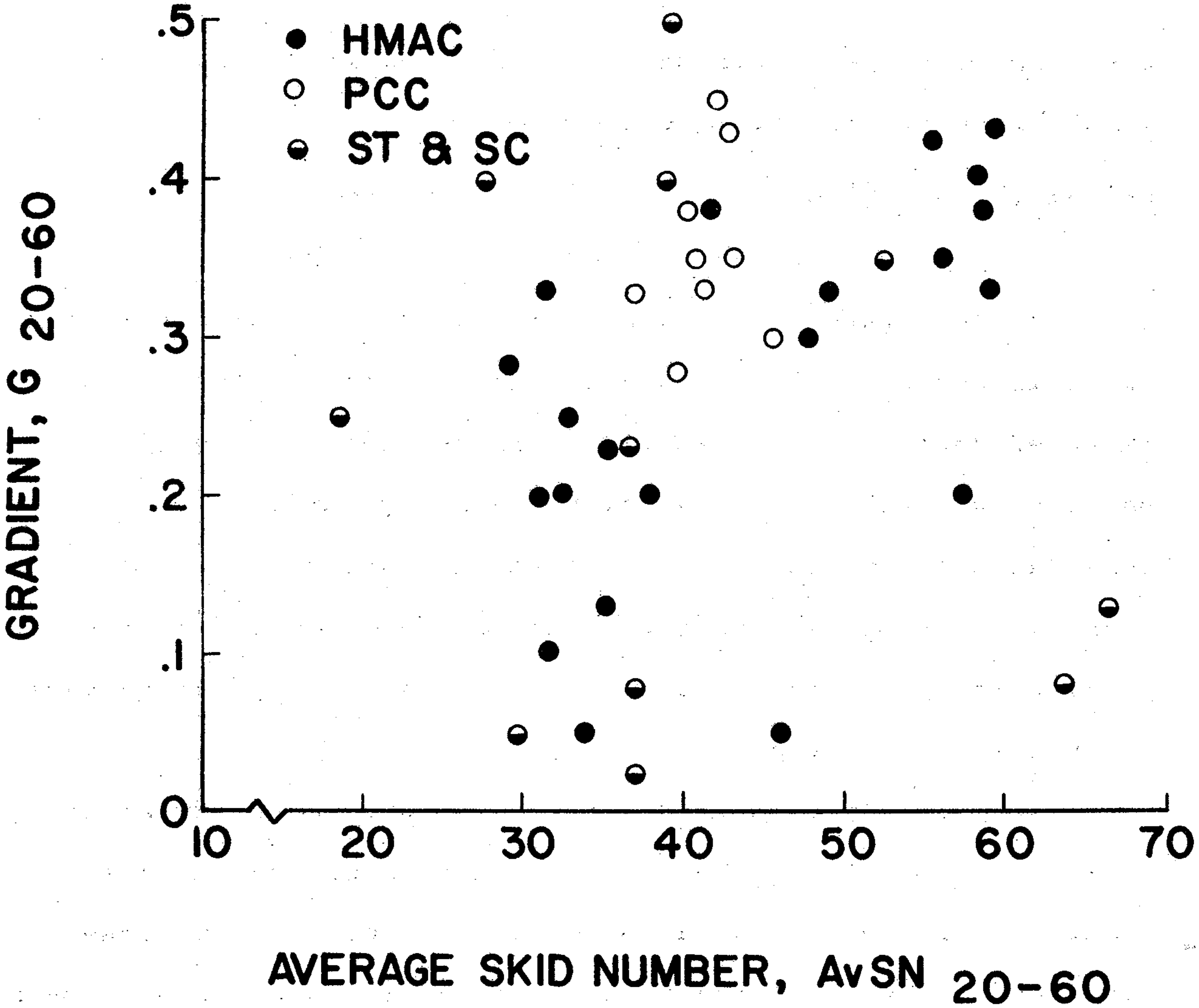


Figure 15. Gradient Versus Average Skid Number.

CONCLUSIONS

1. The four methods used to evaluate pavement surface macro-texture provide acceptable data and furthermore texture values obtained by the different methods compare favorably.
2. The profilograph method for measurement of macro-texture is preferred because of its simplicity, reproducibility, and better correlation with friction parameters. However, statistically, even results obtained with the profilograph do not relate favorably with friction parameters.
3. Macro-texture was found to range from 0.00 to 0.07-inch on a random sample of 41 Texas Highways. The larger values were associated with surface treatments composed almost entirely of aggregate; whereas the smaller values were associated with "flushed" seals. The majority of the surfaces were in the 0.015 - 0.035-inch range which included most of the hot mix asphalt concrete and portland cement concrete pavements.
4. For the water film thicknesses used in this study, no correlation was found between 20, 40, and 60 mph skid numbers and macro-texture. Macro-texture effects accounted for a maximum of three per cent at the variation in skid numbers at 20 mph, nine per cent at 40 mph and 22 per cent at 60 mph.
5. For the water film thicknesses used in this study, poor correlation was found between gradients of the friction-

speed curve and macro-texture. A maximum of 23 per cent at the variations in 20-40 mph gradients was explained by macro-texture effects, whereas 35 per cent of the variations in 20-60 mph gradients was explained.

6. For the water film thicknesses used in this study, a fair correlation was found between percentage gradients of the friction-speed curve and macro-texture. In these cases maximums of 31 and 52 per cents of the variations in 20-40 and 20-60 mph percentage gradients respectively were explained by macro-texture effects.

7. For the water film thicknesses used in this study, a relationship between gradient and skid number was not obtained.

8. For the water film thicknesses used in this study (approximately 0.020-inch), the existence of a high macro-texture level as measured by the four methods does not assure a high coefficient of friction.

9. For the water film thicknesses used in this study, the existence of extremely large scale macro-texture (>0.035-inch) assures a relatively flat friction-speed gradient; however, macro-texture <0.035-inch does not assure a flat friction-speed gradient.

10. The effect of aggregate micro-texture is included in many of the measurements made in the study, but the magnitude of the effect remains unknown. A clear understanding of

the total problem hinges, at least in part, on the magnitude of the effect of micro-texture.

11. Water depth on the pavement surface was held reasonably constant in the study; so, the effect of varying this factor was not investigated. Skid numbers are largely affected by micro- and macro-texture on the surface and internal drainage into the surface as well as pavement water depth and vehicle speed.

12. Somewhat different results would also be expected if smooth rather than treaded tires had been used.

13. The data appear to indicate a need for an increase in the constructed cross slope of Texas pavements, particularly on pavements with a low level of macro-texture which are zoned for relatively high vehicular speeds.

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APPENDIX A

TABLE II. MACRO-TEXTURE, FRICTION, CROSS SLOPE, AND WHEEL TRACK DEPRESSION VALUES FOR EACH SURFACE

Surface Number	Route	County	Surface Type	Macro-Texture: Profilograph: Average Peak Height, inches*	Macro-Texture: Profilograph: Accumulative Peak Height, inches	Macro-Texture: Texture Meter: Average Peak Height, inches*	Macro-Texture: Modified Sand Patch: Average Texture Depth, in.*	Macro-Texture: Putty Impression: Average Texture Depth, in.*	Friction: Skid Number: 20 MPH	Friction: Skid Number: 40 MPH	Friction: Skid Number: 60 MPH	Friction: Gradient: 20-60 MPH	Friction: Percentage Gradient: 20-60 MPH	Cross Slope: in/ft	Cross Slope: in/ft	Cross Slope: ft/ft	Wheel Track Depression: Inside: Inches	Wheel Track Depression: Outside: Inches
1	US 79	Milam	Lignite Boiler Slag Hot Mix Asphalt Concrete	.0300	.023	.0001	.0018	.0081	51	49	49	.05	4	.16	5/32	.013	0	1/32
2	US 75	Freestone	Lignite Boiler Slag Hot Mix Asphalt Concrete	.0040	.005	.0001	.0074	.0065	38	32	27	.28	29	.09	3/32	.008	7/64	5/32
3	St 6	Brazos	Lignite Boiler Slag Hot Mix Asphalt Concrete	.0212	.043	.0062	.0142	.0090	51	41	36	.38	29	.18	3/16	.015	3/64	3/64
4	St 6	Robertson and Falls	Rounded Siliceous Gravel Hot Mix Asphalt Concrete	.0252	.605	.0216	.0268	.0234	39	33	31	.20	21	.13	1/8	.011	1/64	3/64
5	US 77	Milam	Rounded Siliceous Gravel Hot Mix Asphalt Concrete	.0198	.545	.0192	.0292	.0272	39	35	34	.13	13	.18	3/16	.015	5/32	13/64
6	US 77	Milam	Rounded Siliceous Gravel Hot Mix Asphalt Concrete	.0323	1.413	.0296	.0535	.0373	39	37	37	.05	5	.09	3/32	.008	3/32	3/32
7	IH 45	Walker	Crushed Limestone Aggregate Hot Mix Asphalt Concrete	.0213	.400	.0108	.0260	.0255	44	35	35	.23	20	.14	9/64	.012	3/64	0
8	IH 35	Travis	Crushed Limestone Aggregate Hot Mix Asphalt Concrete	.0188	.240	.0100	.0282	.0200	39	32	29	.25	26	.19	3/16	.016	1/16	3/64
9	US 290	Travis	Crushed Limestone Aggregate Hot Mix Asphalt Concrete	.0158	.230	.0134	.0212	.0150	41	33	28	.33	32	.11	7/64	.009	5/64	1/16
10	US 84	Freestone	Crushed Siliceous Gravel Hot Mix Asphalt Concrete	.0175	.245	.0116	.0242	.0220	46	40	38	.20	17	.11	7/64	.009	3/64	1/4
11	St 14	Limestone	Crushed Siliceous Gravel Hot Mix Asphalt Concrete	.0279	.908	.0274	.0463	.0340	39	33	35	.10	10	.16	5/32	.013	0	1/64
12	IH 35	McLennon	Crushed Siliceous Gravel Hot Mix Asphalt Concrete	.0259	.725	.0178	.0332	.0307	39	34	31	.20	21	.15	5/32	.013	1/16	1/16
13	US 84	Freestone	Crushed Sandstone Aggregate Hot Mix Asphalt Concrete	.0182	.168	.0100	.0121	.0182	70	61	57	.33	19	.21	13/64	.017	0	0
14	US 79	Anderson	Crushed Sandstone Aggregate Hot Mix Asphalt Concrete	.0265	.450	.0160	.0185	.0253	70	61	56	.35	20	.13	1/8	.011	0	0
15	US 287	Anderson	Crushed Sandstone Aggregate Hot Mix Asphalt Concrete	.0199	.278	.0166	.0170	.0200	63	58	55	.20	11	.23	15/64	.019	1/64	3/32
16	IH 35	Travis	Open Graded Lightweight Aggregate Hot Mix Asphalt Concrete	.0264	.958	.0294	.0500	.0336	57	50	45	.30	21	.15	5/32	.013	5/64	5/64
17	FM 1687	Brazos	Open Graded Lightweight Aggregate Hot Mix Asphalt Concrete	.0190	.697	.0198	.0289	.0224	67	56	50	.43	25	.19	3/16	.016	11/32	19/64
18	FM 1687	Brazos	Open Graded Lightweight Aggregate Hot Mix Asphalt Concrete	.0333	1.665	.0300	.0430	.0412	67	59	51	.40	24	.28	9/32	.023	7/32	7/32
19	IH 45	Walker	Rounded Siliceous Gravel Portland Cement Concrete	.0225	.270	.0100	.0273	.0240	52	43	38	.35	27	.14	9/64	.012	0	0
20	IH 45	Leon	Rounded Siliceous Gravel Portland Cement Concrete	.0210	.063	.0016	.0200	.0200	54	44	37	.43	32	.13	1/8	.011	0	0

*These are comparable values even though the descriptive terms differ.

TABLE II. (CONTINUED)

Surface Number	Route	County	Surface Type	Macro-Texture: Profilograph: Average Peak Height, inches	Macro-Texture: Profilograph: Accumulative Peak Height, inches	Macro-Texture: Texture Meter: Average Peak Height, inches	Macro-Texture: Modified Sand Patch: Average Texture Depth, in.	Macro-Texture: Putty Impression: Average Texture Depth, in.	Friction: Skid Number: 20 MPH	Friction: Skid Number: 40 MPH	Friction: Skid Number: 60 MPH	Friction: Gradient: 20-60 MPH	Friction: Percentage Gradient: 20-60 MPH	Cross Slope: in/ft	Cross Slope: in/ft	Cross Slope: ft/ft	Wheel Track Depression: Inside: Inches	Wheel Track Depression: Outside: Inches
21	IH 35	Hill	Rounded Siliceous Gravel Portland Cement Concrete	.0220	.225	.0118	.0158	.0173	49	42	38	.28	22	.15	5/32	.013	0	0
22	St 14	Limestone	Rounded Siliceous Gravel Portland Cement Concrete	.0191	.153	.0088	.0105	.0115	53	43	38	.38	28	.06	1/16	.005	0	0
23	IH 45	Walker	Crushed Limestone Aggregate Portland Cement Concrete	.0174	.113	.0016	.0210	.0207	55	43	37	.45	33	.10	3/32	.008	0	0
24	IH 10	Bexar	Crushed Limestone Aggregate Portland Cement Concrete	.0196	.088	.0080	.0178	.0122	49	43	36	.33	27	.17	11/64	.014	0	0
25	IH 10	Bexar	Crushed Limestone Aggregate Portland Cement Concrete	.0193	.183	.0126	.0198	.0182	48	39	35	.33	27	.14	9/64	.012	0	0
26	IH 45	Leon	Crushed Sandstone & Rounded Siliceous Gravel Portland Cement Concrete	.0203	.355	.0140	.0535	.0308	52	43	38	.35	27	.18	3/16	.015	0	0
27	FM 1644	Robertson	Rounded Siliceous Gravel Surface Treatment	.0355	1.863	.0300	.0597	.0364	40	38	37	.08	8	.17	11/64	.014	1/16	7/32
28	FM 2038	Brazos	Rounded Siliceous Gravel Surface Treatment	.0570	3.190	.0550	.0990	.0563	44	40	43	.03	2	.25	1/4	.021	3/64	11/64
29	FM 2818	Brazos	Crushed Limestone Aggregate Surface Treatment	.0330	1.600	.0262	.0560	.0272	37	33	35	.05	5	.16	5/32	.013	5/64	5/32
30	OSR	Brazos	Crushed Limestone Aggregate Surface Treatment	.0247	.518	.0140	.0555	.0448	53	37	33	.50	38	.21	13/64	.017	5/16	1/8
31	St 30	Grimes	Crushed Limestone Aggregate Surface Treatment	.0174	.543	.0216	.0395	.0432	50	41	34	.40	32	.16	5/32	.013	3/32	11/64
32	FM 50	Brazos	Crushed Limestone Aggregate Surface Treatment	.0317	.855	.0286	.0766	.0648	45	37	36	.23	20	.27	17/64	.022	1/16	3/32
33	FM 416	Navarro	Lightweight Aggregate Surface Treatment	.0557	2.840	.0394	.0818	.0648	66	64	63	.08	5	.26	17/64	.022	1/32	3/64
34	FM 2452	Navarro	Lightweight Aggregate Surface Treatment	.0493	2.538	.0352	.0733	.0506	73	68	68	.13	7	.15	5/32	.013	1/64	1/64
35	St 6	Brazos	Lightweight Aggregate Surface Treatment	.0225	.450	.0140	.0397	.0255	63	55	49	.35	22	.33	21/64	.027	1/16	1/16
36	St 6	Brazos	Flushed Seal Coat	.0171	.060	.0126	.0072	.0041	38	30	25	.33	34	.27	17/64	.022	1/16	3/16
T-1	Texas A&M	Brazos	Rounded Siliceous Gravel Hot Mix Asphalt Concrete	.0235	.400	.0156	.0173	.0224	57	51	44	.33	23	.12	1/8	.010	0	0
T-2	Texas A&M	Brazos	Crushed Siliceous Gravel Hot Mix Asphalt Concrete	.0195	.478	.0148	.0195	.0235	65	58	51	.35	22	.15	5/32	.013	0	0
T-3	Texas A&M	Brazos	Curshed Limestone Aggregate (Terrazzo Finish) Hot Mix Asphalt Concrete	.0149	.360	.0150	.0066	.0093	70	61	53	.43	24	.11	7/64	.009	0	0
T-4	Texas A&M	Brazos	Clay Filled Tar Emulsion Flushed Seal Coat	.0136	.009	.0062	.0025	.0019	27	20	17	.25	37	.14	9.64	.012	0	0
T-5	Texas A&M	Brazos	Rounded Sliceous Gravel Portland Cement Concrete	.0203	.484	.0156	.0412	.0280	54	47	42	.30	22	.18	3/16	.015	0	0

*These are comparable values even though the descriptive terms differ.

APPENDIX B

TABLE 12. AGGREGATE TYPE, AVERAGE DAILY TRAFFIC, AND CONSTRUCTION DATE FOR EACH SURFACE

Surface Number	Route	County	Surface Type	Aggregate			Average Daily Traffic (1968)	Construction Date
				% by Weight	Type	Max. Size		
1	US 79	Milam	Lignite Boiler Slag Hot Mix Asphalt Concrete	75	Lignite Boiler Slag Aggregate	3/8"	1,580	1967
				25	Limestone Screenings	#4		
2	US 75	Freestone	Lignite Boiler Slag Hot Mix Asphalt Concrete	75	Lignite Boiler Slag Aggregate	3/8"	6,620	1967
				25	Sandstone Screenings	#4		
3	St 6	Brazos	Lignite Boiler Slag Hot Mix Asphalt Concrete	75	Lignite Boiler Slag Aggregate	3/8"	4,200	1965
				15	Limestone Screenings	#4		
				10	Field Sand	#40		
4	St 6	Robertson & Falls	Rounded Siliceous Gravel Hot Mix Asphalt Concrete	63	Rounded Siliceous Gravel	1/2"	1,420	1968
				37	Siliceous Sand	#10		
5	US 77	Milam	Rounded Siliceous Gravel Hot Mix Asphalt Concrete	55	Rounded Siliceous Gravel	5/8"	1,960	1964
				30	Siliceous Sand	#10		
				15	Limestone Screenings	#10		
6	US 77	Milam	Rounded Siliceous Gravel Hot Mix Asphalt Concrete	58	Rounded Siliceous Gravel	5/8"	1,560	1960
				25	Limestone Screenings	1/4"		
				17	Field Sand	#40		
7	IH 45	Walker	Crushed Limestone Aggregate Hot Mix Asphalt Concrete	30	Crushed Limestone	5/8"	8,933	1968
				30	Crushed Limestone	5/8"		
				40	Field Sand	#10		
8	IH 35	Travis	Crushed Limestone Aggregate Hot Mix Asphalt Concrete	64	Crushed Limestone and Limestone Screenings	3/8"	14,740	1967
				36	Rounded Siliceous Sand	#10		
9	US 290	Travis	Crushed Limestone Aggregate Hot Mix Asphalt Concrete	65	Crushed Limestone Gravel	3/8"	4,695	1965
				35	Rounded Siliceous Sand	#10		
10	US 84	Freestone	Crushed Siliceous Gravel Hot Mix Asphalt Concrete	50	Crushed Siliceous Gravel	3/8"	2,400	1964
				30	Crushed Screenings	#4		
				10	Concrete Sand	#4		
				10	River Sand	#40		
11	St 14	Limestone	Crushed Siliceous Gravel Hot Mix Asphalt Concrete	25	Rounded Siliceous Gravel	3/8"	3,655	1967
				40	Crushed Siliceous Gravel	3/8"		
				15	Siliceous (concrete) Sand	#4		
				20	Siliceous Field Sand	#40		
12	IH 35	McLennon	Crushed Siliceous Gravel Hot Mix Asphalt Concrete	25	Rounded Siliceous Gravel	3/8"	15,855	1967
				40	Crushed Siliceous Gravel	3/8"		
				15	Siliceous (concrete) Sand	#4		
				20	Siliceous Field Sand	#40		
13	US 84	Freestone	Crushed Sandstone Aggregate Hot Mix Asphalt Concrete	65	Crushed Sandstone	3/8"	1,310	1965
				35	Crushed Sandstone Screenings	#40		
14	US 79	Anderson	Crushed Sandstone Aggregate Hot Mix Asphalt Concrete	40	Crushed Sandstone	3/8"	3,075	1964
				25	Crushed Sandstone	#4		
				35	Sandstone Screenings	#40		
15	US 287	Anderson	Crushed Sandstone Aggregate Hot Mix asphalt Concrete	50	Crushed Sandstone	3/8"	4,560	1968
				20	Crushed Sandstone	#4		
				30	Sandstone Screenings	#40		
16	IH 35	Travis	Open-Graded Lightweight Aggregate Hot Mix Asphalt Concrete	58	Lightweight Aggregate	1/2"	47,000	1968
				25	Lignite Boiler Slag	#4		
				9	Limestone Screenings	#10		
				8	Field Sand	#10		
17	FM 1687	Brazos	Open-Graded Lightweight Aggregate Hot Mix Asphalt Concrete	44	Lightweight Aggregate	3/8"	700	1968
				56	Lignite Boiler Slag Aggregate	3/8"		
18	FM 1687	Brazos	Open-Graded Lightweight Aggregate Hot Mix Asphalt Concrete	50	Lightweight Aggregate	1/2"	700	1968
				50	Lignite Boiler Slag Aggregate	3/8"		

TABLE 12. (CONTINUED)

Surface Number	Route	County	Surface Type	Aggregate % by Weight	Aggregate Type	Aggregate Max. Size	Average Daily Traffic (1968)	Construction Date
19	IH 45	Walker	Rounded Siliceous Gravel Portland Cement Concrete	67	Rounded Siliceous Gravel	2-1/2"	11,350	1961
				33	Siliceous Sand	1/4"		
20	IH 45	Leon	Rounded Siliceous Gravel Portland Cement Concrete	67	Rounded Siliceous Gravel	1-3/4"	6,030	1967
				33	Siliceous Sand	#4		
21	IH 35	Hill	Rounded Siliceous Gravel Portland Cement Concrete	60	Rounded Siliceous Gravel	1-1/4"	11,125	1964
				40	Siliceous Sand	1/4"		
22	St 14	Limestone	Rounded Siliceous Gravel Portland Cement Concrete		Coarse Rounded Siliceous Gravel	1-1/2"	920	1936
					Fine Rounded Siliceous Gravel			
					Mineral Filler			
23	IH 45	Walker	Crushed Limestone Aggregate Portland Cement Concrete	67	Crushed Limestone Aggregate	1-3/4"	7,320	1963
				33	Siliceous Sand	#4		
24	IH 10	Bexar	Crushed Limestone Aggregate Portland Cement Concrete	65	Crushed Limestone	1-3/4"	41,300	1967
				18	Crushed Limestone	#4		
				17	Siliceous Field Sand	#4		
25	IH 10	Bexar	Crushed Limestone Aggregate Portland Cement Concrete	65	Crushed Limestone	1-3/4"	19,060	1958
				18	Crushed Limestone	#4		
				17	Siliceous Field Sand	#4		
26	IH 45	Leon	Crushed Sandstone and Rounded Siliceous Gravel Portland Cement Concrete	33	Crushed Sandstone	1-3/4"	Not Open to Traffic	1969
				33	Rounded Siliceous Gravel	1-3/4"		
				33	Siliceous Sand	1/4"		
27	FM 1644	Robertson	Rounded Siliceous Gravel Surface Treatment	100	Rounded Siliceous Gravel	3/8"	105	1967
28	FM 2038	Brazos	Rounded Siliceous Gravel Surface Treatment	100	Rounded Siliceous Gravel	1/2"	135	1968
29	FM 2818	Brazos	Crushed Limestone Aggregate Surface Treatment	100	Crushed Limestone	1/2"	1,275	1964
30	OSR	Brazos	Crushed Limestone Aggregate Surface Treatment	100	Crushed Limestone	3/8"	330	1968
31	St 30	Grimes	Crushed Limestone Aggregate Surface Treatment	100	Crushed Limestone	3/8"	820	1968
32	FM 50	Brazos	Crushed Limestone Aggregate Surface Treatment	100	Crushed Limestone	1/2"	660	1968
33	FM 416	Navarro	Lightweight Aggregate Surface Treatment	100	Lightweight Aggregate	1/2"	100	1964
34	FM 2452	Navarro	Lightweight Aggregate Surface Treatment	100	Lightweight Aggregate	1/2"	300	1964
35	St 6	Brazos	Lightweight Aggregate Surface Treatment	100	Lightweight Aggregate	1/2"	18,210	1968
36	St 6	Brazos	Flushed Seal Coat		No Aggregate		18,210	1968
T-1	Texas A&M Annex	Brazos	Rounded Siliceous Gravel Hot Mix Asphalt Concrete	30	Coarse Rounded Siliceous Gravel	5/8"	none	1968
				25	Fine Rounded Siliceous Gravel			
				35	Crushed Limestone Fines			
				10	Field Sand			
T-2	Texas A&M Annex	Brazos	Crushed Siliceous Gravel Hot Mix Asphalt Concrete	60	Coarse Crushed Siliceous Gravel	1/4"	none	1968
				20	Fine Crushed Siliceous Gravel			
				20	Field Sand			
T-3	Texas A&M Annex	Brazos	Crushed Limestone Aggregate (Terrazzo Finish) Hot Mix Asphalt Concrete	35	Coarse Crushed Limestone	1/2"	none	1968
				30	Medium Crushed Limestone			
				25	Fine Crushed Limestone			
				10	Field Sand			
T-4	Texas A&M Annex	Brazos	Clay Filled Tar Emulsion Flushed Seal Coat		No Aggregate		none	1968
T-5	Texas A&M Annex	Brazos	Rounded Siliceous Gravel Portland Cement Concrete	67	Rounded Siliceous Gravel	1-1/2"	none	1953
				33	Siliceous Gravel	1/4"		