PAVEMENT SURFACE TEXTURE

AS RELATED TO SKID RESISTANCE

by

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The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Bureau of Public Roads.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

A B S T R A C T

There is an increasing awareness of the importance of the contribution of pavement texture to skid resistance. Pavement texture has been characterized in this study by using several parameters which were calculated from microprofile measurements. These parameters were correlated with skid resistance measured at 20 miles-per-hour and 50 miles-per-hour velocities by a two-wheeled test trailer.

An instrument was designed to measure accurately the profile of the pavement surface. This equipment is sensitive to vertical measurements as small as 42 micro inches and as large as one inch. Horizontal sensitivity was found to be 0.0033 inch.

A method was devised to separate the smaller aggregate texture from the large scale pavement texture. An analysis of aggregate and pavement texture indicates that a combination of both types are necessary to describe skid resistance.

I. INTRODUCTION

Background

Since the advent of the automobile, there has been an increasing necessity for skid resistant surfaces to control deceleration or acceleration of the vehicle. While the mechanical age was still in the "Model-A era", a way was found to measure skid resistance quantitatively. This method was described by Agg in 1924[1] and 1928.[2]* Through the years, as more and faster vehicles were placed in operation and more highways and streets were constructed to accommodate these vehicles, researchers began to discover and isolate the variables connected with skid resistance. Probably the most complete list of these variables was reported by Moyer in the Proceedings of the First International Skid Prevention Conference in 1959.[3]

Included in Moyer's list of variables that affect skid resistance is the term "texture". Very little is known about texture as it relates to the behavior of construction materials. Texture is believed to contribute to the strength of materials and to other engineering material properties. The illusiveness of this variable appears to be due largely to the lack of adequate quantitative measurements of texture parameters.

Objectives

The objectives of the investigation reported herein are concerned with the development of equipment and techniques for measuring certain parameters that can be used to describe the texture of pavement surfaces in quantitative terms. By correlating the measured variables of texture with skid resistance measurements, it is thought that a more complete understanding of skid resistance will result.

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*Numbers in parenthesis refer to items in the References.

Properties of Skid Resistance

In order to define skid resistance, it is interesting to review the process of vehicular skidding. Skidding results when the wheels of a vehicle are locked by braking and cease to rotate, but the vehicle continues to skid. "The frictional resistance offered by the pavement surface to the sliding tires is called skid resistance."(4)

Skid resistance is usually thought of as being composed of two terms:

(1) An adhesion term between the tire and pavement which is defined by the molecular forces.

(2) A deformation term between the tire and pavement defined by the energy absorption in the rubber resulting from contact with the surface projections.

Skid resistance is highly reduced on wet pavements when compared to the skid resistance of a dry pavement. This phenomena is largely due to a drastic reduction in the adhesion term since the water acts as a lubricant between the surfaces.

Nature of Pavement Texture

For the purposes of this report pavement texture is defined as that pattern, either regular or irregular, of small projections and depressions developed on the pavement surface by the exposed surfaces of individual aggregate particles or by the aggregate-binder matrix.

The history of pavement texture investigation is rather short. Some of the first reports that mention the influence of texture in connection with skid resistance were from the Oregon State Highway Department. In a two year testing period in 1938 and 1939, it was found that open-textured pavements produced higher skid resistances than closed-textured surfaces. It was believed that the open texture permitted the effective and rapid removal of surface water and provided what appeared to be a more intimate tire to pavement contact than that obtained on dense-textured pavements. It is also interesting to note in reports by Moyer[5] that tire companies in 1938 were developing tire tread designs that provided good drainage for the rapid removal of water.

In an indirect manner, texture was again brought into the spotlight when it was found that the tires of a vehicle can actually hydroplane under certain wet conditions. As early as 1959, it was found that the tire of a moving vehicle can lose all contact with the roadway and, in fact, cease to rotate when certain water film depths, tire pressures, and vehicle speeds are developed. However, the concept which the Oregon Highway Department suggested still provides background for explaining the influence of texture in the hydroplaning phenomena. The following excerpt was taken from a report by James P. Trant, Jr.:[6]

> In other words, before the tire in the footprint area can make contact with the solid surface, it must first force the water out of the way. The pressure of the tires acting on the water ejects the water, but, because of inertia of the water and viscous forces, this process takes time. Therefore, the faster the speed of the vehicle, the greater part of the weight of the wheel the water will support before the water can be squeezed out.

About the time the interest in hydroplaning increased, Sabey, of the United Kingdom, reported on pressure distributions of spherical and conical shapes which were pressed into the plane surface of a rubber sheet or block.[7] This report revealed pressure and penetration depths indicated by these two geometric shapes.

In the Autumn of 1965, Sabey also indicated other remarkable findings, and the following two paragraphs have been taken from a report to The British Granite and Whinstone Federation:[8]

> The first requirements for a good skidding resistance on wet roads is to facilitate breakthrough of the water film in order to establish areas of dry contact between the road and tyre. Drainage channels, provided by the large-scale texture of the road or by a pattern of the tyre, assist in getting rid of the main bulk of water and are of increasing importance the higher the speed. The penetration of the remaining water film can be achieved only if there are sufficient fine scale sharp edges in the road on which high pressures (about 1000 lb./sq. in.) are built up. The existance of such fine-scale sharpness gives the surfaces a harsh feel.
>
> When vehicles are travelling at speeds of about 30 mi./hr. the fine-scale texture of the road is the dominant factor determining skidding resistance. However, as they travel faster, it becomes increasingly difficult to penetrate the water film in the time available, however harsh the surface. At high speeds the requirements for a good skidding resistance are therefore difficult. The resistance to skidding arises to a larger extent from energy losses in the rubber of the tyre as the surface of the tread is deformed by projections in the road surface and, although the physical properties of the tread rubber are important in this respect, it is essential to have sufficiently large and angular projections in the road surface to deform the tread, even though a water film may still be present on the surface. At higher speeds the coarseness of texture becomes as important as its harshness.

Sabey also relates wet-road accidents to texture depth and reveals that the percentages of wet-road accidents involving skidding were 54 per cent of the total accidents on smooth surfaces and 39 per cent on coarse surfaces.

These facts point out the need for a closer examination of coefficient of friction differential with speed.

Coefficient of friction decreases with increased speed, but it is apparent that this reduction is not the same for all wet pavement surfaces. This coefficient differential variance appears to be due to the ability to remove water from between the tire and the surface. Texture is at least partially responsible for the removal of this water.

Moore, of Cornell Aeronautical Laboratory, Inc., describes three zones that affect skid resistance of wet pavement surfaces.[9] The first zone is the sinkage or squeeze-film zone in the initial stage of tire passage. In this zone the tire is not in contact with the pavement surface, but is separated by a layer of water. This is the area in which the water has not had time to squeeze out, a fact also reported by Trant and cited above. The second zone is the draping or transition zone in which the tire begins to make contact or drape over and around the surface asperities. The third zone is the actual contact or traction zone. This zone consists of the area under the tire in which the water has been squeezed out and the tire contacts the roadway surface. This zone occupies the rear portion of the overall contact area.

This theory indicates that the portion of the overall area in which the tire contacts or drapes over the surface asperities is highly important to skid resistance. It is interesting to digress at this point to observe the actual contact area in question. Most students of highway engineering are familiar with asperity prints of the tire pavement combination obtained by placing some form of printing paper between the tire and pavement surface. It may be noted by visual observation of these prints that the actual contact area is a small percentage of the total area which the tire covers.

Texture is needed to disperse water and texture is needed for skid resistance. It is quite possible that an optimum combination of the actual contact area between tire and pavement, and water dispersal area are indicated.

Methods of Measuring Texture

Texture measurements have been obtained by various means, but probably the method used the most is the sand patch method.[8] This consists of spreading a known volumn of uniformly graded sand over the pavement surface. This sand is leveled to the tops of the surface projections and the surface area which is covered is measured. The relation of area covered to the volume used is a relative measure of texture height.

A method of measuring the reflected light from a known source with the use of a photronic cell has been used as a measure of texture. James H. Havens reveals the use of a "60° Reflectometer" for measuring the "gloss" of pavement specimens in studying polishing characteristics of material in Kentucky.[9]

The Transportation Research Department, Cornell Aeronautical Laboratory, Inc. used a profile measuring device as well as an outflow meter to measure texture.[10] The profile measuring device produces a microprofile of the pavement surface irregularities. The outflow meter is essentially a transparent lucite open-end cylinder with a thin neoprene ring of square cross-section cemented to one end of the ring. In use, the apparatus is placed on the surface to be measured with the neoprene ring against the surface irregularities. The neoprene ring drapes over the surface asperities similar to the tread of a tire, and weight may be added to the ring to simulate increased tire pressure if necessary. The lucite ring is filled with water and the time of efflux for a certain quantity of water to flow between the neoprene and the surface is obtained. Assuming no water flow through the pavement structure, measurements of the drainage abilities of pavement surfaces may be obtained using the idea of the channel area and water quantity. These methods are used by hydraulics engineers when determining bridge or culvert size. Cornell Aeronautical Laboratory also used asperity-density prints in this study. Prussian blue was used to coat the surface before the paper and surface were pressed together.

It is believed that texture can be measured photogrammetrically. Stereo photographs can be used to measure planimetric detail as well as differences in elevations by using techniques similar to those used in aerial mapping.

Another method of defining texture is by visual inspection. In fact, most descriptions of texture to date stem from an attempt to define texture from visual inspection. Such words as "closed-textured", "open-texture", and "sandpaper-texture" have been used.

Pavement texture needs closer study. Interested parties should be able to converse about texture in quantitative terms.

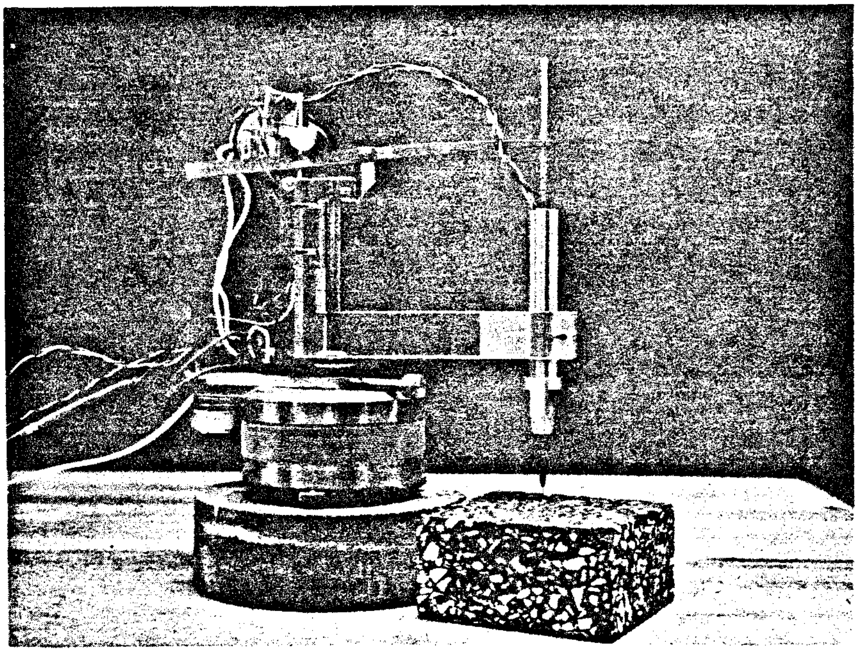
II. DESCRIPTION OF EQUIPMENT FOR EVALUATING TEXTURE

After reviewing the various methods that have been used for measuring texture it appeared that the most practicable method for characterizing texture was to determine the texture profile. Upon writing to several manufacturers, it was found that equipment with resolution sufficient to measure a range in heights from one-half inch down to micro inches was not in existence. Therefore, it was necessary to develop such equipment.

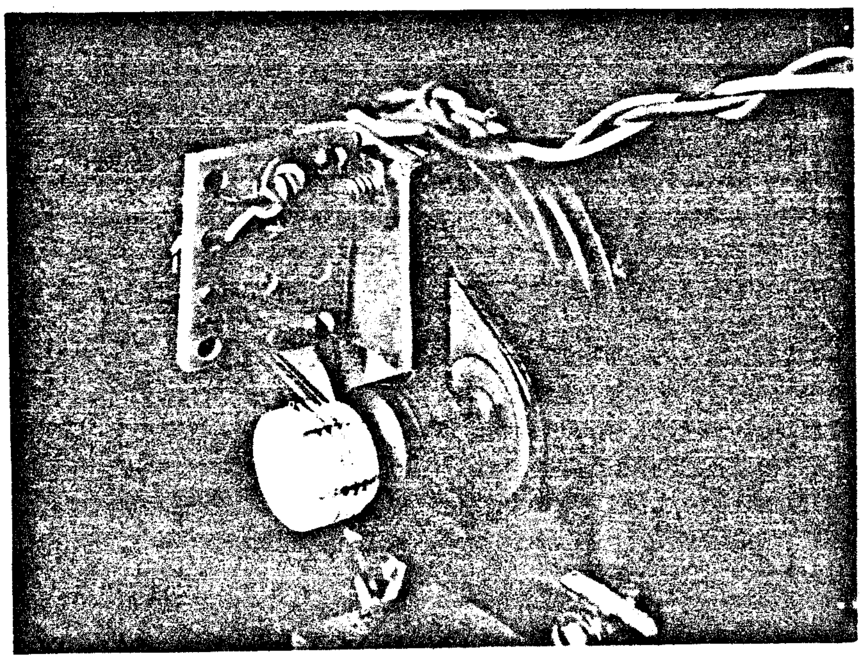
Probing Unit

The equipment used to evaluate texture was designed to produce a profile of the surface of the specimen measured. The profile is measured along the arc of a circle and is produced by the equipment shown in Figure 1. This figure shows a round steel shaft supported vertically in the center of a heavy steel cylindrical base. Attached to the shaft is a transverse cantilevered arm supported rigidly in the vertical direction, but allowed to swing freely in the horizontal direction. A synchronous clock motor, through a system of sprockets and chain, is used to drive the cantilever arm around the vertical shaft at a predetermined angular speed. A rubber "O" ring provides the frictional resistance necessary to transmit the driving torque from the large sprocket to the cantilever arm, but also precludes damage to the equipment if the traverse of the arm is stopped.

A linear variable differential transformer is attached to the cantilever arm near the outer extremity of the arm. The transformer is fed a constant D.C. voltage of 24 volts by a regulated power supply. The highly sensitive output voltage is dependent upon the vertical position of the transformer core. A second synchronous clock motor driving an offset cam moves a lever and causes the core inside the transformer to probe vertically. The lower end of the transformer core is fitted with an extension and a chuck for holding a common sewing needle. The tip of the needle probes along an arc as it is lifted and lowered at preselected intervals. The output voltage



Profile Measuring Equipment
FIGURE 1



Timing Switch
FIGURE 2

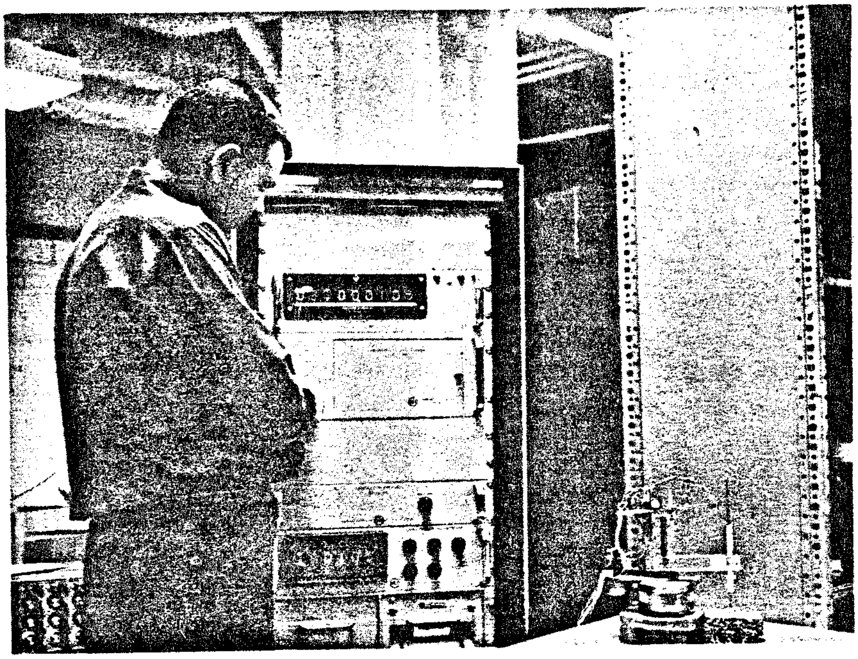
from the transformer is sampled while the needle rests on the surface of the test specimen. This voltage is proportional to elevations; thus when the needle is lowered the voltage is sampled and stored. While the needle is raised the voltage information is recorded and the system cleared for the next needle probe. As the needle is lifted and the data is being recorded, a small horizontal shift is accomplished along the circular arc allowing the needle tip to again rest on the next portion of the specimen to be tested. Repeated applications of the needle in this manner produces a profile.

The probing unit is leveled by means of three leveling screws. To accomplish the leveling, a short test is made over a flat surface such as a piece of polished glass laid over the specimen, and the axis of the instrument is tilted until a nominally horizontal profile is produced.

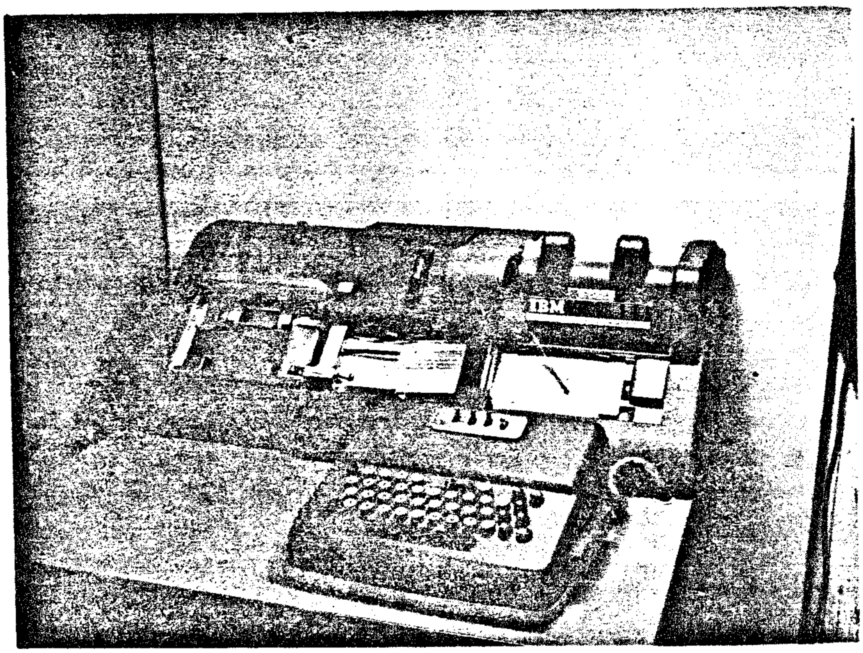
Data Recording Equipment

A mass of data can be cumulated using this equipment, and it was therefore necessary to provide a feasible method of collecting and retrieving the data. This was accomplished by storing the data on IBM computer cards using an automated system.

The output voltage from the linear variable differential transformer was sampled as the needle rested on the selected surface by attaching a plastic cam to the synchronous motor used to probe the core. The cam was affixed with two small copper bars (see Figure 2) embedded in the outer circumference of the plastic cam. Four piano wires were spring loaded against the revolving cam in such a manner to form an electrical circuit sufficient to allow the voltage information to be transferred through a Data Logging System by Non-Linear Systems, Inc., Del Mar, California (see Figure 3) and punched out on IBM cards using an IBM - 526 Printing Summary Punch (Figure 4). The entire system was activated by means of a switch located on the probing unit.



Data Recording and Storage System
FIGURE 3



Printing Summary Punch Used for Data Storage
FIGURE 4

Calibration

Initial calculations were made to determine the size and type motors, size of sprockets, the radial length of the cantilever arm, and the probing speed needed in order that the probing equipment could be fabricated. The calculations for these needs are found in Appendix A.

It was believed grain sizes on the order of those passing the 100 and retained on the 200 mesh screen should be measured. This means that horizontally one probe on each side and one probe near the center of a grain is needed to at least partially define a protrusion of this size. Therefore, approximately one probe every 0.04 of one inch is needed. Assuming the grain to be round, the height or vertical accuracy would also be required to obtain this sensitivity. However, A. J. P. Van der Burgh and D. H. F. Obertop reporting in the Netherlands indicated protrusions of microscopic size influenced skid resistance.[11] Becuase of this report it was decided to attempt measurements smaller than those dictated by the 200 mesh screen.

The horizontal calibration was performed by allowing the needle to probe along a steel scale graduated in 0.01 inch increments and counting the probes required to cover a distance of about one-half inch. Repeated horizontal calibrations were made throughout the data collection period, and the mean of the determinations was used in the study. It was found that the horizontal distance between successive probes was 0.0033 inch with a standard deviation of ±.000168 inch. A coefficient of variation of 5.05 per cent was calculated for all horizontal calibration data used in the study.

The vertical calibration was performed before each series of tests on any given day. The calibration was accomplished by correlating the output voltage of the linear variable differential transformer with a reference height as indicated by an inside micrometer, improvised from parts of a transit leveling screw. The vertical sensitivity of the data recording equipment can be varied by selecting one of several sensitivities on the digital voltmeter of the data logging system. It was found that a vertical sensitivity of 0.000042 inch could be achieved reliably and, with the vertical calibration methods used, a standard deviation of ± 2.6 microinches with a coefficient of variation of 6.4 per cent was found. It is believed that the majority of the variation in the vertical calibration was due to operator error in setting and reading the inside micrometer.

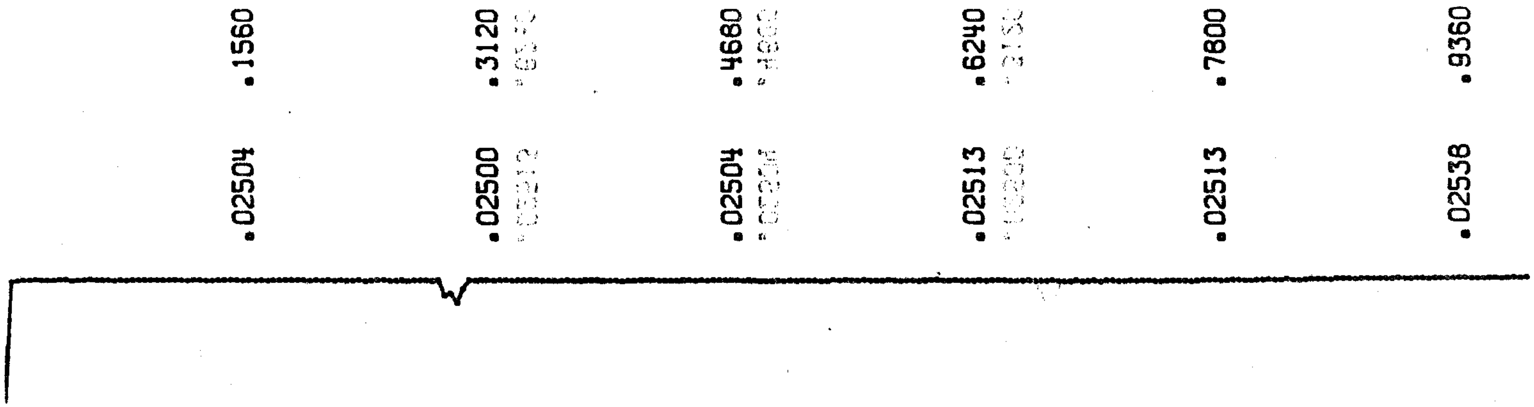
III. ACCURACY OF EQUIPMENT

It is desirable to check the accuracy and calibration by inspecting the equipment as it performs. Since little can be determined from visual observations, a computer program was devised to plot various profiles directly from the data cards on a computer oriented "off line" plotter. The program incorporated a system to plot the profile to a preselected large scale to observe the minor variations in the profile. Since the plotter used paper 30 inches in width, sufficient scale expansion was available.

Graphical Output

An estimate of the accuracy of this equipment may be obtained by analyzing the profile data shown in Figure 5. These data resulted from scanning a polished glass surface. A very small scratch was noted in a piece of ordinary window glass and a profile measurement was performed to determine whether the equipment was capable of sensing the scratch. The scratch was discernible and the depth as shown is approximately 0.0017 of an inch. Individual probes at which the needle touched the surface during the lower portion of the probing cycle are indicated by the small dots. The two sets of numbers show (1) elevations in inches from an orbitrary beginning point and (2) the longitudinal distance from the beginning of test in inches.

Figure 6 shows a profile across a Lincoln penny. The test was conducted at approximately the diameter of the penny and the right hand portion of the profile on the penny was across Lincoln's nose. It should be noted that the individual probes marked by the dots along the vertical edge of the penny do not indicate an actual vertical edge. A canted edge of approximately 4^{o} from vertical was obtained. It was noted during the actual probing that the point of the needle did not touch the edge, but rather the rounded side of the needle was in contact. The needle is a common sewing needle and does terminate in a rounded, beveled edge. Additional beveling was accomplish by inserting the needle in a small lathe



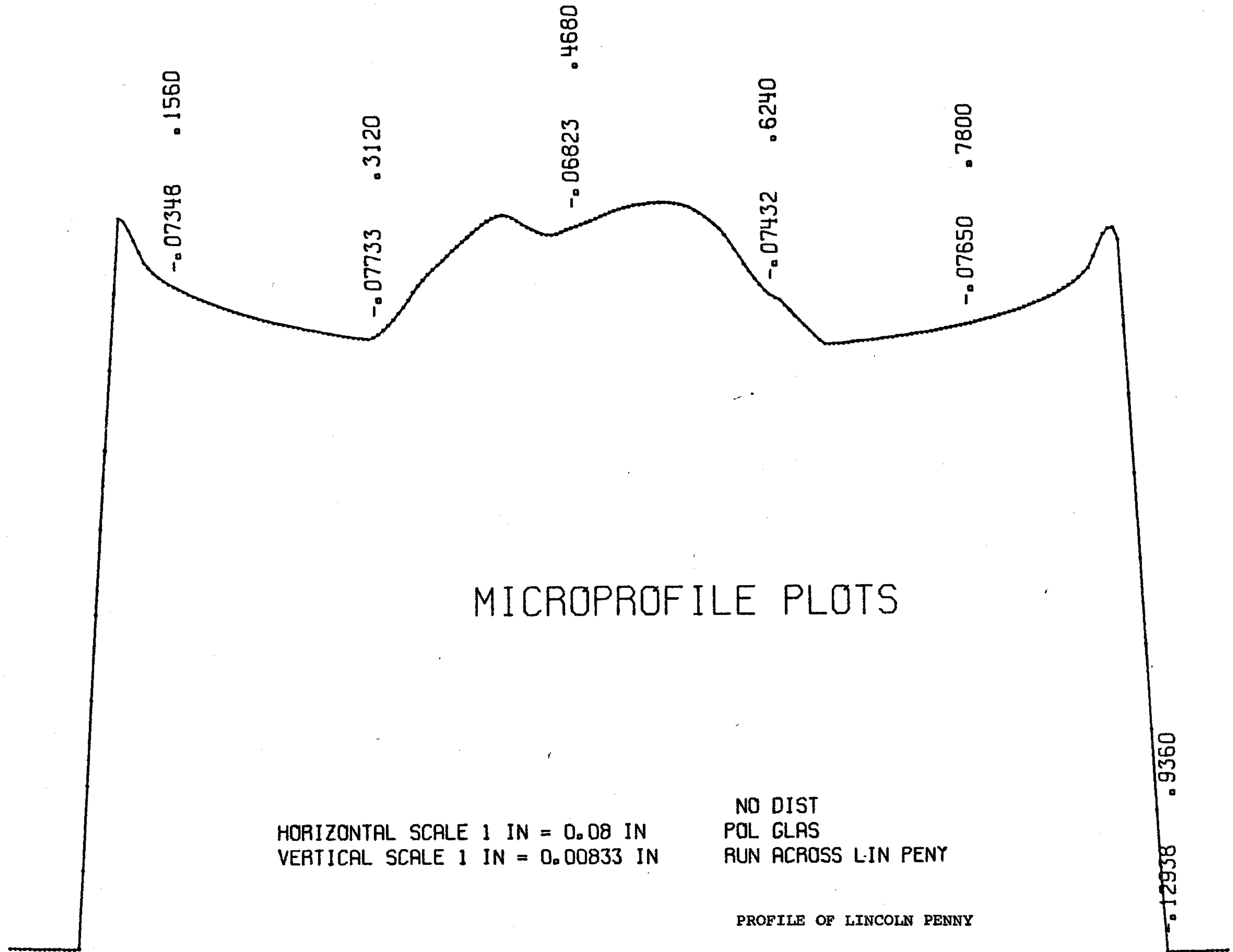
MICROPROFILE PLOTS

HORIZONTAL SCALE 1 IN = 0.08 IN
VERTICAL SCALE 1 IN = 0.00833 IN

NO DIST
POL GLAS
SCRATCH 1/4 FR START

PROFILE OF POLISHED GLASS WITH SMALL SCRATCH

Figure 5

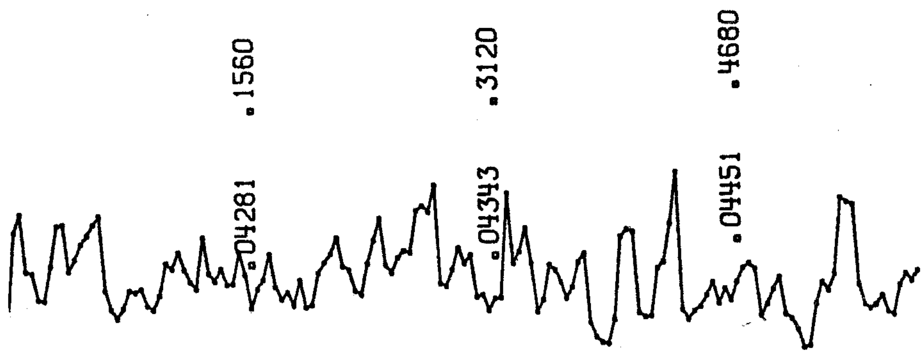


PROFILE OF LINCOLN PENNY

Figure 6

and sharpening the point with a fine stone. However, equally spaced dots in Figure 6 point out the horizontal and vertical stability of the equipment.

Profiles of a coarse sandpaper and a 220 grit sandpaper are found in Figures 7 through 9 respectively. Figures 8 and 9 reveal height differentials expected between the two grades of sandpaper. An estimate of the repeatability of the profile data produced by the equipment can be determined by examing the profiles shown in Figures 7 and 8. These two profiles were obtained by consecutive repeat tests across the same portion of sandpaper. Close inspection indicates duplication of profile with the heights being approximately equal. Minor variations exist, but these are probably due to the fact that the profile was not made across exactly the same path.



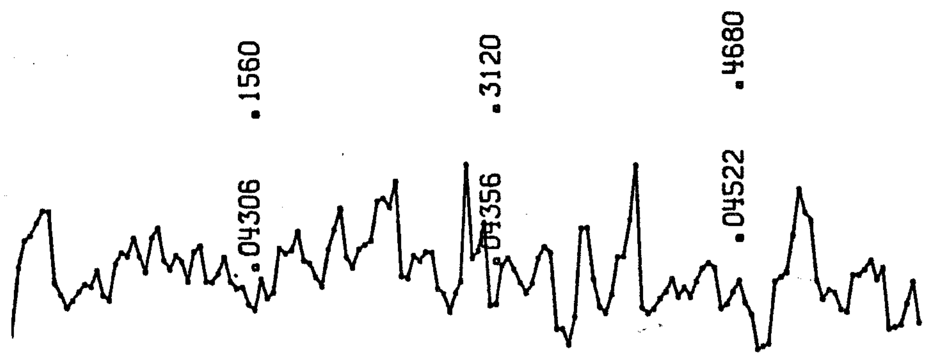
MICROPROFILE PLOTS

HORIZONTAL SCALE 1 IN = 0.08 IN
VERTICAL SCALE 1 IN = 0.00833 IN

NO DIST
NO SECT
COARSE SANDPAPER 2
COEF. NOT KN

PROFILE OF COARSE SANDPAPER

Figure 7



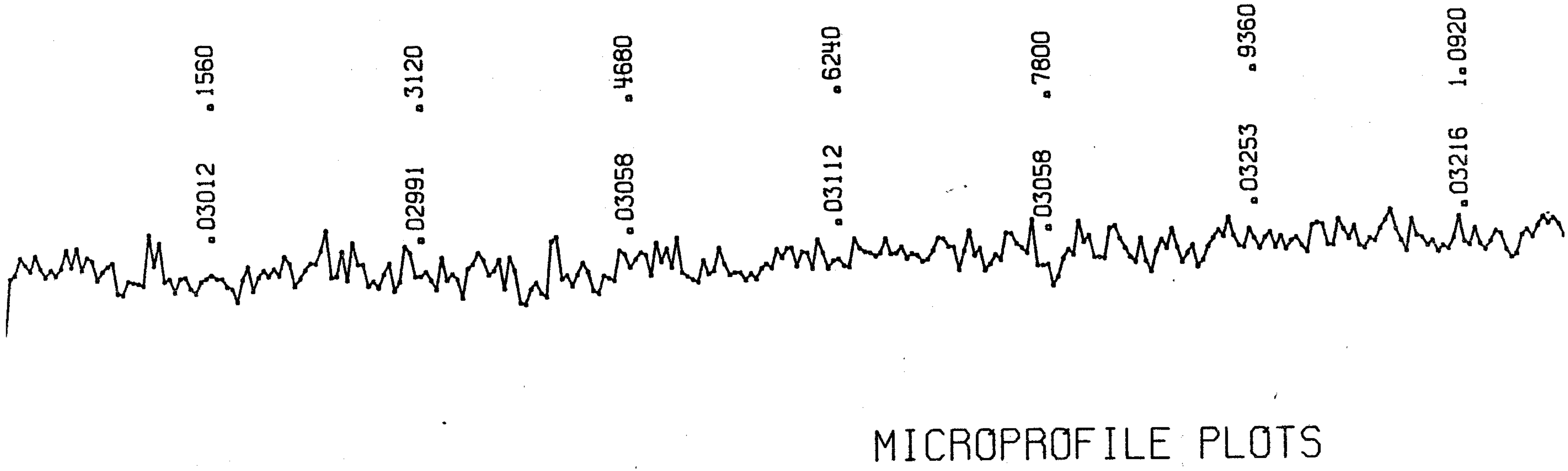
MICROPROFILE PLOTS

HORIZONTAL SCALE 1 IN = 0.08 IN
VERTICAL SCALE 1 IN = 0.00833 IN

NO DIST
NO SECT
COARSE SANDPAPER 3
COEF. NOT KN

REPEAT PROFILE OF COARSE SANDPAPER

Figure 8



NO DIST

HORIZONTAL SCALE 1 IN = 0.08 IN
VERTICAL SCALE 1 IN = 0.00833 IN

220 GRIT SANDPAPER 4
NO COEF

PROFILE OF 220 GRIT SANDPAPER

Figure 9

IV. METHOD OF ANALYZING TEXTURE

Various parameters may be studied in analyzing pavement texture. It is not known whether any certain set of parameters will sufficiently describe texture in completely general terms; however, surface profile was chosen as a basic parameter for analyzing texture characteristics. Selected texture characteristics were then studied in relation to skid resistance.

Hypotheses

It may be postulated that the angularity, height, spacing, shape and orientation of peaks influence skid resistance. Hypotheses are stated as follows:

(1) Sharp or angular peaks produce high skid resistance.

(2) High peaks provide high skid resistance.

(3) The larger the number of peaks per unit area the greater the skid resistance.

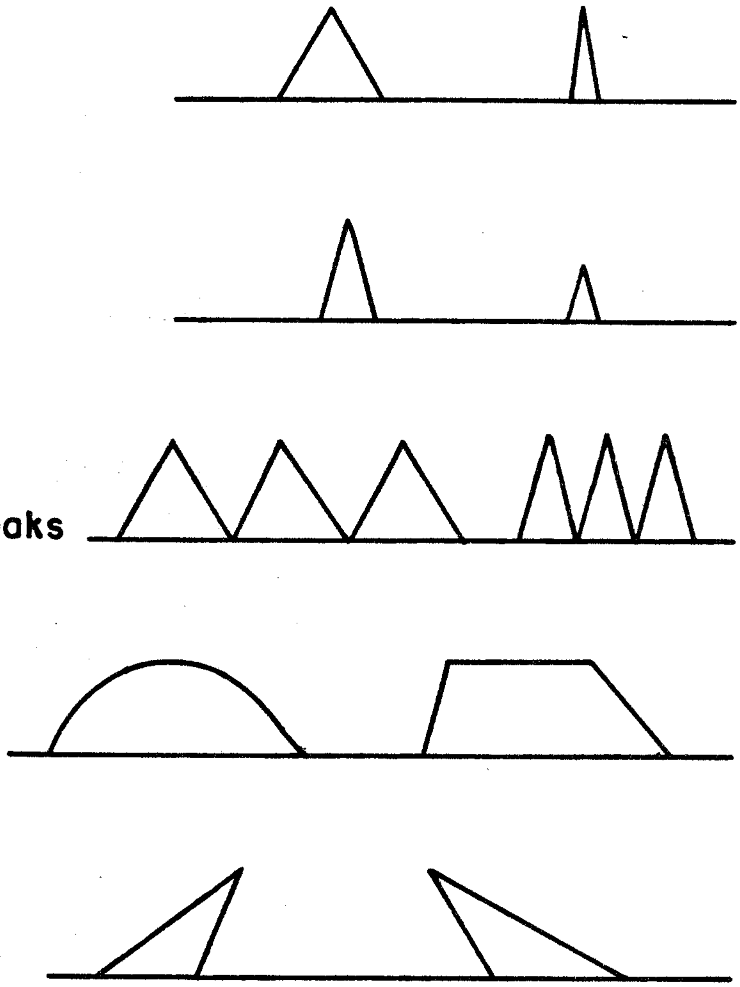
(4) Angular peaks result in higher skid resistance than rounded peaks.

(5) Projections slanted toward the direction of traffic provide higher skid resistance than projections slanted away from the direction of traffic.

Figure 10 illustrates the terminology used in the hypotheses outlined above.

With the equipment described previously it is possible to obtain a direct measure of each of the five variables stated in the hypotheses with the possible exception of the orientation of peaks. A combination of height and number of peaks per unit length provides a measure of the angularity of the peaks.

1. Angularity of Peaks
2. Height of Peaks
3. Spacing Between Peaks
4. Shape of Peaks
5. Orientation of Peaks



TERMINOLOGY USED IN TEXTURE HYPOTHESIS

FIGURE 10

Laboratory Program to Measure Texture

The laboratory program consisted of obtaining micro-profiles from 77 cores of flexible pavement surfaces. Associated skid resistance values were collected under field conditions. The cores were selected at random from a source of over 200 cores from test sections thought to be representative of Texas pavement surfaces. The selection of the 77 cores are biased to the extent that the selection was made by visual inspection. This visual inspection insured a full range of polished to nonpolished specimens.

Skid Resistance Information

In 1963, the Texas Highway Department completed the fabrication of a two-wheeled skid test trailer. This trailer was provided with a braking system which locks the wheels of the trailer as a two-ton tow truck pulled the trailer at a constant speed. The trailer was instrumented to measure the force required to pull the braked trailer at a preselected, desired speed. A coefficient of friction of the roadway surface was obtained by knowing the characteristics of various components of the trailer plus the measured towing force and the weight of the trailer. A watering system which wet the pavement surface immediately prior to the passage of the trailer tires was also provided.

Shortly after the completion of this equipment a research program was devised to evaluate the skid resistance of highways in Texas. Included in this program was the intention to test approximately 500 highway sections including a wide variety of pavement types. During the process of selecting these test sections it was noted that the Texas Transportation Institute was collecting data relating to the pavement structure on approximately the same number and types of pavements as part of a research study in connection with the AASHO Road Test. Eventually, both structural tests and skid resistance were determined on each test section. Cores were obtained from the surfaces approximately 1250 feet from the beginning of each 2500 foot flexible pavement test section. These cores were obtained from the Texas Transportation Institute for this study. The associated skid resistance values of each section were collected in artificially wet conditions at 20 miles per hour and 50 miles per hour. From the cores obtained from the Texas Transportation Institute approximately seventy-seven of these cores were selected at random for a texture study. It should be noted that all the cores used in this study were from flexible pavements; however, both surface treatment and plant mixes were included. From the selected cores the following aggregate types were noted:

(1) Crushed limestone
(2) Rounded limestone
(3) Crushed silicious
(4) Rounded silicious
(5) Limestone rock asphalt
(6) Precoated crushed limestone
(7) Iron Ore sandstone
(8) Expanded shale - lightweight
(9) Trap rock
(10) Oyster shell

A complete list of sections, aggregate types, and texture measurements are found in Appendix B.

Assumptions

Several assumptions or arbitrary selections were made in order to facilitate the study:

(1) A probe length of approximately two inches was arbitrarily selected. It was postulated that this length would incorporate sufficient numbers of aggregate particles to be representative of the total core. It also appeared that the larger the peak height of the individual aggregate particles, the longer the length needed and two inches was thought sufficient to provide this facet on every core.

(2) It was assumed that any one profile would be indicative of a profile taken in any position on the core surface.

(3) It was assumed there were an equal number of peaks transverse to the number of peaks in the measured profile. Based on this assumption the value of the number of peaks obtained in any one profile was squared to provide the number of peaks per square inch.

Testing Procedure

On each testing day a vertical calibration was obtained and the probing unit was leveled by an initial test performed on a smooth glass plate. Each individual core was then placed in an adequate position for probing and a profile of approximately two inches in length was obtained. Appropriate informational header cards were key-punched and placed before each profile data deck. The header cards contained the test section information associated with the core. At the close of each testing day the vertical calibration was again performed to insure against mistakes or equipment malfunction. In general, only one test was performed on each core.

Computer Program

The data consisted of approximately 600 voltage readings key-punched on IBM cards for any given core. These voltage readings were essentially vertical elevations calibrated to be 0.0033 inch apart. Since the initial probe elevation was not known it was decided to concentrate on determining numbers of peaks, heights of peaks, surface probe length, longitudinal position of the peaks and to attempt to separate the texture of the aggregate from the larger scale texture of the pavement surface. A computer program was devised to determine these parameters.

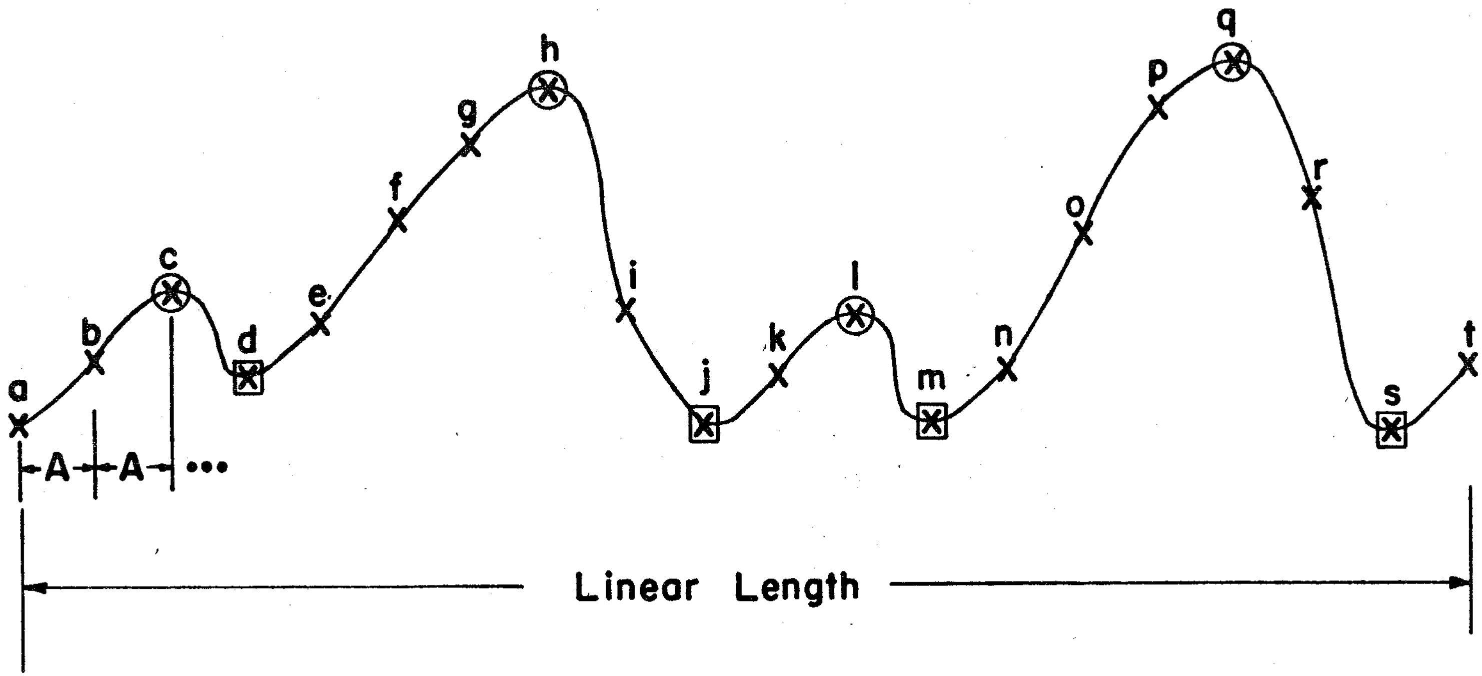
V. PARAMETERS USED IN ANALYSIS

For the purposes of this study, the hypotheses formed the guide for procuring texture variables. By comparing each measured parameter to skid resistance, the influence of each parameter is studied. Also the influence of various combinations of parameters on skid resistance is noted.

Number of Peaks and Average Height of Peaks

The existence of a peak was determined by first checking the elevation of the probed point under consideration to determine if the preceding or succeeding point was higher or lower (see Figure 11). If both the preceding and succeeding values were lower in elevation, the elevation of the point being checked was retained and termed a "high peak". The letters c, h, l, and q in Figure 11 with the circular symbol indicate high peaks. In like manner, each individual contact was checked to determine if the preceding and succeeding values were higher in elevation. If both preceding and succeeding values were higher in elevation, the elevation of the contact in question was retained and termed a low peak. The letters d, j, m, and s with the square symbol in Figure 11 refer to low peaks. If the preceding value was higher and the succeeding value was lower, the point in question was disregarded and the next or succeeding point was then brought into focus to be checked. Similarly, if the preceding value was lower and the succeeding value was higher, the contact in question was dismissed. This means that only the high and low peak values were retained. The number of high peaks were counted and divided by the total horizontal length scanned (in order to develop a unit basis). This value was squared, and reported as "Number of Peaks". Thus the term number of peaks refers to the calculated number of high peaks per unit area.

The difference in elevation between each consecutive high and low peak was accumulated. The accumulated value



$$\frac{\text{Number of Peaks}}{\text{Square inch}} = \left(\frac{\overset{(1)+(1)+(1)+(1)}{c+h+l+q}}{\text{Linear Length}} \right)^2$$

$$\text{Average Height of Peaks} = \frac{(c-d)+(d-h)+(h-j)+(j-l)+(l-m)+(m-q)+(q-s)}{\dfrac{\text{Number of Peaks}}{\text{Linear Length}}}$$

$$\text{Surface Length} = \sqrt{(a-b)^2 + A^2} + \sqrt{(b-c)^2 + A^2} \ldots$$

DEFINITION OF TEXTURE VARIABLES

FIGURE 11

was divided by two times the number of high peaks in order to obtain an average height. This average height is reported as the "Average Height of Peaks".

Surface Length

An estimate of the actual exposed length along the surface of a section taken through the specimen was calculated. Surface Length is thus the summation of the length of the inclined lines connecting successive probed points. Each individual length was found by summing the square root of the sum of the squares of the distance between the probes and the differences in probe elevations.

Variations of Heights and Peaks in Short Lengths

A study was made of the variation in longitudinal position of peaks and their related heights. This was accomplished by dividing the total length scanned into 0.1 inch segments and then determining the Number of Peaks and the Average Height of Peaks for each segment. The values for Number of Peaks were retained for each 0.1 inch segment and the variation between segments was determined by solving for the mean and reporting one standard deviation from the mean. The Average Height of Peaks was treated in like manner. The variation in the number of peaks was reported as "Standard Deviation in Number of Peaks per 0.01 Square Inch Unit" and the variation in the height of peaks was reported as "Standard Deviation in Height of Peaks per 0.01 Square Inch Unit". The value of Number of Peaks found for each 0.01 square inch segment was expanded to a unit basis of one square inch before the statistical procedures were used. It is apparent that this method of study shows the variation that occurs in the texture variables between 0.01 square inch units. For a complete analysis several sizes of square units should be studied, but only one unit of 0.01 square inch was used in this work.

The Moving Array Process

Since it was desirable to analyze the effects of both the small-scale or aggregate texture (hereafter termed micro texture) and the large-scale or pavement texture (hereafter termed macro texture), the profile was rounded by the method of moving arrays. Figure 12 shows the results of applying the moving array process to a profile obtained from a core sample. A reduced plot of the identical actual profile (Control 25, Section 7, Job 1) is found in Appendix C.

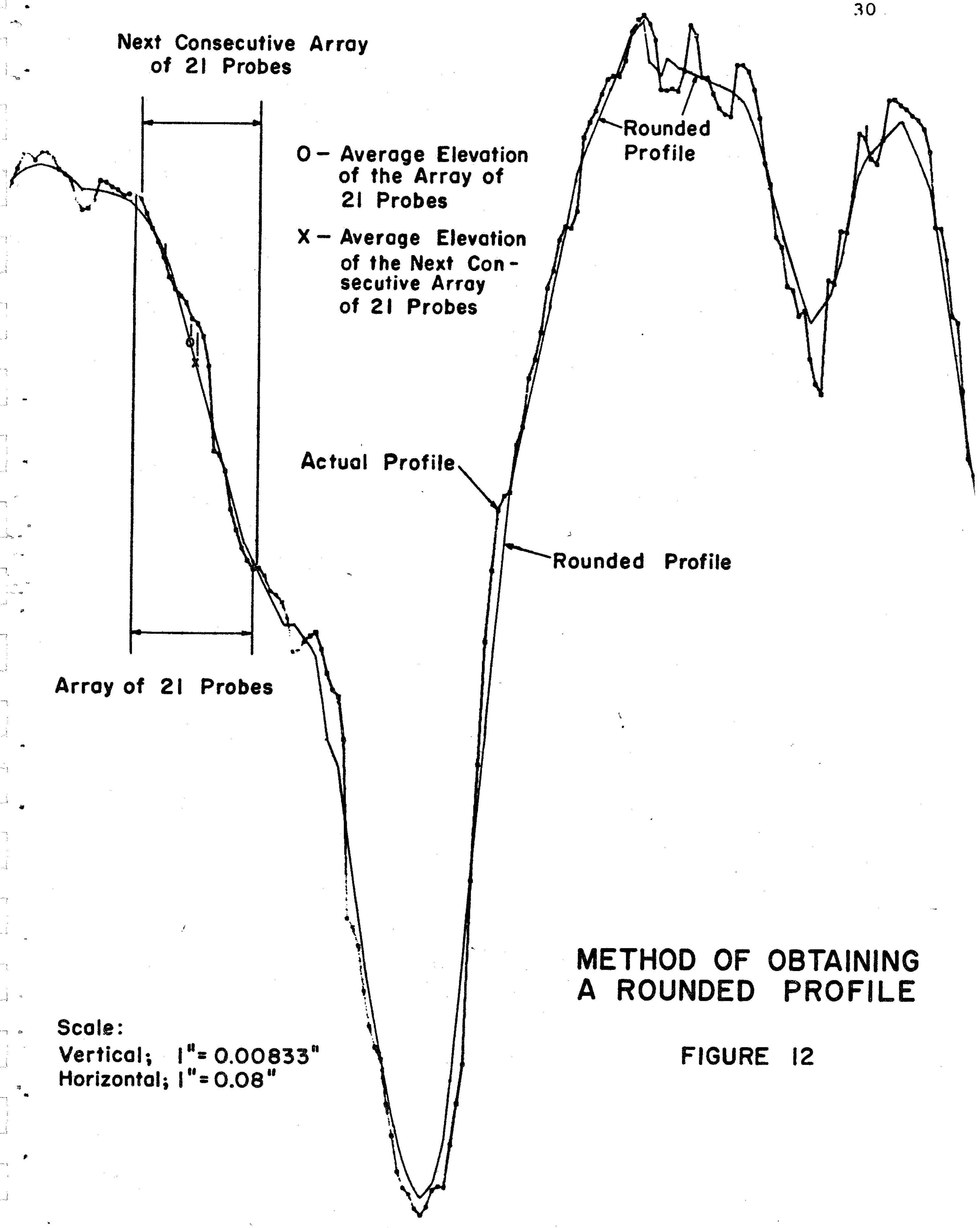
A moving array of 21 points was selected as an example in Figure 12. The elevation of the first 21 points are averaged and this average elevation is plotted in a vertical line opposite the eleventh point in the array. The first point is dropped, the twenty-second point is added and points two through twenty-two are averaged. This process is continued until all points have been used.

Three trials were made in order to select an optimum condition for a moving average curve. That is, the data were processed using the average of three points, nine points, and twenty-one points in the moving array process. In each case the moving average profile of each trial was plotted along with the actual profile for a selected specimen. The moving array of twenty-one points was arbitrarily chosen since this number of points appeared to better describe the actual conditions observed visually on the core.

<u>Number and Average Height of Macro and Micro Peaks</u>

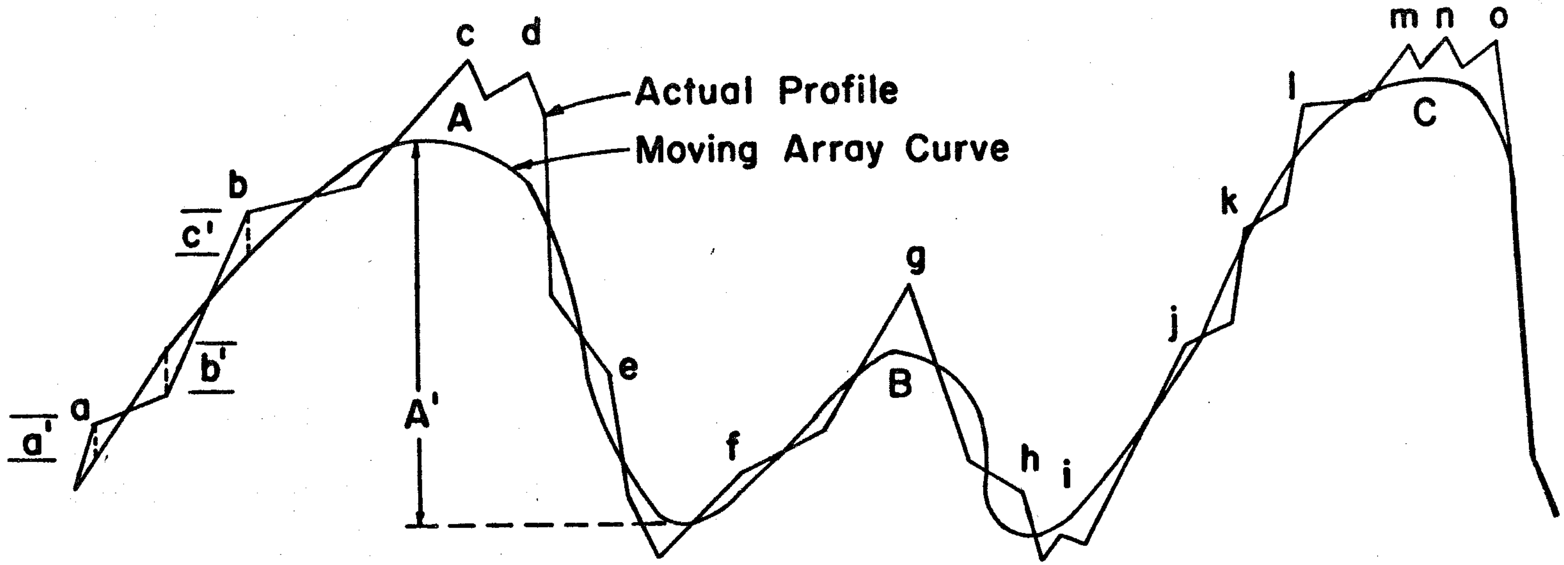
Figure 13 is a diagram showing the method used to define macro and micro texture variables. The lower case letters indicate micro peaks and the capital letters indicate macro peaks. A measure of the aggregate size is obtained by determining the difference between the "high peaks" and the "low peaks" indicated by A^1 in Figure 13. A measure of the height of the aggregate texture is indicated by a^1, b^1, and c^1.

The Number of Macro Peaks and the Average Height of Macro Peaks were found by a duplication of the process reported in "Number of Peaks and Average Height of Peaks" previously--except that points on the rounded profile were used in place of the actual profile. This method reveals relatively small numbers of macro peaks as Figure 13 indicates.



METHOD OF OBTAINING
A ROUNDED PROFILE

FIGURE 12



Examples of:

Micro Peaks = a, b, c, d, e, f, g, h, i, j, k, l, m, n, o,

Macro Peaks = A, B, C,

Micro Height = a' + b' & b' + c'

Macro Height = A'

METHOD OF MEASURING MICRO AND MACRO TEXTURE VARIABLES

FIGURE 13

The process used in determining the micro texture variables may be visualized by imagining the rounded profile as a straight line and determining the Number of Peaks, and the Average Height of Peaks of the original profile in relation to this line. To accomplish this, each individual data point was again used. The elevation of each original contact was subtracted from the "moving average" elevation which occurred at the same horizontal location. This difference in elevation was determined for each probe. The difference in elevation at each contact was substituted for the contact elevation and the process described in the section entitled Number of Peaks and Average Height of Peaks was again repeated. It is apparent that the Micro Height of Peaks will be slightly larger for large macro peaks since vertical differences were used. Heights measured perpendicular to the rounded profile would provide better results; however, sufficient storage for this accomplishment was not available in the CDC 1604A Computer with the program used.

Maximum Height

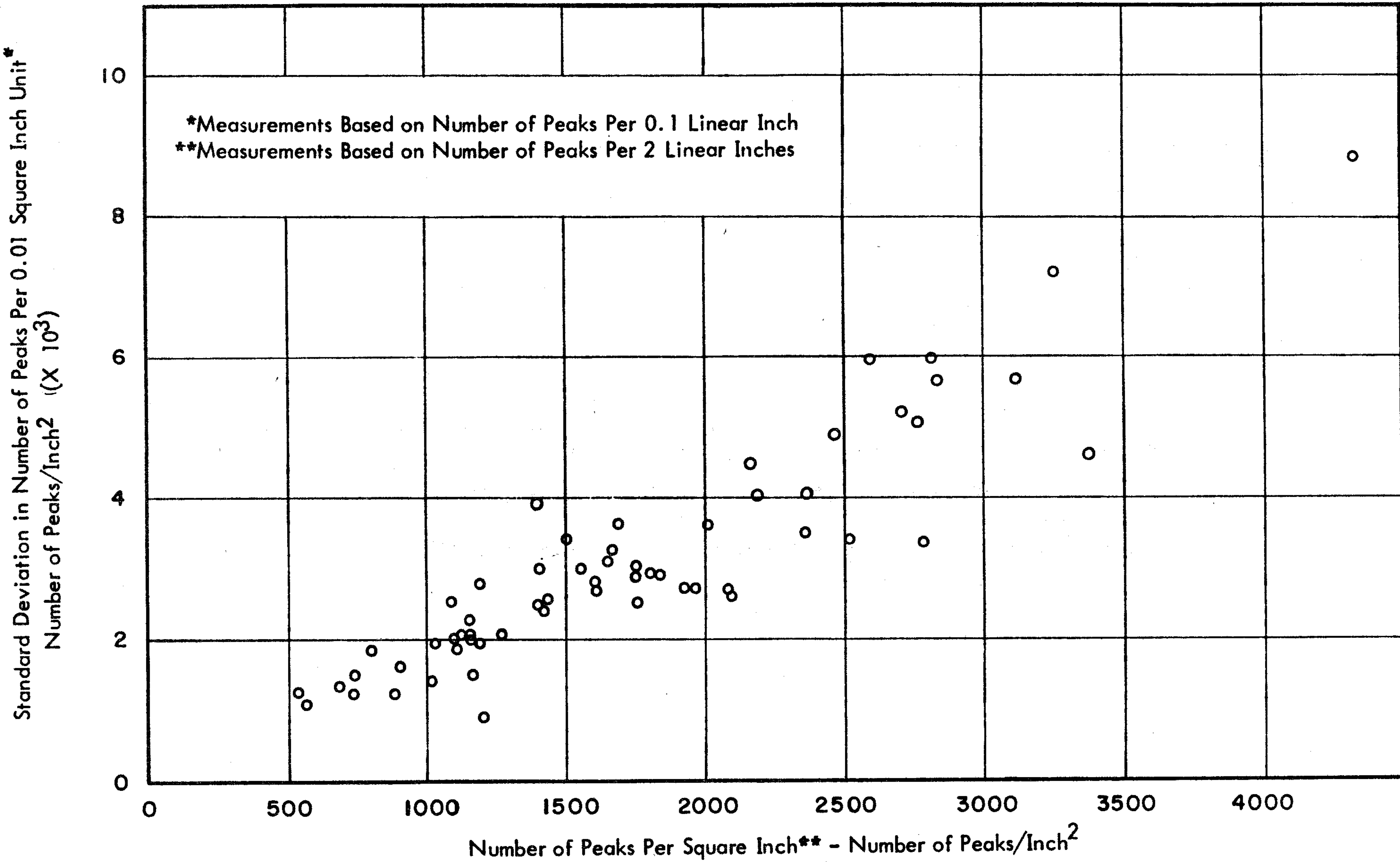
After obtaining the average height values and the macro height values, a visual examination of the related cores was made. It was found that a general relationship existed between the calculated values and a visual estimate of the maximum aggregate size. However, there was some discrepancy between the magnitude of the calculated values and the magnitude of those estimated by visual inspection. In an effort to explain these differences it seemed desirable to calculate a maximum height. This calculation was accomplished by the simple expedient of subtracting the highest elevation obtained on the actual profile from the lowest elevation. The full distance scanned was used in determining these elevations.

VI. PRESENTATION OF RESULTS

The first analysis involved an evaluation of two methods of measuring number of peaks and heights of peaks. It was assumed that some variation of texture would exist within any prescribed longitudinal length of roadway surface. To study this effect, the Variations of Heights and Peaks in Short Lengths, as previously described, was incorporated. To determine the fruitfulness of this study method, correlation was made between the Variation of Heights and Peaks in Short Lengths and the Number of Peaks and Average Height of Peaks. Figure 14 shows data relating to the number of peaks and Figure 15 is the relation between the peak heights. One standard deviation in peak variations was found to range from 910 to 8,830 peaks per square inch and the variation of heights recorded as one standard deviation was found to range from 0.00007 to 0.01409 inch. The two plots indicate a linear relation between the variables and relatively little scatter was found. Since this study revealed close correlation, the Variation of Heights and Peaks in Short Lengths was dropped from study. That is, one method successfully predicts the other and to avoid duplication of results the Variation of Heights and Peaks in Short Lengths was not used further. It should be stated, however, that no evidence of ravelling or aggregate stripping was noted during the visual observation of the cores.

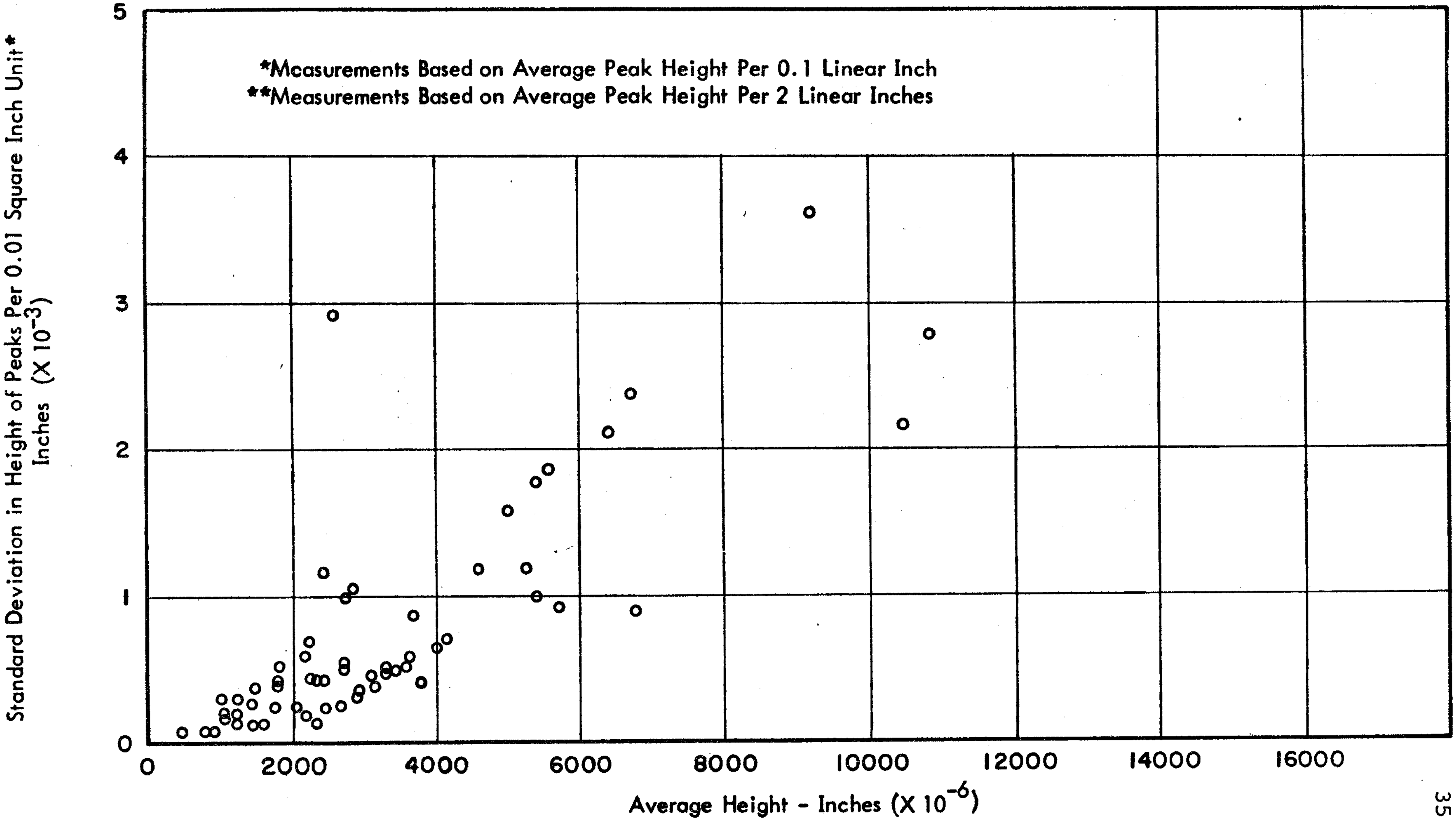
The Relation of Numbers of Peaks with Average Height of Peaks

Based on the results of the first analysis, a study was made of the relation between Number of Peaks and Average Height of Peaks. It was thought that various pavement types which were properly constructed would exhibit a uniform distribution of exposed aggregates, particularly in surface treatments. Figure 16 indicates the relation of the Average Number of Peaks and the Average Height of Peaks for the 77 cores studied. The data in this plot tend to form a curve with the Number of Peaks being inversely proportional to the Average Height of Peaks. The variation within the general trend is



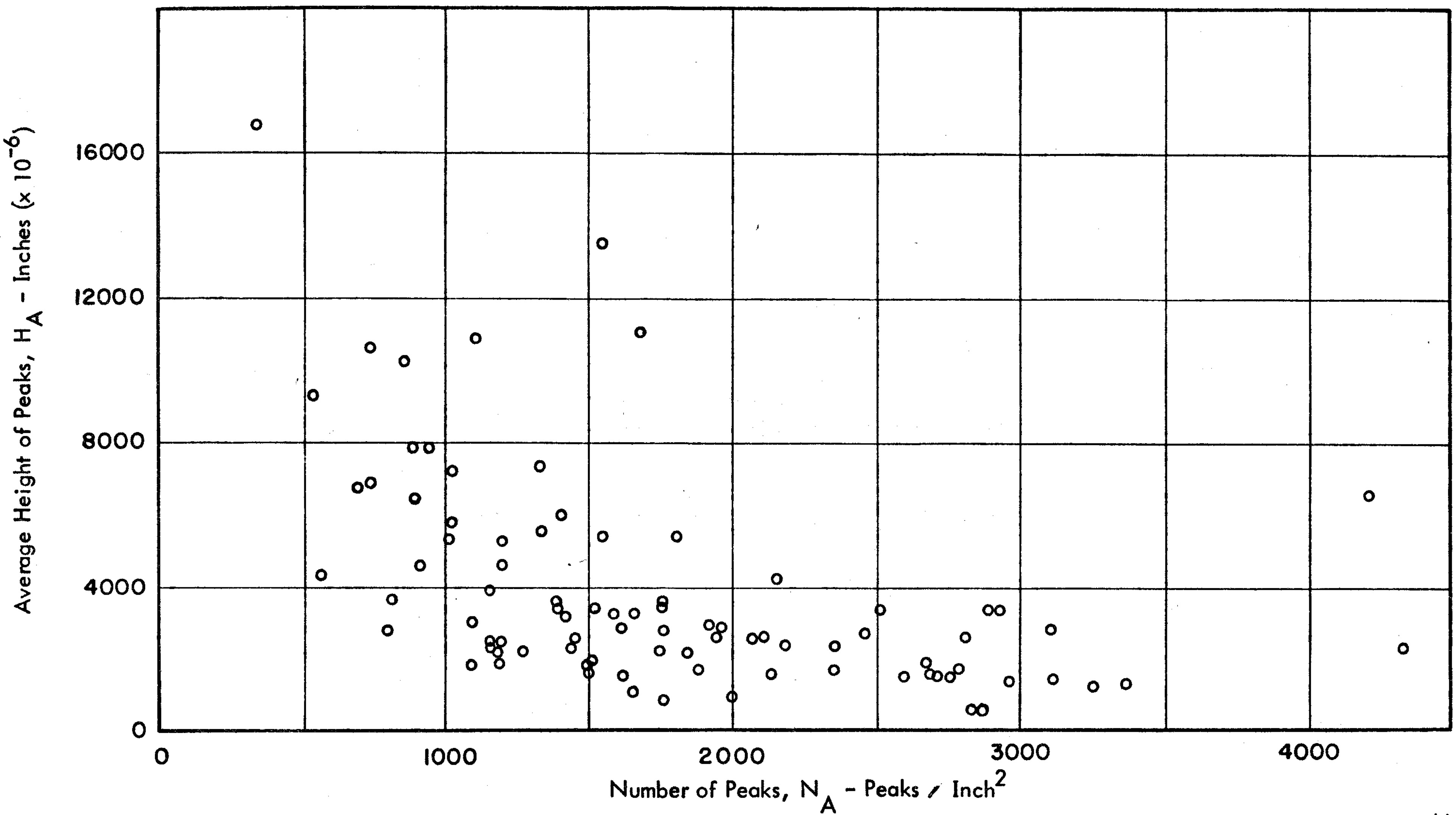
COMPARISON OF TWO METHODS OF STUDYING NUMBER OF PEAKS

Figure 14



COMPARISON OF TWO METHODS OF STUDING HEIGHT OF PEAKS

Figure 15



RELATION OF AVERAGE HEIGHT OF PEAKS AND NUMBER OF PEAKS

Figure 16

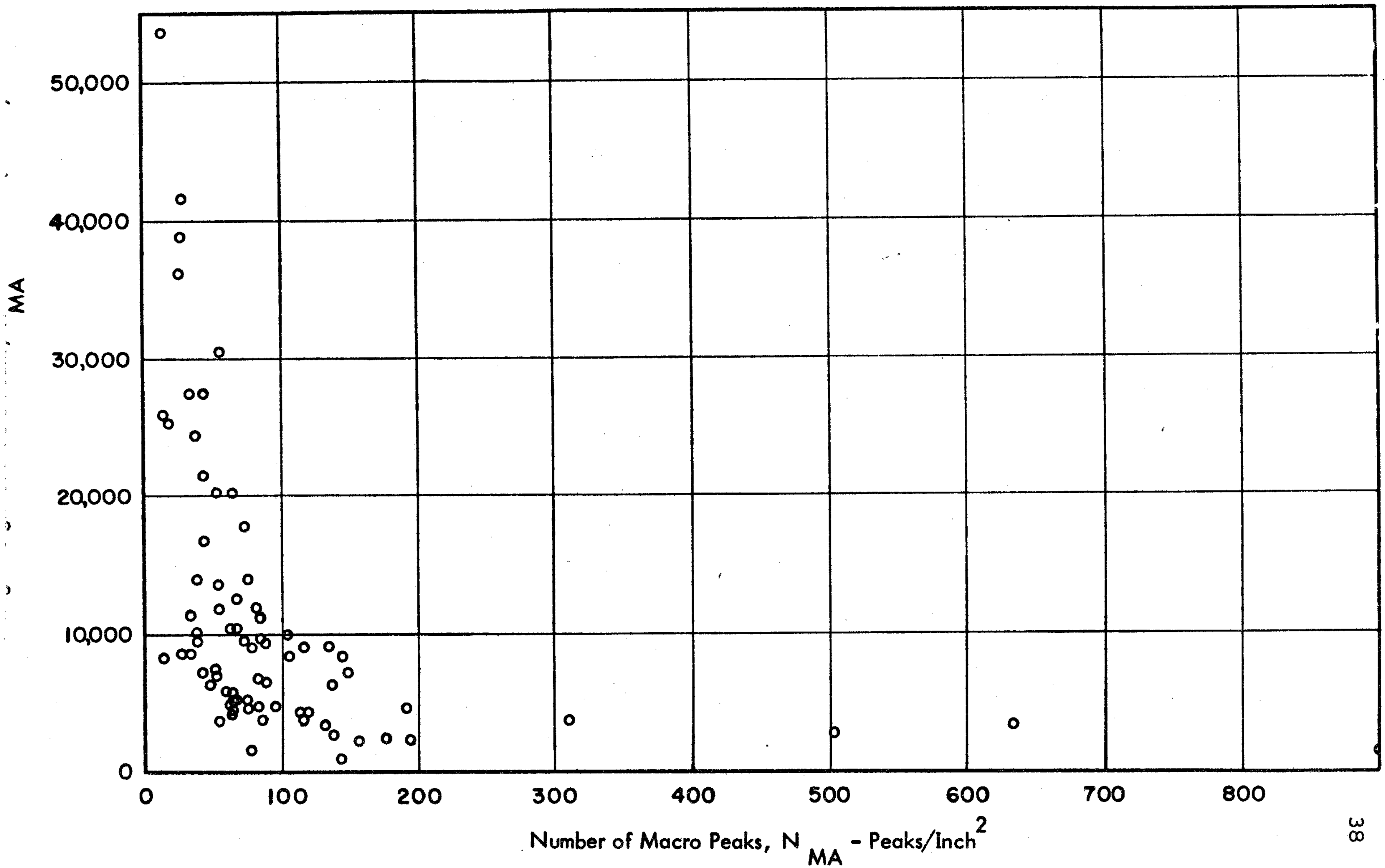
rather large, however, if the Average Number of Peaks is a large quantity; a small Average Height of Peaks can be expected. The Average Height of Peaks ranged from approximately 0.0005 inch to 0.0169 inch and the Average Number of Peaks ranged from 346 to 4,333 per square inch.

Macro texture was the next factor studied. This data resulted from the rounded curve and simulated the large scale or pavement texture profile which has been stripped of the small scale aggregate texture. Figure 17 is a plot of Average Height of Macro Peaks (H_{MA}) related to the Number of Macro Peaks (N_{MA}). The data in this plot reveal the same trend as in the "average" texture variables shown in Figure 16 with the relationship tending to be hyperbolic. It appears that Average Height of Macro Peaks (H_{MA}) and Number of Macro Peaks (N_{MA}) are closely related, with only small variation. Large heights exist when very small number of peaks are present, whereas, large numbers of peaks are present at low heights. H_{MA} ranged from approximately 0.0008 to 0.0538 inch and the N_{MA} reveal a range of 13 to 1,414 peaks per square inch.

Figure 18 is a plot relating to micro texture. The micro data resulted from obtaining the numbers of peaks and heights of peaks present about the rounded or macro curve. The micro data characterize the small scale of "aggregate texture". The points which were plotted in this figure indicate very wide scatter along with the general hyperbolic trends previously noted. The Number of Micro Peaks (N_{MI}) ranged from 1,362 to 4,202 peaks per square inch. No Average Height of Micro Peaks (H_{MI}) were noted smaller than 0.0004 inch or larger than 0.0107 inch.

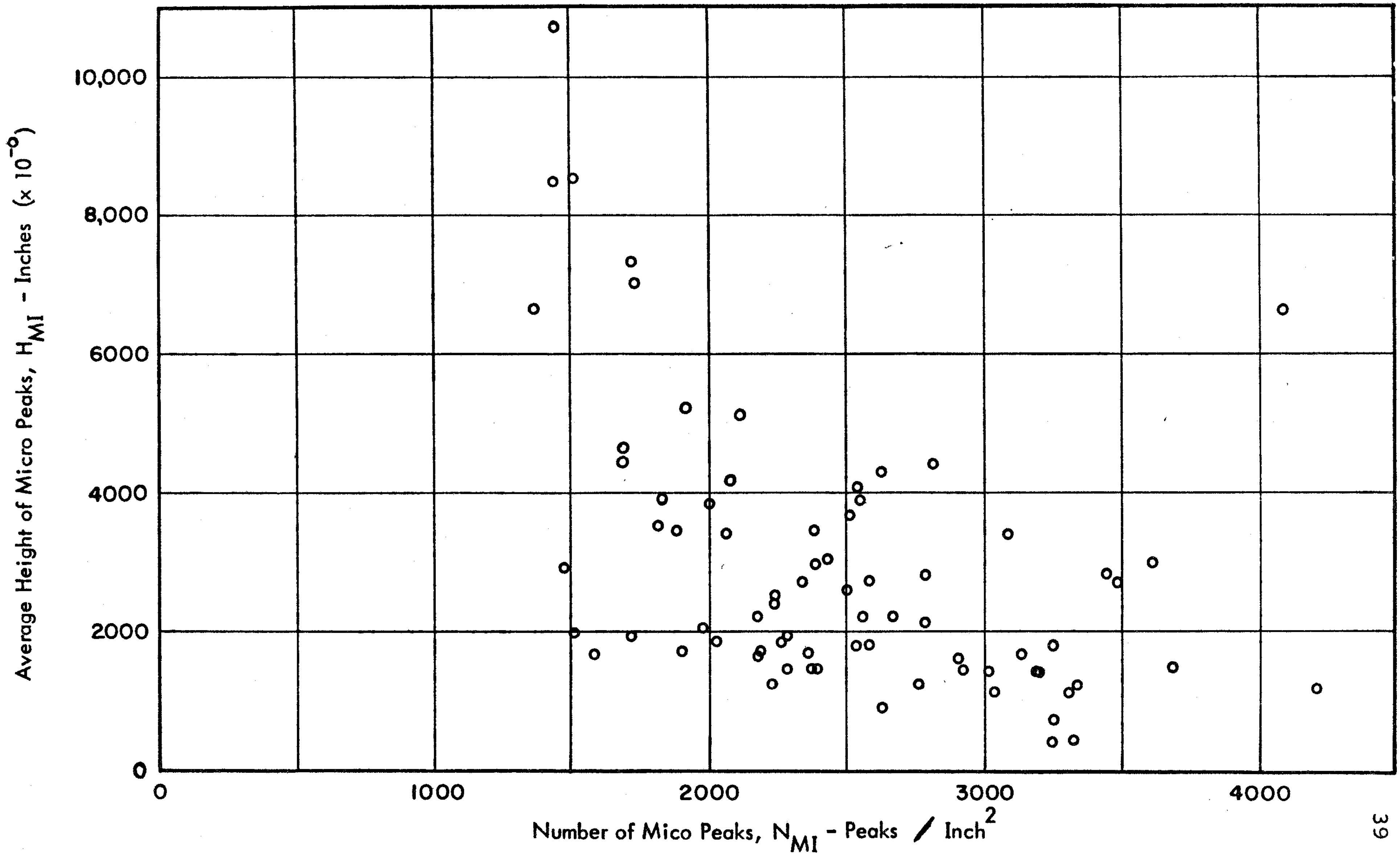
The Relation of Number of Peaks and Average Height of Peaks with Skid Resistance

Data concerning the coefficient of friction obtained at 20 miles per hour (C_{20}) and the Average Height of Peaks (H_A) are shown in Figure 19. A very wide scatter of data points with no visual indication of an existing relation is obvious. Because of the range in values observed, with the C_{20} varying from near 0.2 to around 0.9, no curve fit was attempted.



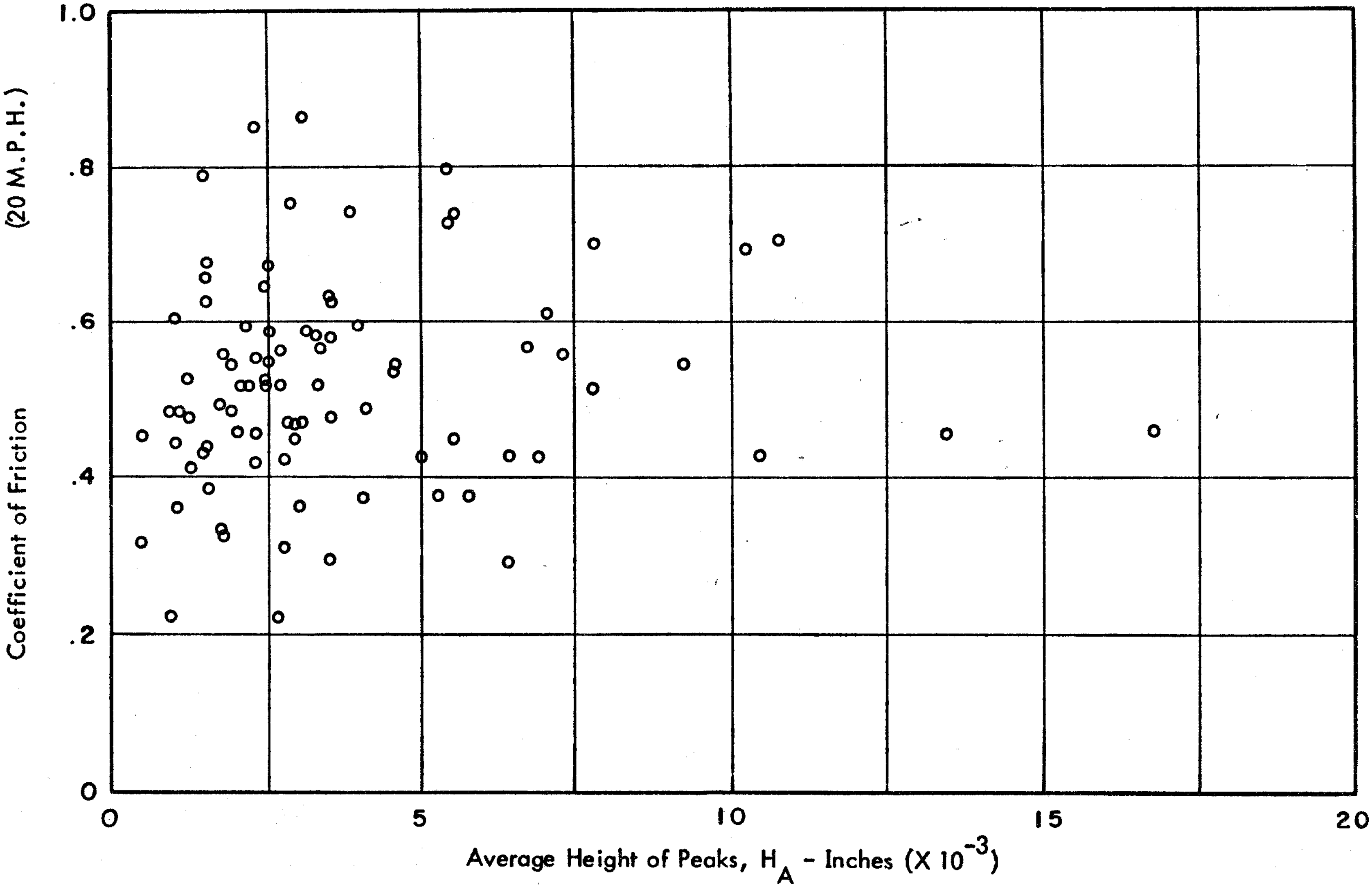
RELATION OF AVERAGE HEIGHT OF MACRO PEAKS AND NUMBER OF MACRO PEAKS

Figure 17



RELATION OF AVERAGE HEIGHT OF MICRO PEAKS AND NUMBER OF MICRO PEAKS

FIGURE 18



RELATION OF C_{20} AND AVERAGE HEIGHT OF PEAKS

Figure 19

The study of Average Height of Peaks (H_A) and the coefficient at the increased speed of 50 miles per hour (Figure 20) reveals the same wide scatter of points and again no curve fit was made. The coefficient at 50 miles per hour (C_{50}) ranged from slightly above 0.15 to near 0.7.

Figure 21 indicates the relation of C_{20} and the Average Number of Peaks (N_A). It appears that no correlation exists between these two variables for the data used in this study. The coefficient at 20 miles per hour varied from approximately the highest to the lowest values at around 1,500 peaks per square inch. The values plotted in Figure 22 again indicated the same tendencies when C_{50} was used as the dependent variable. The data seem equally distributed about a mean coefficient of around 0.4 with no systematic effects due to a higher or lower number of peaks.

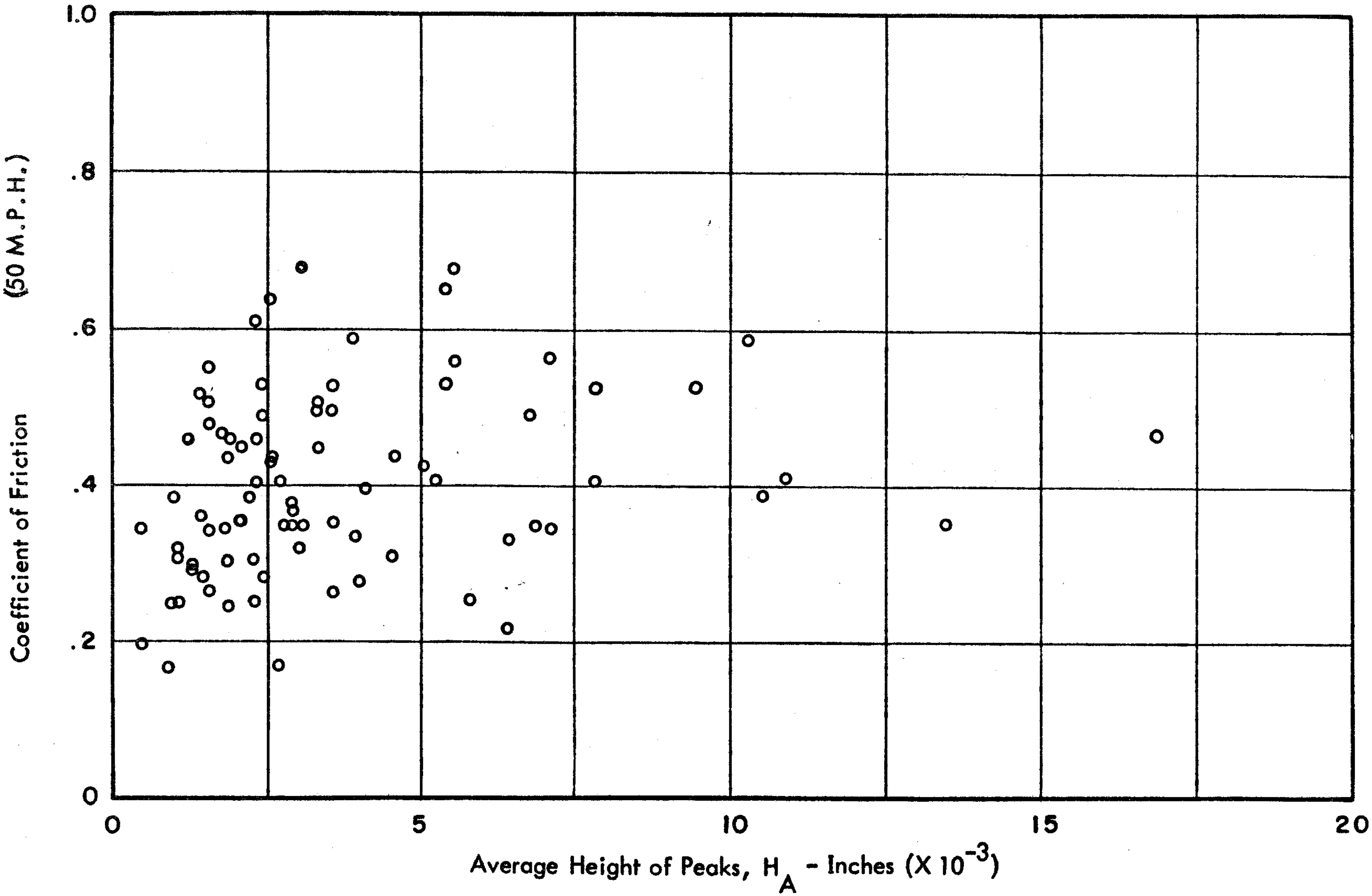
<u>The Relation of Numbers of Micro Peaks and Average Height of Micro Peaks with C_{20}</u>

Figure 23 reveals the findings obtained when studying skid resistance at lower speeds and H_{MI}. There is a general indication that C_{20} increases as the Micro Height increases. The linear "least squares" curve does indicate a positive slope with the equation being:

$$C_{20} = 0.496 + 7.89 \, (H_{MI})$$

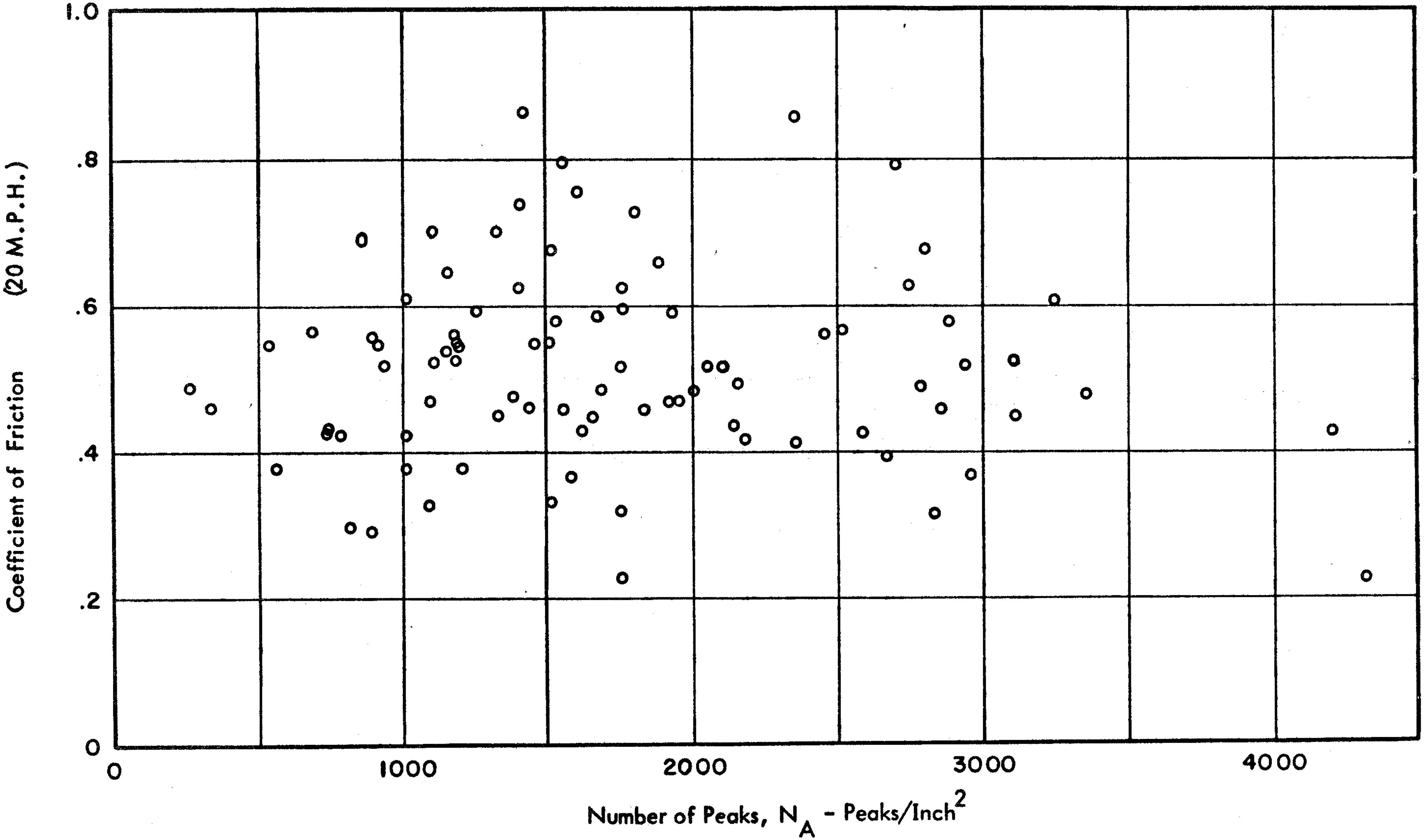
However, the correlation coefficient was determined to be 0.09 indicating very poor confidence in the fit. The Standard Error of the Estimate was 0.133 which is given in terms of coefficient of friction. The symbols in Figure 23 were used in an attempt to study the effect of Micro Number of Peaks and Micro Height in relation to the skid resistance at the slower speed.

Figure 24 is the study of N_{MI} with C_{20}. Poor correlation was again found; in fact, the scatter of points discouraged further analysis, and curve fits were not attempted.



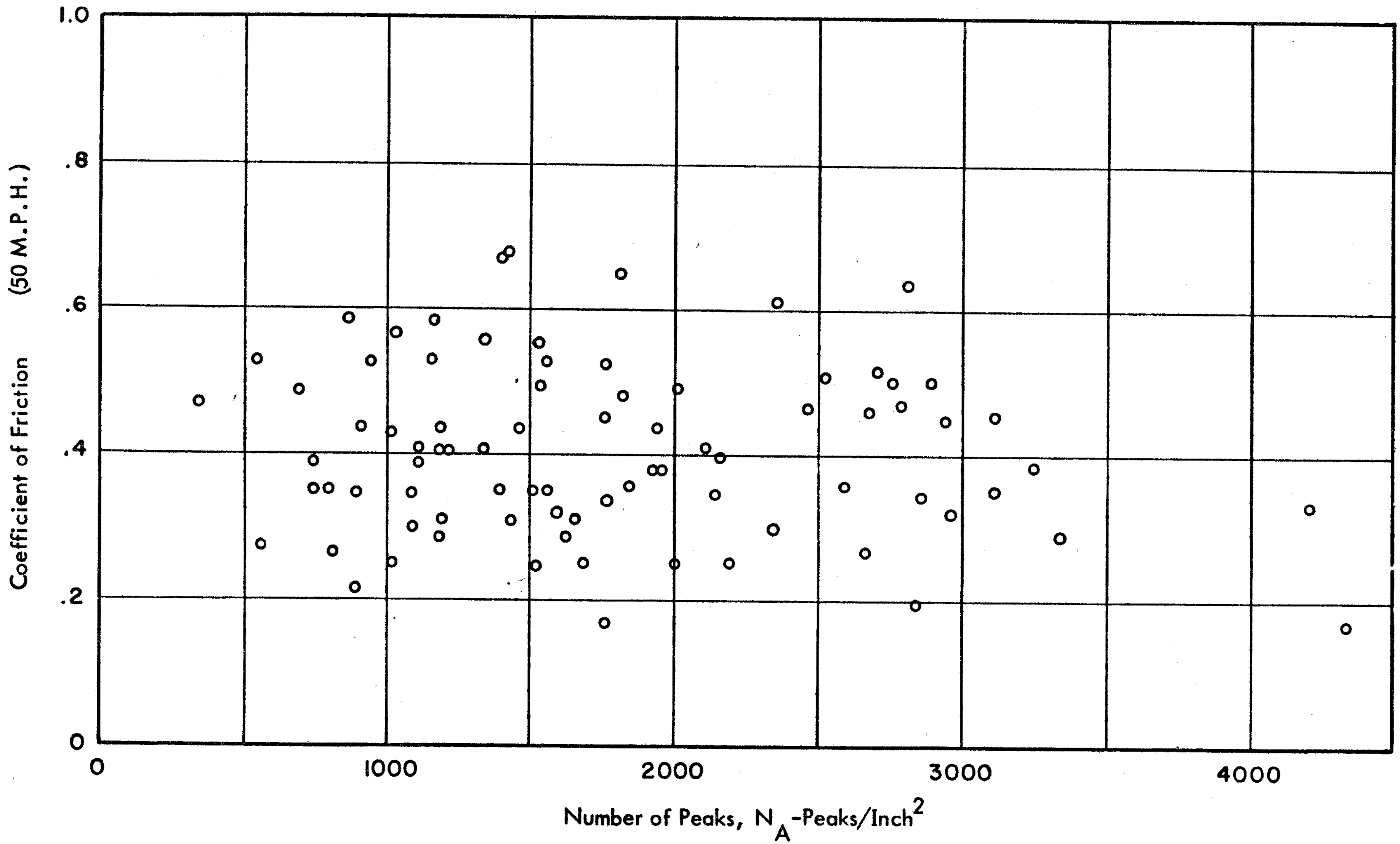
RELATION OF C_{50} AND AVERAGE HEIGHT OF PEAKS

Figure 20



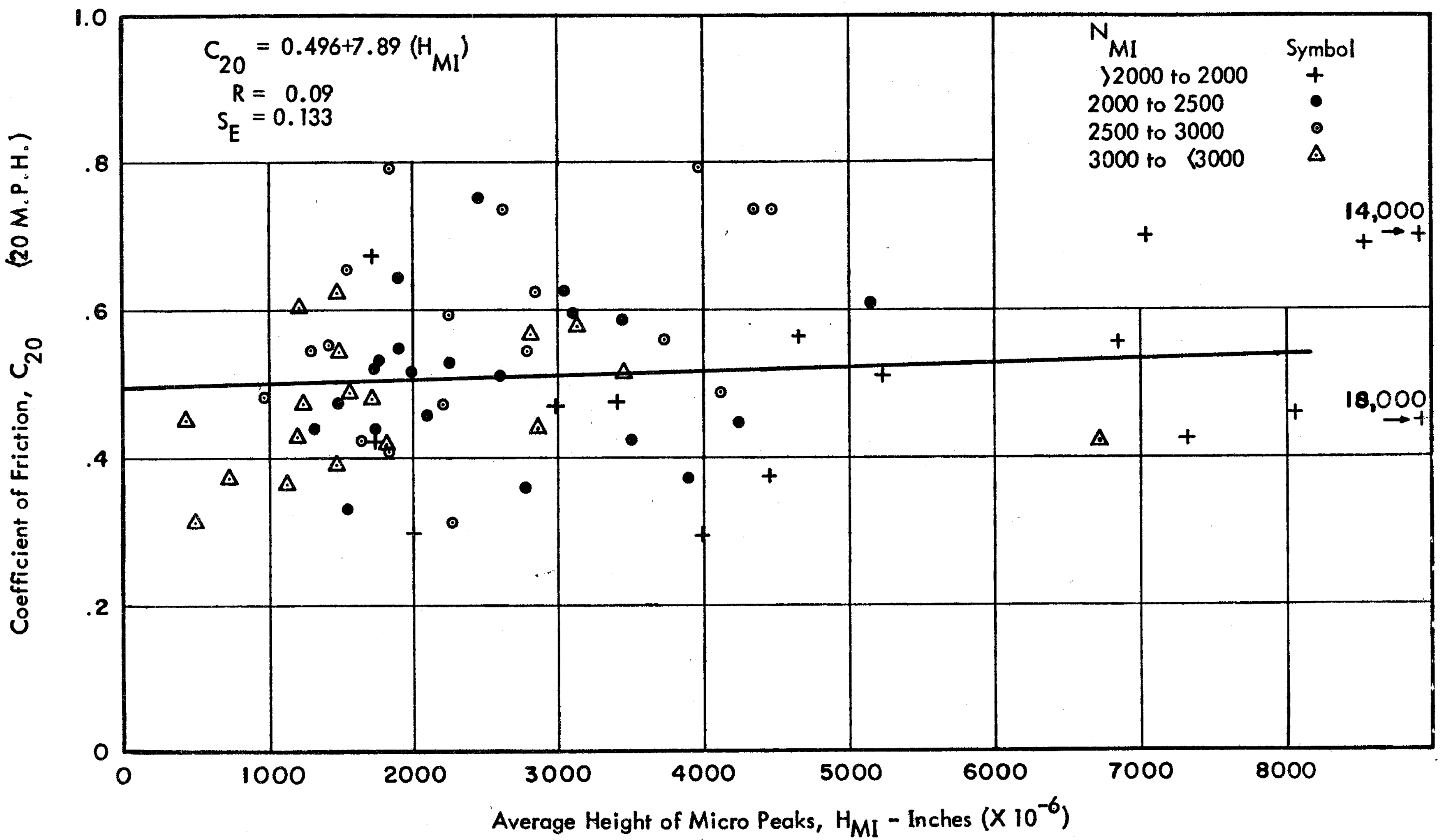
RELATION OF C_{20} AND NUMBER OF PEAKS

FIGURE 21



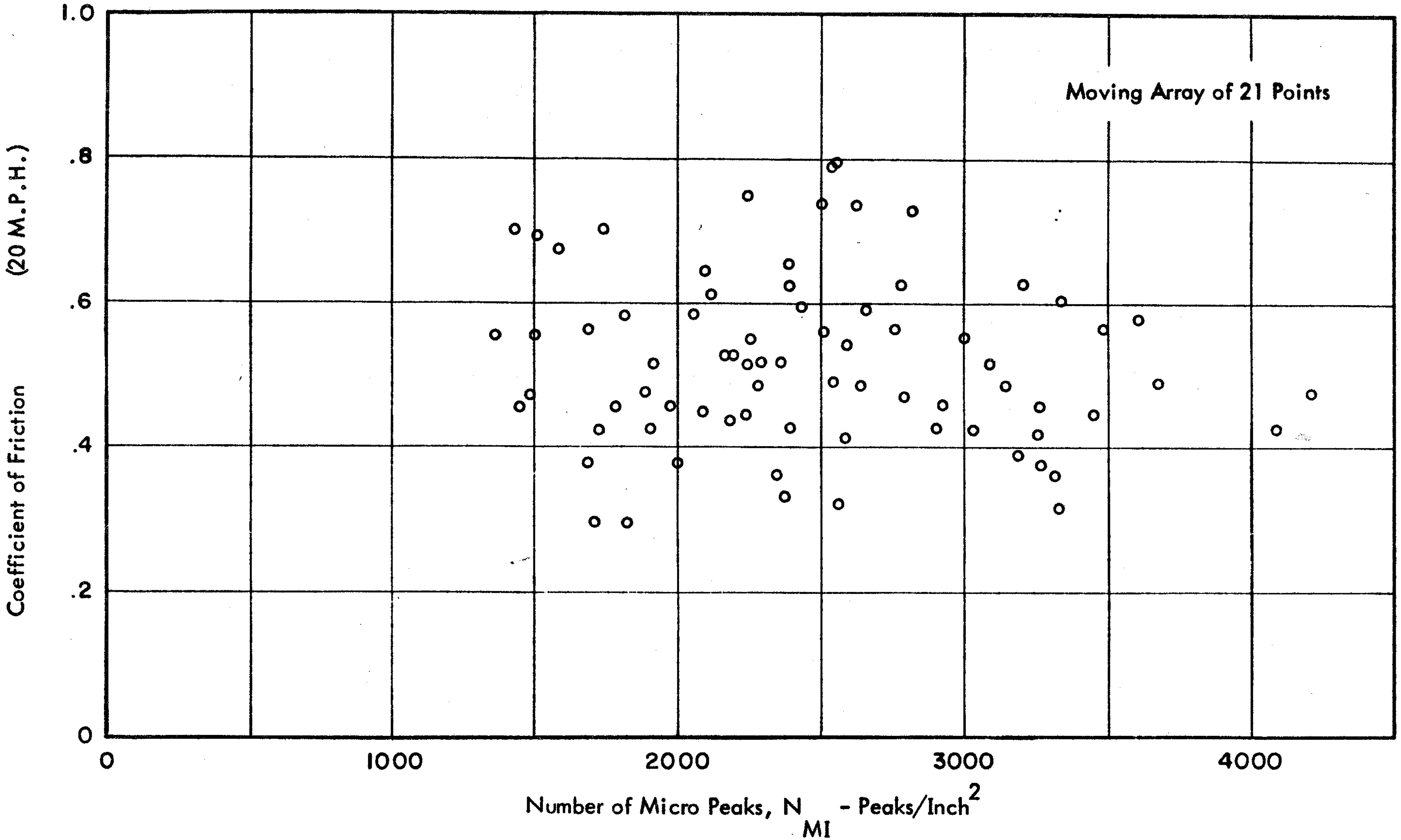
RELATION OF C_{50} AND NUMBER OF PEAKS

FIGURE 22



RELATION OF C_{20} AND AVERAGE HEIGHT OF MICRO PEAKS

FIGURE 23



RELATION OF C_{20} AND NUMBER OF MICRO PEAKS

FIGURE 24

The Relation of Number of Macro Peaks and Average Height of Macro Peaks with C_{50}

Figure 25 indicates a plot of the coefficient at 50 miles per hour and H_{MA}. The equation of the linear curve fit is:

$$C_{50} = 0.348 + 3.15 \text{ (Macro Ht.)}$$

The Correlation Coefficient (R) was found to be 0.19 with a standard error of the Estimate of 0.144. The R value indicates poor correlation.

Figure 25A was an attempt to define texture relations with skid resistance at 50 miles per hour more completely. Each plot contains H_{MA} correlations with C_{50}. By grouping the Number of Macro Peaks, one group for each plot, efforts were made to study micro texture within any N_{MA} group. Symbols were used to denote Number of Micro Peaks (N_{MI}) groups for each plot.

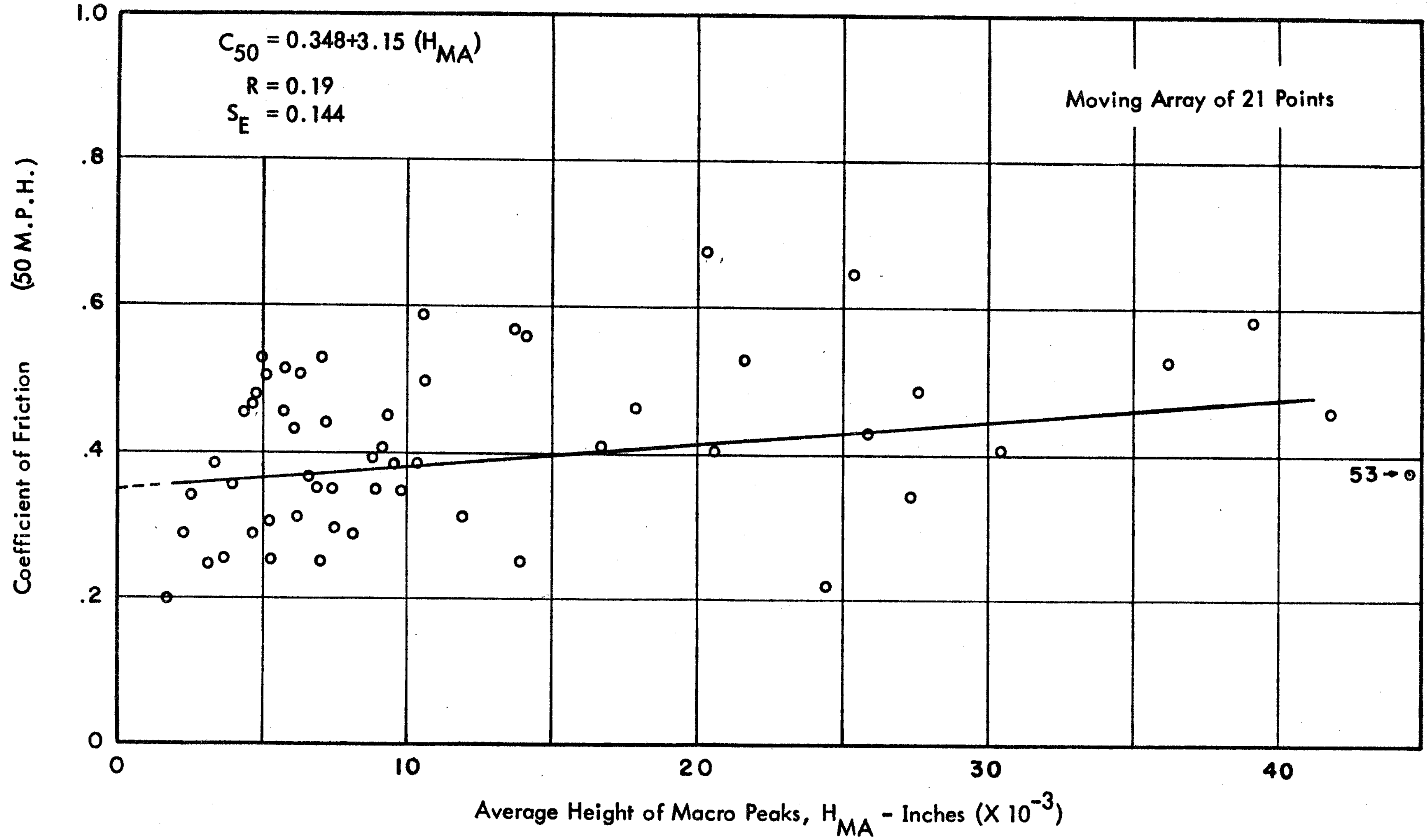
The influence of the addition of the variable, N_{MA}, was studied by comparing the general distribution of data points on each of the four plots, and the influence of N_{MI} was studied by noting the distribution of symbols within each plot.

The Numbers of Macro Peaks was correlated separately with the coefficient of friction at 50 miles per hour (C_{50}) and the results are presented in Figure 26. Again, wide scatter was found and no predicting equation was attempted.

The Relation of Maximum Height with C_{50}

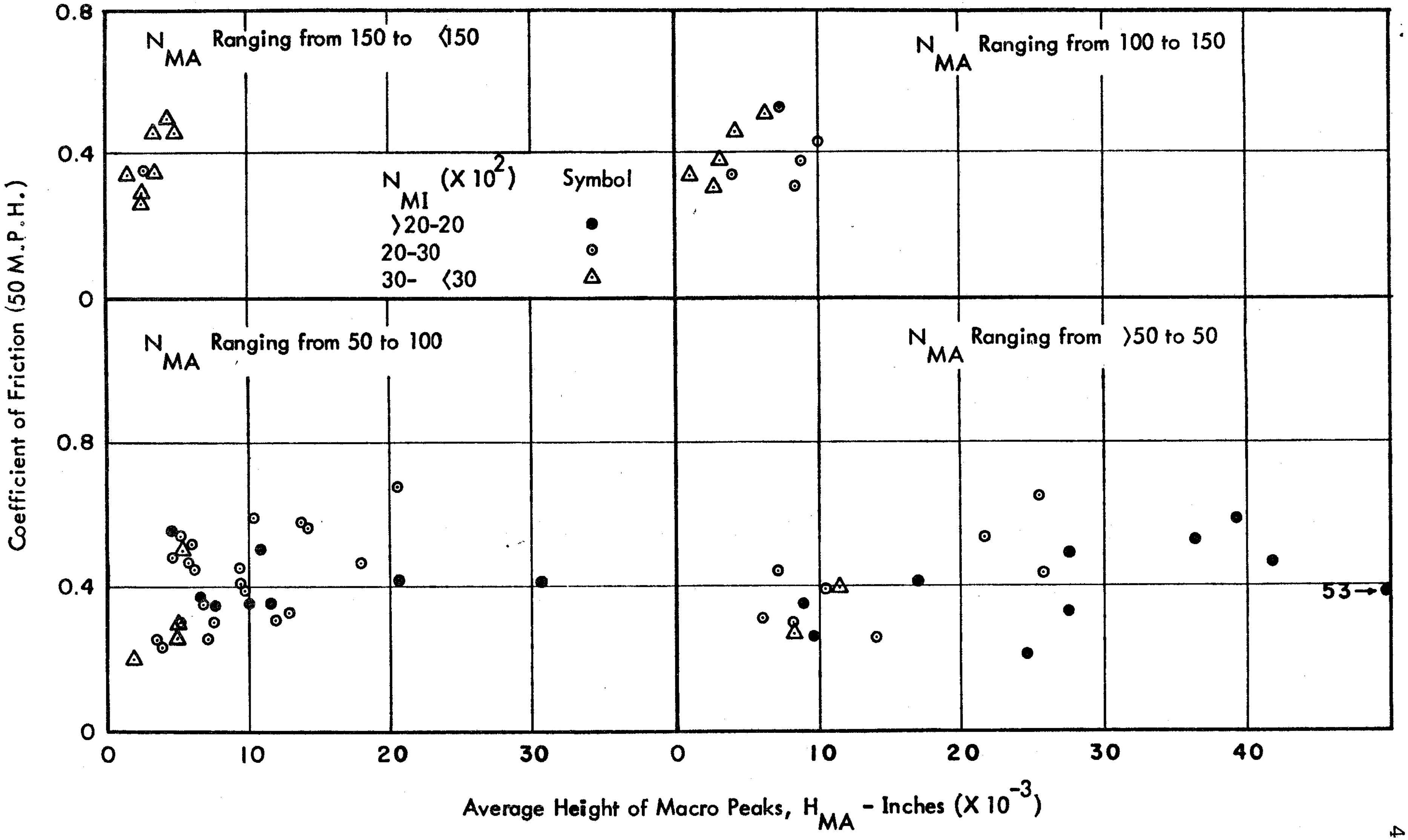
Figure 27 indicates the same general positive trend with the wide variation when the Maximum Height is studied in relation to the C_{50}. The "least squares" linear fit was found and the resulting equation was:

$$C_{50} = 0.342 + 0.553 \text{ (Maximum Ht.)}$$



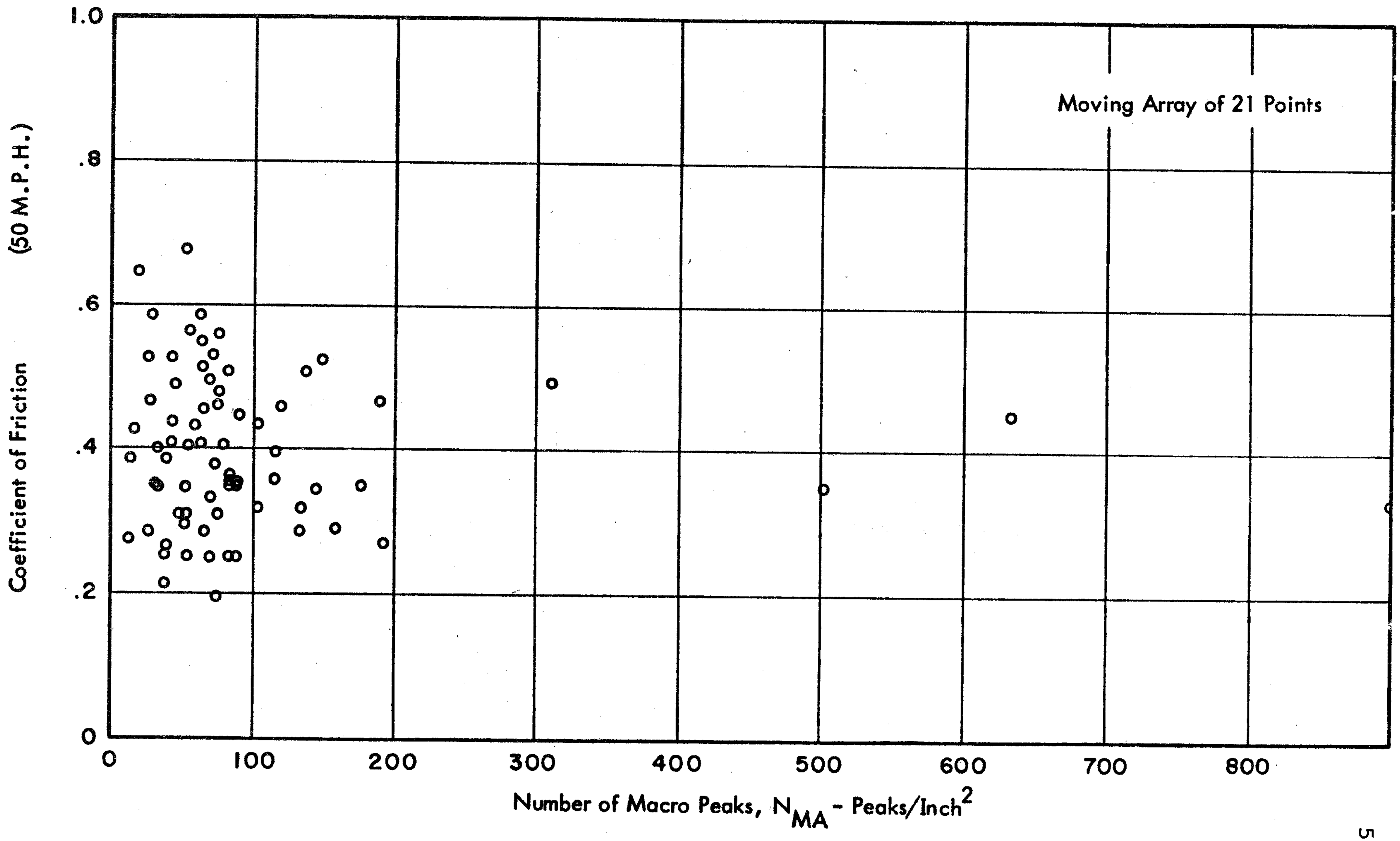
RELATION OF C_{50} AND AVERAGE HEIGHT OF MACRO PEAKS

FIGURE 25



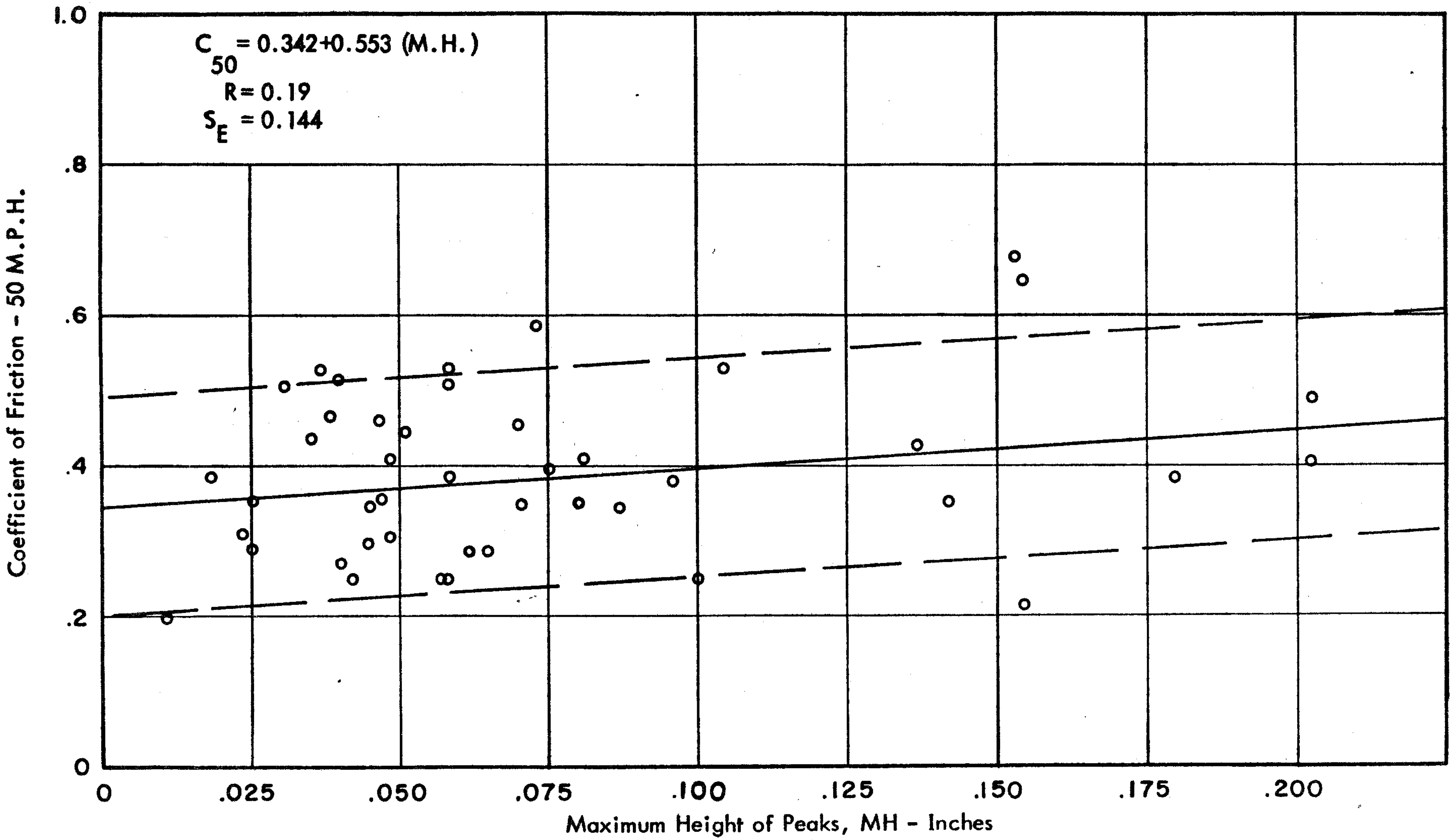
RELATION OF C_{50} AND AVERAGE HEIGHT OF MACRO PEAKS FOR VARYING NUMBERS OF MACRO PEAKS

FIGURE 25A



RELATION OF C_{50} AND NUMBER OF MACRO PEAKS

FIGURE 26



RELATION OF C_{50} AND MAXIMUM HEIGHT OF PEAKS

FIGURE 27

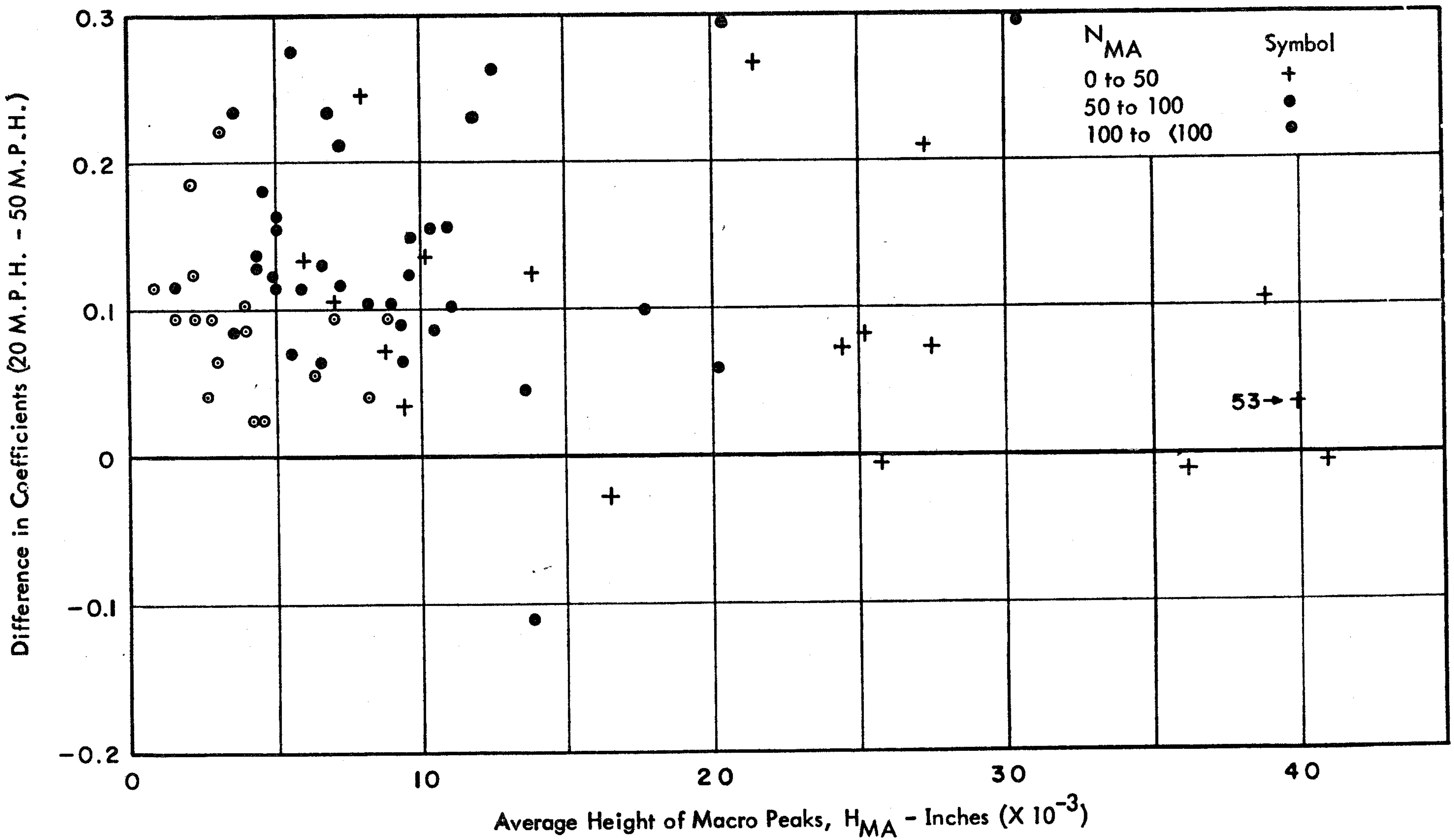
It was interesting to note that the coefficient of correlation ($R = 0.19$) and the standard error of the estimate ($S_E = 0.144$) for both the Macro Height and Maximum Height studied indicate values which are equal.

The Relation of the Difference in Coefficients with Average Height of Macro Peaks

It is not known if conditions of partial hydroplaning causes loss of skid resistance with increased speed since decreasing coefficients are also noted in dry conditions. In any event, surface texture probably contributes to the difference in coefficients. To study this effect the coefficient differential between the Coefficient of Friction at 20 miles per hour (C_{20}) and the Coefficient of Friction at 50 miles per hour (C_{50}) was studied in relation to H_{MA} (Figure 28). A very wide scatter of the plotted points covering virtually the entire graph was found. The influence of Number of Macro Peaks was studied by using symbols to denote three groups with varying magnitudes. Several tests were found in which the skid resistance at the higher speed was larger than the coefficient at the lower speed.

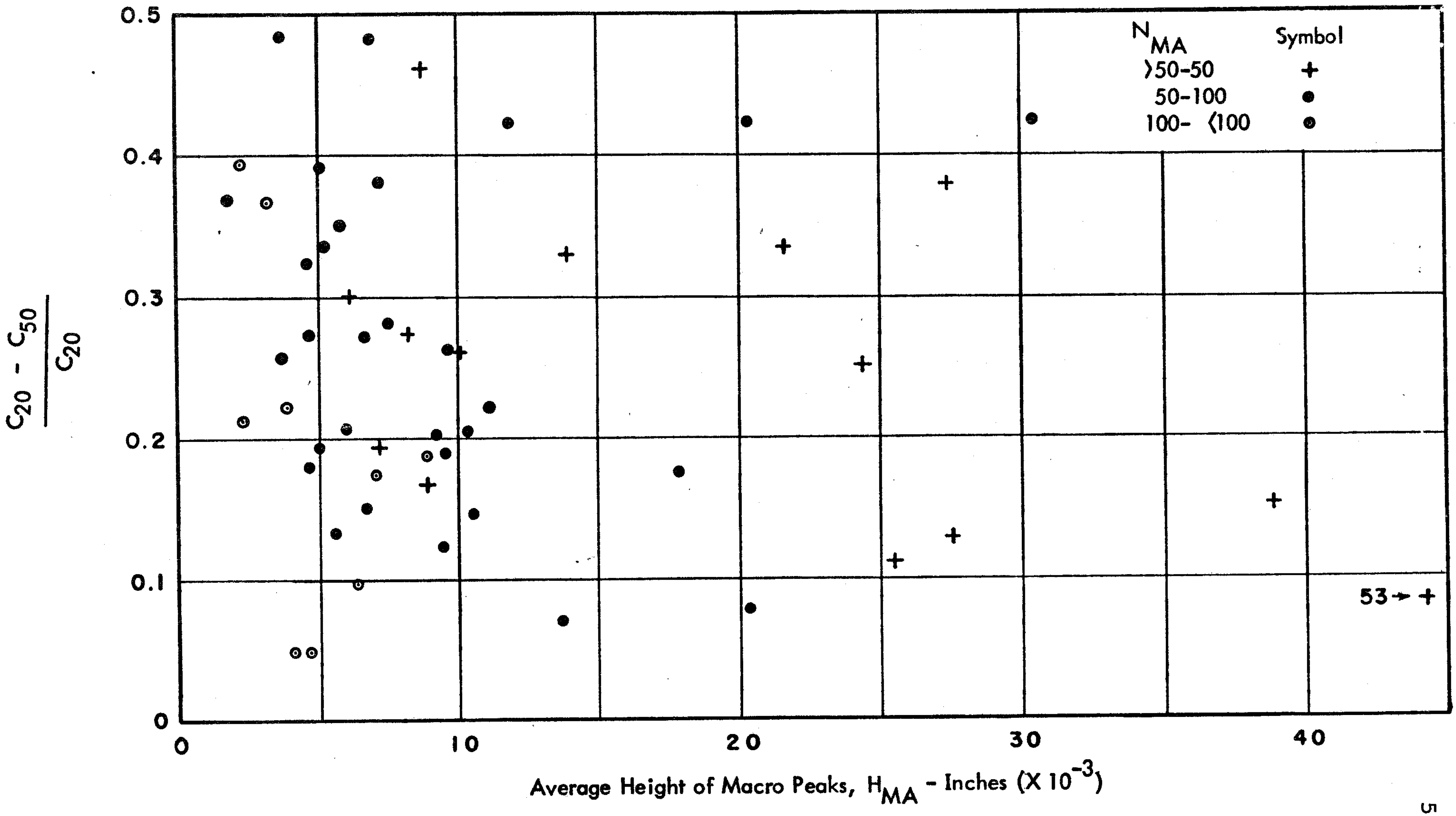
Relation of Difference in Coefficients per C_{20} with Average Height of Macro Peaks

It was postulated that skid resistance loss with increased speed was dependent on skid resistance at some lower speed. That is, if a low coefficient of friction was measured at a slow speed it could not be much lower at an increased speed because theoretically skid resistance cannot be less than zero. It was expected that higher differentials might occur in higher coefficient ranges. If this were true, the loss in skid resistance with speed in wet conditions would be partially related to both skid resistance magnitude and pavement texture. To study this effect $C_{20} - C_{50}$ was divided by the coefficient occurring at 20 miles per hour and plotted with H_{MA} (Figure 29). Attempts to study the influence of Number of Macro Peaks resulted in the use of symbols to denote three magnitude groupings. The use of Number of Macro Peaks seemed to



RELATION OF DIFFERENCE IN COEFFICIENTS AND AVERAGE HEIGHT OF MACRO PEAKS

FIGURE 28

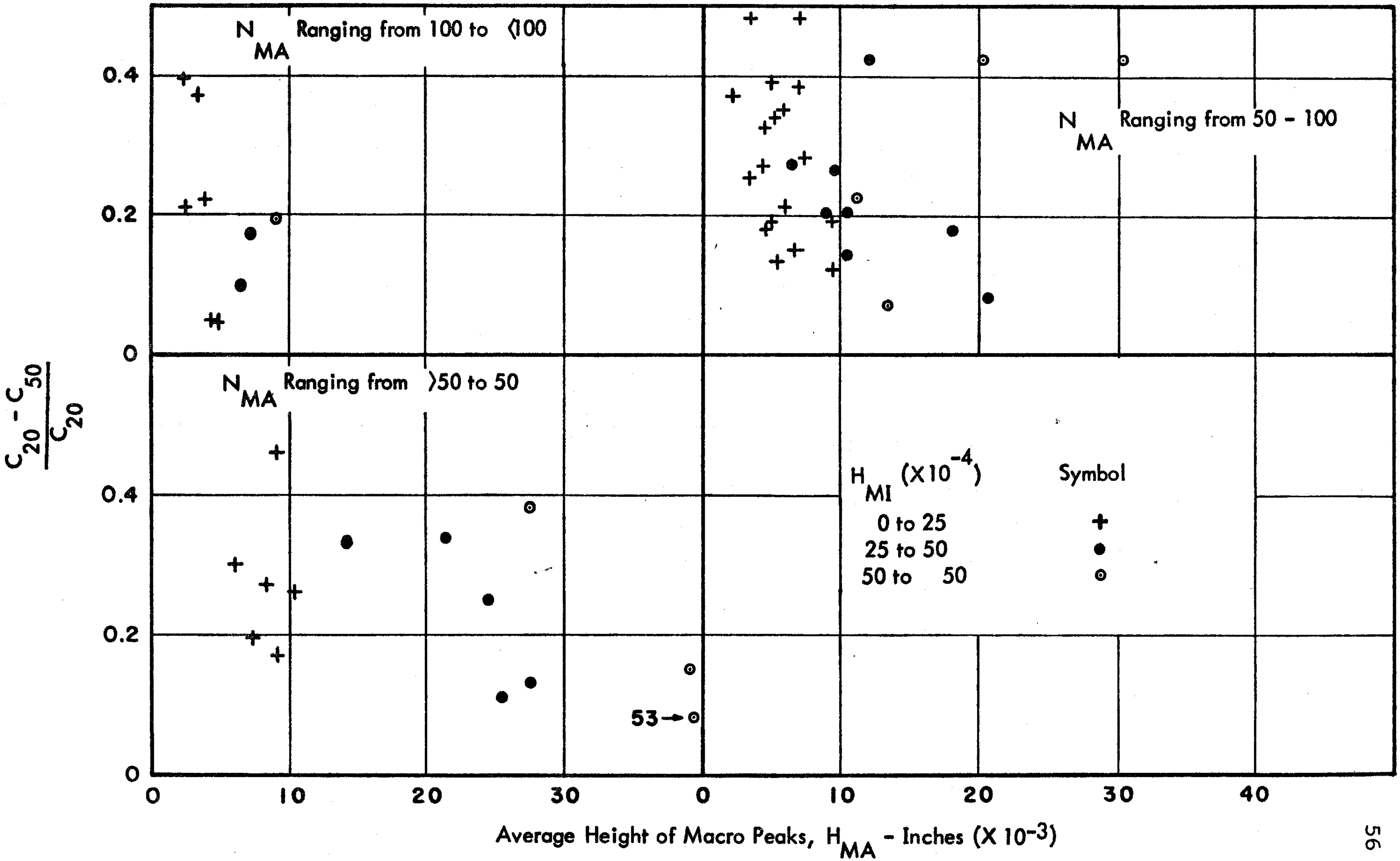


STUDY OF DIFFERENCE IN COEFFICIENTS PER C_{20}

FIGURE 29

place the data in three general locations on the plot. Large numbers of peaks were found generally at small heights and the small numbers of peaks were found at large heights as expected. The medium numbers of peaks were found generally between the high and low numbers. There was a slight indication that the rate of decrease in Coefficient Differential per C_{20} is rapid as H_{MA} increases if large numbers of macro peaks are encountered; however, the rate of decrease is less if smaller numbers of macro peaks are found.

Figure 29A includes plots in which an attempt has been made to hold the N_{MA} variable constant while studying micro texture. Each plot contains one group in which the magnitude of Number of Macro Peaks was within the same range. Average Height of Micro Peak groups were denoted by symbols.



DIFFERENCE IN COEFFICIENTS Per C_{20} FOR VARYING NUMBERS OF MACRO PEAKS

FIGURE 29-A

VII. DISCUSSION OF RESULTS

One of the objectives of this study was to develop equipment which could obtain texture measurements with sufficient accuracy to contribute to the advancement of knowledge of texture in the field of construction materials. The accuracy of the equipment developed is evident when Figures 5 through 9 are studied. The profile of the polished glass when noted closely indicates that very minor irregularities exist, and that there was a scratch in the polished glass surface. The scratch was noticed before the profile was determined, and the header card was key punched to indicate a scratch approximately 1/4 inch from the beginning point.

The horizontal and vertical stability of the equipment is evident from the results presented in Figure 6 as the needle attempted to probe along the vertical face of the penny. The repeat tests in Figures 7 and 8 also indicate sufficient equipment repeatability.

As stated previously, commercial instrumentation was not found which could measure the pavement surface profile with the accuracy and range desired for this study. Therefore, equipment was developed to measure accurately a microprofile. Vertical sensitivity of approximately 40 micro inches, which is microscopic, was achieved and greater sensitivity is available on demand. Horizontal sensitivity of 0.004 inch was achieved and greater sensitivity is available by adapting a slower motor or by inserting the correct system of sprocket sizes. Time is a factor, however. Longer testing periods are necessary for a more precise definition of the surface profile by more frequent sampling.

The Relation of Number of Peaks and Average Height of Peaks

If a comparison is made of Number of Micro Peaks vs. Height of Micro Peaks (Figure 18), Number of Peaks vs. Average Height of Peaks (Figure 16), and Number of Macro

Peaks vs. Height of Macro Peaks (Figure 17) it may be found that the general hyperbolic curve trend is indicated in each case. Also, the variation of points tends to decrease as each is viewed in consecutive order. It can be postulated that the variation of data points found in these plots results in, and possibly accounts for, variation in skid resistance. Therefore, when studying pavement texture, it would seem that both the number of peaks and the heights should be considered.

If it is necessary for water to disperse as the tire passes over wet pavements, there should be an optimum number of peaks for any given height. It can also be hypothesized that excessive micro texture could hamper the dispersal of water in certain conditions.

Where polishing occurs, there could be the same number of peaks, but height would be reduced. Also extreme polishing may reduce both height and number of peaks.

The texture heights obtained in this study have been compared to the height measurements found by others. The Height of Macro Peaks found in this study is of the same order as that found by Wilson(12) and Sabey(13).

Relations of Skid Resistance and Pavement Texture

Texture must of necessity be important to skid resistance. Hydroplaning and partial hydroplaning are also undoubtedly somewhat dependent on texture. If the drainage channels formed by the texture of aggregate height are needed at high speeds in wet conditions, it can be hypothesized that the smaller aggregate texture is important when the tire disperses the water film and contacts the aggregate surface. This means that the pavement surface which contains the proper combination of the larger "pavement texture" and the smaller "aggregate texture" results in the highest skid resistance for wet conditions.

Skid Resistance at Slower Speeds. It seems that there should be less water in existance under the tire at slow speeds because of the larger dispersal time. This means that water dispersal is not as difficult to accomplish on roadways designed for slow speeds as compared with high speed highways. The data in Figure 23 indicates a general increase in coefficient of friction at 20 miles per hour as the Height of Micro Peaks increases, but the scatter in data destroys confidence in this knowledge.

There is some indication that skid resistance at 20 miles per hour could be expected to increase rapidly with increases in the height of the micro peaks if there are large numbers of peaks present (see Figure 23, triangular symbol). However, the data in Figure 18 (Height of Micro Peaks vs. Number of Micro Peaks) reveal that a low number of peaks was associated with large heights. The symbols used in Figure 23 also reflect this occurrence, and due to large scatter present in each group, conclusive evidence of the trend in increased skid resistance is not present.

<u>Skid Resistance at Higher Speeds</u>. Figure 25 reveals an increase in skid resistance as the Height of Macro Peaks increases; however, the Correlation Coefficient indicates that macro height explains only a small portion of the variation in C_{50} obtained in this study. The Standard Error was used as a measure of variation about the least squares linear curve fit. The Standard Error was found to be 0.144. This value is larger than the increase in coefficient noted for the full range of H_{MA} values in Figure 25. This evidence indicates that little faith can be placed in the H_{MA} values as a measure of skid resistance as found in this study.

It is possible that other measured variables could explain the scatter of data found in Figure 25. The grouping of the magnitudes of number of peaks appears to explain part of this scatter. The first indications were that skid resistance at 50 miles per hour could be improved remarkably with combinations of large macro peak heights and large numbers of macro peaks. The upper left plot in Figure 25A using large numbers of macro peaks indicates rapid increases in skid resistance as macro height increases. The upper right plot reveals less rapid increases. The lower left plot seemed to indicate a less rapid rate and the lower right plot the smallest rate.

It was thought that the variation in each plot could be further explained by studying micro texture. The larger magnitudes of Number of Micro Peaks appear to fall to the upper left positions on the plots or in the lower Macro Height ranges and in the higher coefficient areas. Micro height (not shown) does not appear to provide further clarification of the data.

If these trends are true, pavement surfaces with combinations of average Heights of Macro Peaks, large Numbers of Macro Peaks and large Numbers of Micro Peaks would provide higher skid resistance values at higher speeds.

Relation of Difference in Coefficients and Pavement Texture

Vehicle braking is generally discussed along with hydroplaning. Skid resistance is implied in hydroplaning conditions since pavement conditions are critical in both cases. However, skid resistance is associated with braking and hydroplaning results without braking. Loss of vehicle control is evident with each phenomenon. It must be assumed that little difference could be noted by braking a tire in hydroplaning conditions because the tire has previously ceased to rotate. However, violent maneuvers could be expected if one of the braked tires again touched the pavement surface before the other tires.

The Texas Highway Department has performed several tests in which skid resistance values were obtained over the same pavement area at various speeds. In some instances large skid resistance differentials were noted, but no tests were obtained in which hydroplaning conditions were found. It is assumed from these unpublished tests that hydroplaning conditions did not exist before or after braking. Yet, the test trailer's water system could have established partial hydroplaning conditions. This partial hydroplaning should, to some extent, be dependent on pavement texture. The probability exists that optimum pavement texture is indicative of small coefficient differentials.

Difference in Coefficients (20 mph - 50 mph). Very little correlation was found between the coefficient differential (at 20 miles per hour and 50 miles per hour) and macro height. The use of Number of Macro Peaks as the second independent variable again seemingly separated the scattered data points into general groups. These groups were as expected since the Number of Macro Peaks with the larger magnitudes were found at the lower macro heights and the lower magnitudes were found at the larger macro heights. Several values were found in which the Coefficient of Friction at 50 miles per hour was larger than the Coefficient of Friction at 20 miles per hour. It is interesting to note that these negative coefficient differential values occur generally in higher macro height ranges with associated low Numbers of Peaks which indicates good drainage.

Difference in Coefficients per C_{20}. Low values of Difference in Coefficients per C_{20} should be considered as optimum as indicated in the plot on Figure 29. Noted was the fact that these conditions were experienced at all H_{MA} ranges. The rate of decrease appears generally related to the Number of Macro Peaks (N_{MA}), if the Average Height of Macro Peaks (H_{MA}) is increased. The faster rate of decrease is found in the larger N_{MA} group. The interesting fact is that H_{MI} appears to be detrimental to this rate of decrease since the larger magnitudes of H_{MI} appear on the right most edges of the plots in Figure 29A. This was not as previously postulated and could mean that entrapped fluids may be hampered by the micro texture as they are forced through the exit routes provided by the macro texture.

Visual Observations

Several cores were selected on the basis of a range in coefficient values and profiles obtained were plotted and are included in Appendix C. By noting these profiles and studying the related skid resistance values, the following concepts can be surmised:

(1) Skid resistance is not fully dependent on aggregate height.

(2) Skid resistance is not entirely dependent on the number of aggregates in place.

(3) Skid resistance is not fully dependent on the small-scale aggregate texture heights.

(4) Skid resistance is not fully dependent on the number of small-scale projections.

The profile of 101-2-1 indicates practically non-existent small scale "aggregate texture", but large "pavement texture" was found. The coefficient is in the medium class (C_{20} = 0.542 and C_{50} = 0.524). Control 356, Section 1, Job 1 indicates approximately the same micro texture as the previous core, but the macro heights are smaller. The coefficient is also smaller (C_{20} = 0.376 and C_{50} = 0.273).

The profile of 356-1-1 could also be compared to 300-2-1 (C_{20} = 0.860 and C_{50} = 0.674) since approximately the same macro texture is present. The difference in coefficients between the two specimens appears to be due to the micro texture in this case.

Coefficient differentials were also noted in the profiles plotted. Small increases in the Difference in Coefficients in apparent in 300-2-1 (Differential = 0.186), 23-5-2 (Differential = 0.251), and 37-3-1 (Differential = 0.276) as the "aggregate height" decreases. The large macro texture revealed in 101-2-1 also results in the smallest differential in the group (Differential = 0.018). The profiles in 5-7-1 (Differential = 0.055) and 37-3-1 (Differential = 0.276) result in approximately the same macro texture; however, 37-3-1 indicates extremely good micro texture. The coefficient differential is much greater on 37-3-1.

General Discussion

There are many materials available in Texas which contain good aggregate texture. Several of these materials polish rapidly under traffic and lose their texture in the process. Other aggregates with good texture polish slowly and are thought to be better suited as surfacing materials than those that polish rapidly. Other aggregates flake or disintegrate slowly under traffic action and thereby continually expose new skid resistant surfaces to traffic. There is a class of porous aggregates which maintains high skid resistance, regardless of traffic wear, since the porous openings in the aggregate provide the needed texture. These porous aggregates produce some of the highest friction readings which have been obtained in Texas. Still another type of aggregate has little visible texture. These aggregates may be rounded and worn by stream bed action, or they may be angular when fractured by crushing. In either case a smooth non-textured surface results.

If the engineer understands texture, he can select materials which produce skid resistant surfaces that stand up under traffic wear and weathering. Correct construction techniques must, of course, be employed in using the material. A fresh concrete surface can be broomed, for instance, to provide large scale pavement texture. Thin open-textured asphaltic concretes can be designed for use as a surface course over other nonporous, cheaper mixes. The open-textured asphaltic concrete can be placed full depth if desired. Surface treatments are considered standard and have been used for years. The primary consideration in this case is the determination of the correct type of material and the proper aggregate grade.

In general, both visual observation of the profiles and the results of the formal measurement study indicate that increased skid resistance results if both micro and macro texture are present. Regrettably, only general relationships were found among the several parameters evaluated in this study, and conclusive evidence of the influence of each variable was not found. The small Correlation Coefficients and large values of Standard Error of the Estimate testify to this fact.

Recommendation for Improvement in Analysis Procedures

The skid test trailer was used to obtain five test values for the wet coefficients of friction in each 2500 foot field pavement section and the core for micro profile measurements was obtained at approximately the middle portion of the test section. Only one core was used from each section, and, in almost every case, only one profile measurement was made on each core. Thus, a two-inch profile represents a 2500 foot section of pavement in these studies.

The Texas Highway Department has found a standard deviation of ±0.017 (in terms of coefficient of friction) can be expected with five tests in 2500 feet. This means that a skid resistance value of 0.5 can be expected to vary from 0.466 to 0.534 if two standard deviations are considered. The coefficients of friction predicted from the texture parameters measured in this study vary considerably more than the expected variation in five tests with the trailer. However, only skid resistance variation along the roadway has been measured in Texas. There is possibly some day-to-day variation in the coefficient of friction and in the equipment used for measuring the coefficient.

Five replicate profile tests were obtained on one core for the purpose of determining the precision with which texture parameters could be measured. The mean of the Average Height of Peaks of these five replications was 6,372 micro inches with a standard deviation of 1,020 micro inches. The coefficient of variation was 16.6 per cent. These statistical observations indicate large variation can be expected on any individual core. However, five repeat tests were obtained across the same path using 220 grit sandpaper as the surface. The mean of the Average Height of Peaks of these readings was 1,541 micro inches and the standard deviation was 39 micro inches. The coefficient of variation was 2.5 per cent. This observation indicated good repeatability of measurements.

Poor correlation between the texture parameters and coefficients of friction is probably due primarily to the method of analysis which was used. Techniques which could be improved are as follows:

(1) A better technique of data smoothing can probably be developed. Due to the data smoothing process employed in this analysis, large Average Height of Micro Peaks are encountered where large Average Height of Macro Peaks are found.

(2) More than one core should be obtained to represent the pavement surface on which the skid resistance is measured. This core should be taken in the skid path immediately after skid testing.

(3) More than one profile should be obtained on each core.

VIII. RECOMMENDATIONS FOR FUTURE STUDY

This study has revealed several interesting areas which can be studied. Those areas which are apparent are as follows:

(1) Material texture as related to structural properties.

(2) Texture variations as related to the seasonal fluctuations in skid resistance.

(3) Texture variations as related to traffic wear.

(4) Pavement texture as related to vehicle headlight reflectance.

Many construction materials depend, in part, on material texture for strength. Asphaltic concrete, for example, depends upon some combination of aggregate texture and aggregate shape for good asphalt adhesion and high resistance to wheel loads. The texture of clay brick influences the strength properties of related masonry structures. The equipment reported herein is not specifically designed to measure texture variables of individual aggregate particles; however, it is possible that a study technique can be developed.

Skid resistance appears to have seasonal variables. Coefficient of Friction values tend to be higher in the winter than in the summer.[4] It is possible that texture plays an important role in this fluctuation.

Little is known about light reflectance along the pavement structure. The length of pavement that is visible to the driver depends partly on pavement color, and it is possible that this length also depends on the surface texture.

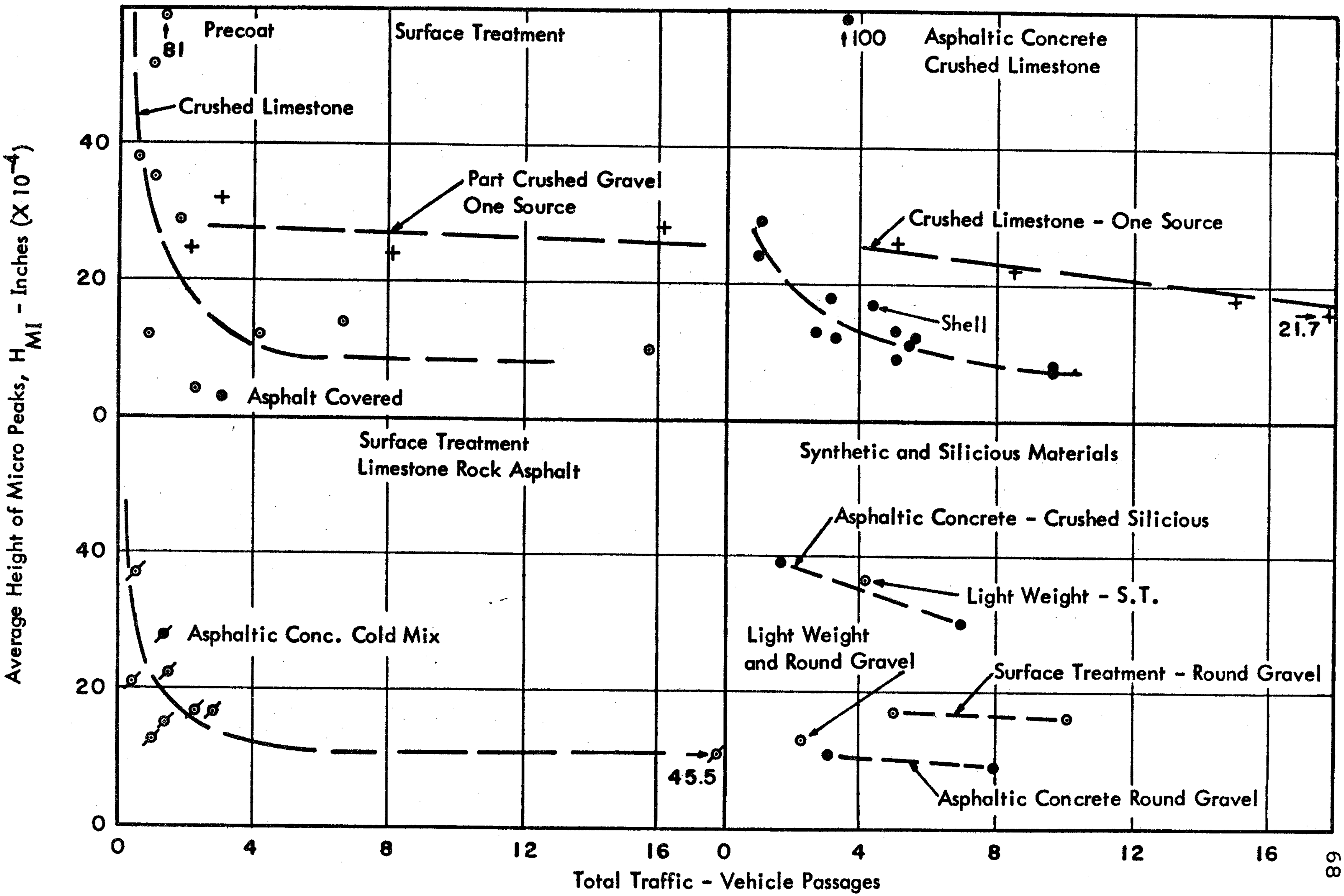
Maintenance-free, skid resistant surfaces are not determined entirely by the initial condition of the surface, but by the surface condition after being subjected to long periods of traffic "polish". Figure 30 indicates the effect of traffic wear on micro texture characteristics of several materials used in this study. These results imply that the same material type, even though used on different roadways, polishes in the same manner and at the same rate. It is possible that rate of polish is dependent on time and type of traffic as well as on the number of traffic applications. It is also possible that texture and skid resistance do not steadily decrease in value.

Figure 31 indicates the results of a cursory analysis of the effect on skid resistance made in conjunction with a study conducted at The University of Texas during the early stages of this work.[14] Newly molded cores were polished in a specially designed "accelerated wear polishing machine". The machine was designed to polish any four-inch diameter core. Polish was accomplished by a tire which was allowed to roll freely on a reciprocating table. The cores were inserted in hangers so that the surface of the core was in the same plane as the surface of the table. Various wheel load and tire pressure were available, and the wheel could be set to roll at an angle to the longitudinal axis of the plate. The polishing wheel was replaced periodically with a spare wheel which was instrumented to obtain friction readings. Thus, coefficient values were measured at periodic intervals during the polishing process.

Prior to the friction measurements, texture profiles were obtained and analyzed as reported previously. It appears (1) that the Average Height of Peaks was related to the coefficient values, and (2) fluctuations in texture and skid resistance probably occur as traffic wear progresses. Visual observations of the polished asphaltic concrete core, at the time of texture measurements, revealed the following:

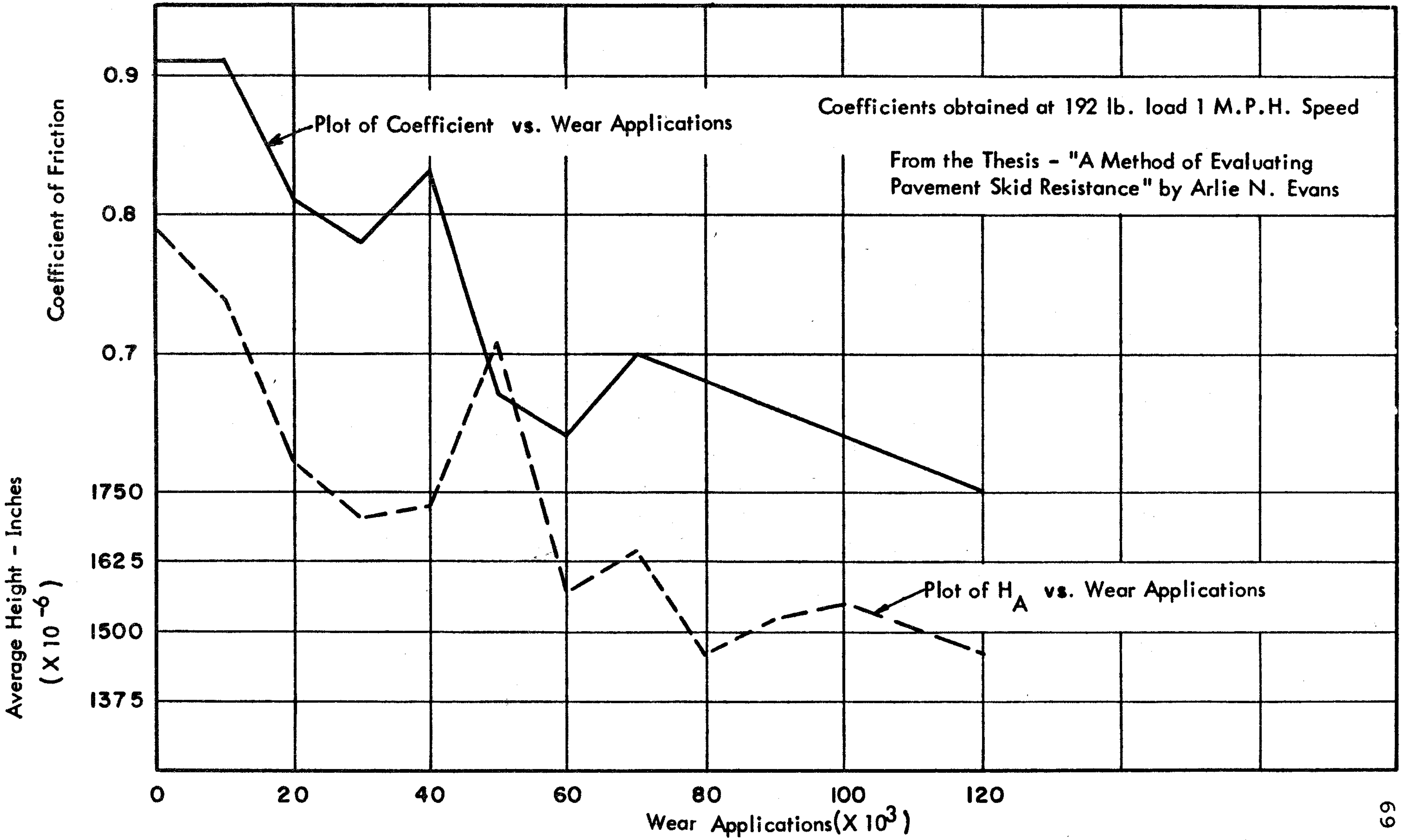
(1) Initially, the molded cores showed large aggregates coated with a mixture of asphalt and fine aggregates.

(2) The coating of asphalt and fines was worn from the surface of the large aggregate by the first 30,000 applications.



MATERIAL WEAR AS RELATED TO TRAFFIC APPLICATIONS

FIGURE 30



COMPARISON OF COEFFICIENT OF FRICTION
AND TEXTURE WITH INCREASED WEAR

Figure 31

(3) The large aggregates were protruding slightly at about 50,000 applications. It is thought that additional consolidation had occurred which caused the slight protrusion; however, the wheel was set at a small angle to the reciprocating action of the plate in an effort to accelerate polish. This small angle could have caused a stripping of the small aggregate of the surface.

Further study is needed in this area.

IX. CONCLUSIONS

Equipment was developed for measuring accurately the microprofile of a pavement surface. Vertical sensitivity of 0.000042 inch was achieved with a calibration variation of $\pm$0.0000026 inch. Horizontal measurements were made at 0.0033 inch intervals, and it was found that these measurements could be made with a variation of $\pm$0.000168 inch.

The texture parameters of Surface Length, Average Height of Peaks, Number of Peaks, Variation of Heights and Peaks in Short Lengths, Heights of Micro Peaks, Number of Micro Peaks, Height of Macro Peaks, Number of Macro Peaks, and Maximum Height were calculated from the microprofile of the surface of 77 pavement cores. Unsuccessful attempts were made to relate the measured texture parameters to skid resistance measured at 20 miles per hour and 50 miles per hour; however, it is believed that other analysis procedures will provide useful information concerning the relationship between pavement surface texture and skid resistance.

This study indicates that both the small scale "aggregate texture" and the large scale "pavement texture" are necessary to describe the texture characteristics which are related to skid resistance measured under wet conditions.

APPENDIX A

Equipment Information

Equipment Information and Calculations

Radius from Center of Vertical Shaft to Center of LVDT	= 4.625 inches
Circumference of Contact Circle	= 29.06 inches
Speed of Horizontal Drive Motor	= 1 rev./min.
Speed of Vertical Probing Motor	= 30 rev./min.
Reducing Sprocket Ratio	= 1 : 4.8

Vertical Probing Rate = 30 probes/60 sec.

= 0.5 probes/sec.

Angular Speed of Cantilevered Arm $= \dfrac{\text{1 rev.}}{\text{60 min. X 4.8}}$

$= \dfrac{\text{1 rev.}}{\text{288 min.}}$

Horizontal Speed of Needle = 288 min./29.06 inches

= 9.91 min./inch

= 594.6 sec./inch

OR $\dfrac{1}{\text{594.6 sec./inch}}$ = 0.00168 inch/sec.

Linear Probing Rate $= \dfrac{\text{0.00168 inch/sec.}}{\text{0.5 probe/sec.}}$

= 0.00336 inch/probe

APPENDIX B

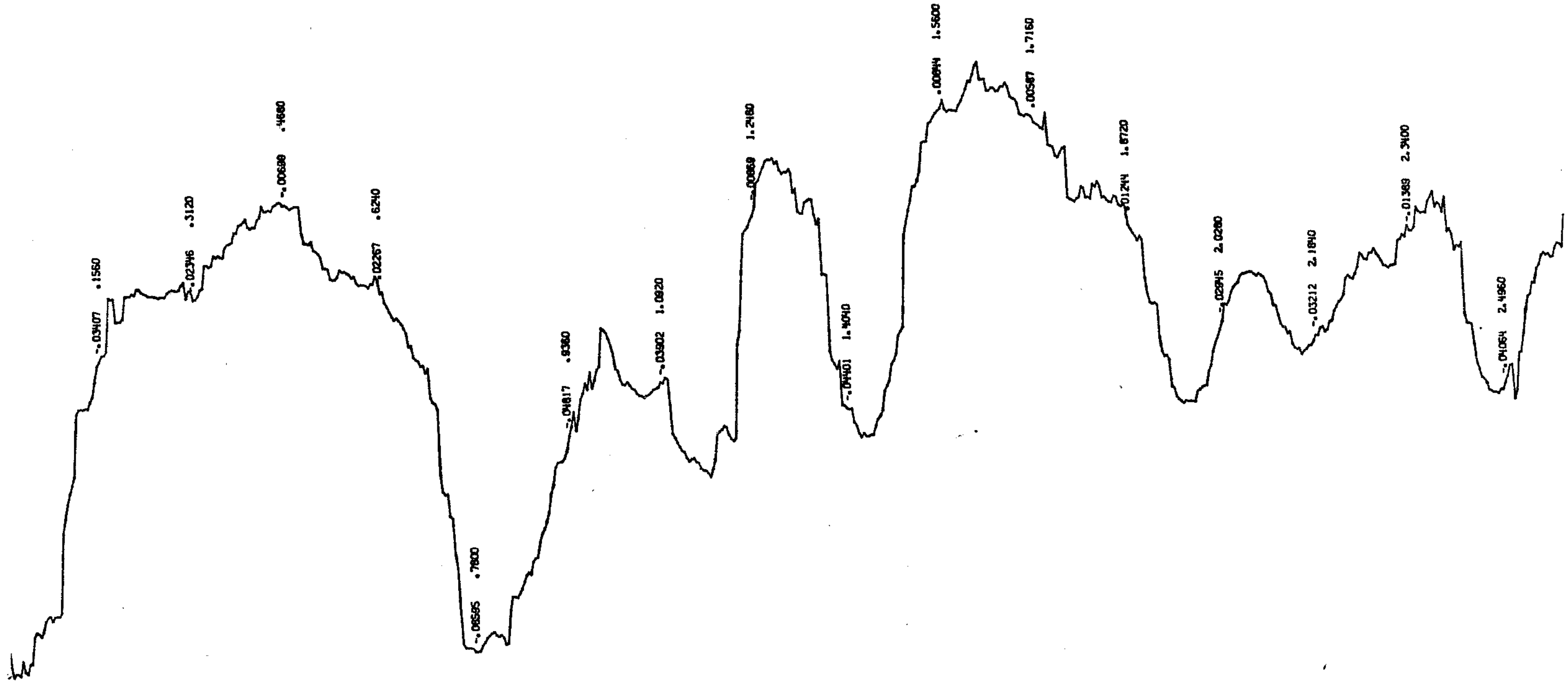
Data List

DATA INFORMATION

Core Number	District	C-S-J	Number of Probes	Core Material	C_{20}	C_{50}	Total Traffic ($X10^3$)	N_A peaks/inch^2	H_A inches (X10-6)	Surface Length inches	N_{MI} Peaks /in.^{2}	H_{MI} inches (X10-6)	N_{MA} peaks /in.^{2}	H_{MA} inches (X-10-6)	MH inches
1	13	25-7-1	600		0.421	0.351	955	743	6,808	2.668					
2	16	101-2-1	600	ST-Lge Cr Lime	0.542	0.524	668	534	9,238	3.039					
3	4	356-1-1	600	ST-Lge Cr Lime	0.376	0.273	6,799	562	4,039	2.491	3,267	734	13	8,277	0.0402
4	2	1978-1-1	600	HMAC-Cr Lime	0.545	0.438	5,031	904	4,613	2.717					
5	8	5-7-1	600	HMAC-Emulsion Covered	0.222	0.167	3,066	1,766	808	2.357					
6	20	508-4-1	600	HMAC-Cr Lime	0.324	0.300	5,616	1,098	1,788	2.417					
7	24	1-2-1	600	HMAC-Sil Part Cr	0.593			1,272	2,182	2.432					
8	4	425-1-1	600	ST-Cr Sil	0.622	0.527	822	1,751	3,633	2.658	2,799	2,827	149	7,181	0.0587
9	22	300-2-1	600	ST-Lime Rock Asphalt	0.860	0.674	1,553	1,423	3,192	2.571					
10	22	37-3-1	600	ST-Lime Rock Asphalt	0.790	0.514	1,092	2,707	1,492	2.404	2,548	1,807	64	5,759	0.0392
11	22	22-7-1	600	CMRA-Lime Rock Asphalt	0.674	0.637	1,316	2,809	2,593	2.693					
12	22	23-5-2	600	ST-Lime Rock Asphalt	0.857	0.606	2,399	2,356	2,375	2.500					
13	15	613-2-1	579	ST-Lime Rock Asphalt	0.519	0.490	2,858	2,073	2,452	2.475					
14	20	28-9-1	600	ST-Lime Rock Asphalt	0.524	0.453	45,542	3,114	1,213	2.461	2,176	2,241	63	5,622	0.0700
15	8	5-7-1	600	HMAC-Emulsion Covered	0.222	0.167	3,066	4,333	2,705	2.674					
16	3	134-2-1	529	HMAC-Lime & Sil Rd	0.476	0.290	3,028	3,370	1,257	2.400	4,202	1,228	158	2,205	0.0258
17	1	203-2-1	527	ST-Cr Lime	0.519	0.384	4,280	1,155	2,215	2.450	2,358	1,720	39	10,287	0.0588
18	2	250-1-1	600	ST-Sil Rd	0.413	0.451	10,200	2,187	2,338	2.514	3,251	1,838	67	5,086	0.0577
19	1	203-1-1	600	ST-Cr Lime	0.423	0.285	15,791	1,621	1,471	2.389	3,035	1,197	64	4,564	0.0652
20	3	134-2-2	519	ST-Lime & Sil Rd	0.512	0.408	4,920	2,102	2,726	2.510	2,240	2,592	78	9,045	0.0486
21	2	7-10-1	600	HMAC-Cr Lime	0.458	0.305	3,105	1,445	2,262	2.476	1,977	2,087	74	5,149	0.0482
22	2	260-1-1	600	HMAC-Cr Lime	0.453	0.352	3,517	1,560	13,505	4.366	1,787	12,715	82	11,261	0.1424
23	3	282-2-1	564	HMAC-Cr Lime	0.411	0.295	4,923	2,357	1,277	2.455	2,583	1,839	52	7,307	0.0440
24	3	282-2-2	584	ST-Synthetic Lightwt	0.729	0.648	4,241	1,807	5,435	2.860	2,812	4,455	19	25,336	0.1540
25	2	1978-1-1	584	HMAC-Cr Lime	0.545	0.438	5,031	1,198	1,821	2.400	2,766	1,273	43	7,070	0.0352
26	2	8-12-2	600	HMAC-Cr Lime	0.423	0.359	21,737	2,591	1,472	2.452	2,907	1,652	81	6,645	0.0477
27	1	47-1-1	600	HMAC-Cr Lime	0.603	0.382	5,443	3,251	1,081	2.385	3,339	1,213	131	3,273	0.0188
28	3	224-2-1	549	HMAC-Cr Lime	0.458	0.357	3,284	1,839	2,064	2.407	2,924	1,472	114	3,978	0.0257
29	2	902-30-1	519	HMAC-Cr Lime	0.489	0.463	99,999	2,783	1,776	2.425	3,678	1,555	190	4,561	0.0382
30	5	380-1-1	600	ST-Lightwt Sil Rd	0.555	0.344	2,331	1,501	1,814	2.418	1,501	2,005	52	7,296	0.0452
31	5	227-3-1	600	HMAC-Cr Lime	0.645	0.529	2,789	1,159	2,454	2.445	2,036	1,898	60	4,977	0.0379
32	16	254-3-1	600	ST-Cr Lime	0.421	0.426	1,851	1,020	5,029	2.726	2,392	3,506	15	25,815	0.1374
33	16	155-4-1	600	ST-Lime Rock Asphalt	0.531	0.285	1,320	1,194	2,474	2.450	2,183	1,729	28	8,070	0.0628
34	13	370-1-1	600	ST-Lime Rock Asphalt	0.737	0.679	696	1,410	5,598	2.918	2,629	4,354	52	20,253	0.1538
35	5	67-5-2	600	HMAC-Lime Sil Rd	0.443	0.310	7,929	1,663	1,020	2.376	2,232	1,275	47	6,028	0.0231
36	12	389-12-1	600	HMAC-Trap Rock & Lime	0.586			1,676	3,216		2,069	3,433	134	9,170	0.0546
37	16	102-4-1	600	ST-Cr Lime Polished	0.312	0.198	2,606	2,837	462	2.346	3,322	481	76	1,725	0.0111
38	13	25-7-1	600	ST-Cr Lime	0.421	0.351	955	794	2,798	2.464	1,906	1,741	30	8,857	0.0710
39	12	110-3-1	600	HMAC-Iron Ore	0.624	0.502	31,696	2,757	1,580	2.416	3,205	1,450	81	4,975	0.0319
40	19	10-13-1	600	HMAC-Lime & Sil Rd	0.750			1,615	2,890	2.499	2,245	2,436	111	4,198	0.0497
41	23	79-1-1	600	HMAC-Cr Lime	0.469	0.344	8,530	1,086	3,136	2.469	1,479	2,967	83	9,746	0.0872
42	15	521-4-1	514	-Cr Lime	0.469	0.379	15,049	1,923	2,919	2.490					
43	18	574-1-1	600	ST-Lime Rock Asphalt	0.739	0.586	483	1,168	3,886	2.525	2,503	2,602	62	10,410	0.0733
44	20	306-3-3	600	HMAC-Cr Lime	0.625			1,402	3,682	2.541	2,385	3,005	80	11,987	0.0571
45	15	25-2-1	600	HMAC-Cr Lime	0.481	0.249	9,626	2,006	946	2.362	2,638	957	54	3,557	0.0583
46	20	304-5-1	600	ST-Cr Lime	0.423	0.388	1,051	743	10,513	3.152	1,723	7,334	13	53,861	0.1800
47	22	23-5-1	597	ST-Lime Rock Asphalt	0.795	0.527	2,559	1,556	5,427	2.740	2,559	3,957	41	21,536	0.1040
48	24	2121-1-1	600	HMAC-Sil Cr	0.560	0.460	6,876	2,465	2,717	2.568	2,506	3,712	73	17,839	0.0474
49	24	2121-6-1	600	HMAC-Sil Cr	0.491	0.398	1,733	2,163	4,181	2.733	2,548	4,114	115	8,950	0.0756
50	19	62-1-1	600	ST-Prec Cr Lime	0.700	0.403	1,325	1,112	10,879	3.466	1,439	10,747	56	30,490	0.2027
51	16	180-6-1	599	HMAC-Shell	0.514	0.448	4,367	1,753	2,159	2.425	2,290	1,974	88	9,318	0.0517
52	24	2-5-1	600	HMAC-Part Cr Lime	0.476	0.347	1,096	1,390	3,693	2.630	1,882	3,422	86	6,791	0.0805
53	15	25-2-1	600	HMAC-Cr Lime	0.481	0.249	9,626	1,683	1,101	2.380	2,278	1,498	82	6,838	0.0424
54	16	447-3-1	600	ST-Cr Lime	0.563	0.489	1,223	687	6,777	2.688	1,689	4,669	44	27,554	0.2030
55	18	134-9-1	398	ST-Cr Lime	0.379	0.406	3,083	1,204	5,291	2.720	1,691	4,460	41	16,683	0.0815
56	4	90-5-1	544	ST-Cr Lime	0.290	0.217	16,260	894	6,428	2.720	1,826	3,989	38	24,457	0.1541
57	4	67-1-2	537	ST-Cr Lime	0.376	0.251	8,239	1,019	5,789	2.670	2,007	3,875	38	13,940	0.1006
58	15	521-5-1	525	-Cr Lime	0.563	0.507	2,226	2,521	3,346	2.583	3,479	2,795	136	6,319	0.0586
59	15	521-4-1	514	-Cr Lime	0.469	0.379	15,049	1,963	2,919	2.490	2,785	2,170	71	9,343	0.0963
60	16	155-5-1	600	HMAC-Shell	0.580	0.494	1,208	2,894	3,323	2.672	3,613	3,102	311	3,923	0.0353
61	16	180-6-1	539	HMAC-Shell	0.514	0.448	4,367	2,930	3,342	2.620	3,087	3,442	633	3,059	0.0408
62	18	81-3-2	600	ST-Cr Lime Lge Polished	0.295	0.261	5,837	811	3,618	2.439	1,720	1,987	39	9,546	0.0800
63	12	50-8-1	534	HMAC-Shell	0.388	0.366	29,537	2,679	1,558	2.400	3,198	1,453	193	2,271	0.0515
64	20	243-1-1	440	HMAC-Cr Lime Lge Polished	0.314			1,752	2,800	2.515	2,558	3,252	97	4,908	0.0935
65	14	265-2-1	600	HMAC-Polished Lime & Sil Rd	0.361	0.319	5,566	1,590	3,150	2.534	2,345	2,773	103	8,280	0.0562
66	14	265-2-1	600	HMAC-Lime Pea Gravel Polished	0.361	0.319	5,566	2,960	1,115	2.396	3,311	1,131	137	2,719	0.0230
67	16	612-1-2	524	HMAC-Shell	0.423	0.331	15,532	4,219	6,476	3.270	4,093	6,705	1,414	1,568	0.0292
68	9	184-3-1	514	HMAC-Part Cr Lime & Sil	0.443	0.349	1,726	3,109	2,892	2.540	3,451	2,848	501	2,816	0.0329
69	9	382-2-1	524	HMAC-Part Cr Lime & Sil	0.596	0.334	1,321	1,764	3,951	2.595	2,433	3,085	67	12,648	0.0671
70	4	379-1-1	600	ST-Polish Lime Emulsion Covered	0.458	0.344	5,518	2,858	445	2.346	3,260	417	144	841	0.0134
71	5	67-3-1	600	HMAC-Rd Sil Emulsion	0.557	0.401	2,882	1,187	2,314	2.417	3,022	1,422	32	11,175	0.0933
72	4	557-1-1	600	ST-Lge Part Cr Lime & Sil Rd	0.588	0.438	1,266	1,946	2,654	2.522	2,668	2,264	103	9,827	0.0772
73	4	1245-4-1	600	HMAC-Part Cr Lime & Sil	0.676	0.548	259	1,526	1,593	2.412	1,581	1,702	64	4,466	0.0380
74	10	191-1-1	600	HMAC-Iron Ore & Sil Rd	0.448	0.558	6,559	1,333	5,647	2.732	2,073	4,220	74	13,944	0.2089
75	16	155-5-1	600	HMAC-Shell	0.580	0.494	1,208	1,537	3,635	2.619	1,815	3,578	68	10,584	0.0998
76	5	380-1-1	600	ST-Sil Rd & Lightwt	0.555	0.344	2,331	894	7,283	2.948	1,362	6,856	33	27,316	0.1379
77	12	389-5-1	554	HMAC-Sil Rd & Shell	0.540	0.310	14,587	1,200	4,603	2.665	2,582	2,781	54	11,900	0.0949
78	20	213-8-1	600	ST-Lime Rock Asphalt Open Texture	0.692	0.586	2,758	862	10,298	3.398	1,511	8,560	28	38,997	0.2661
79	19	62-1-1	588	ST-Precoat Cr Lime	0.700	0.403	1,325	1,337	7,827	3.025	1,746	7,025	61	20,439	0.1197
80	20	214-2-1	600	ST-Cr Lime Open Texture	0.458	0.463	2,246	346	16,875	3.226	1,447	8,053	28	41,703	0.2323
81	16	74-6-1	600	HMAC-Shell Polished	0.438	0.344	15,371	2,141	1,528	2.400	2,180	1,734	178	2,341	0.0153
82	21	1138-1-1	600	ST-Sil Rd Open Texture	0.511	0.522		946	7,860	2.907	1,917	5,213	26	36,280	0.1751
83	15	521-4-2	600	HMAC-Cr Lime Polished	0.329	0.244	25,871	1,520	1,754	2.401	2,375	1,523	86	3,719	0.0343
84	13	144-6-1	600	ST-Cr Lime New	0.609	0.565	2,212	1,024	7,146	2.950	2,111	5,143	54	13,776	0.0728
85	12	1844-2-1	600	HMAC-Shell Lime & Sil	0.547	0.433	598	1,463	2,504	2.462	2,267	1,876	59	5,969	0.0530
86	12	179-2-1	600	HMAC-Lime Rock Asphalt	0.658	0.479	976	1,882	1,650	2.403	2,392	1,521	75	4,683	0.0579
87	9	231-4-1	539	HMAC-Part Cr Lime & Sil	0.484	0.458	10,027	2,678	1,864	2.422	3,139	1,741	119	4,338	0.0209

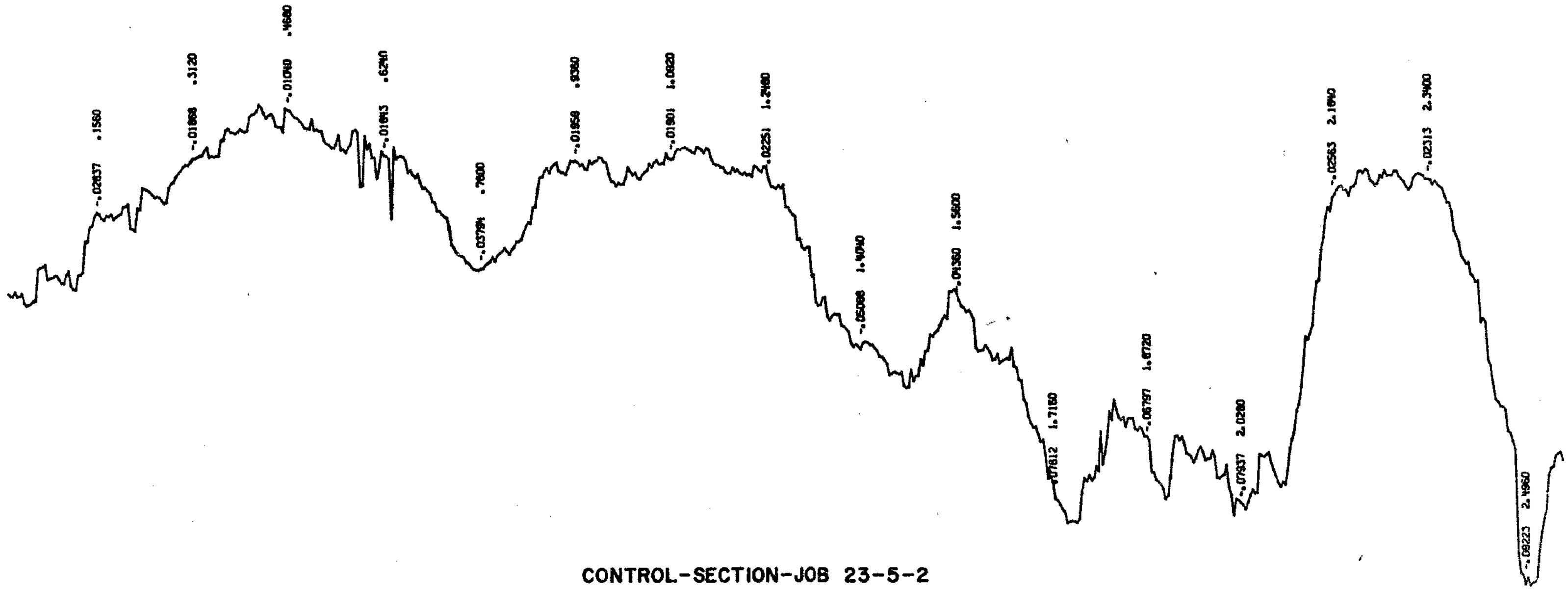
APPENDIX C

Texture Profiles from Selected Specimens



CONTROL-SECTION-JOB 300-2-1
C_{20} 0.860
C_{50} 0.674
AVERAGE NUMBER OF PEAKS 1423
AVERAGE HEIGHT 0.003192
LIMESTONE ROCK ASPHALT

SCALES: 0 0.08 HOR. 0 0.00833 VERT.



CONTROL-SECTION-JOB 23-5-2

C_{20} 0.857

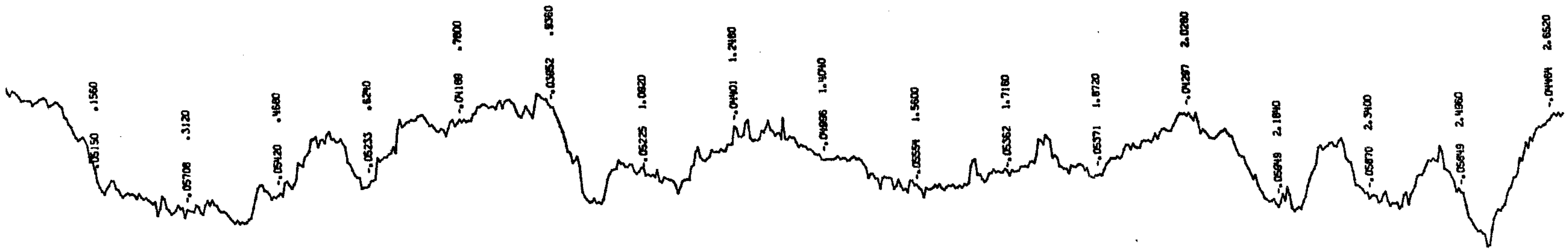
C_{50} 0.606

AVERAGE NUMBER OF PEAKS 2356

AVERAGE HEIGHT 0.002375

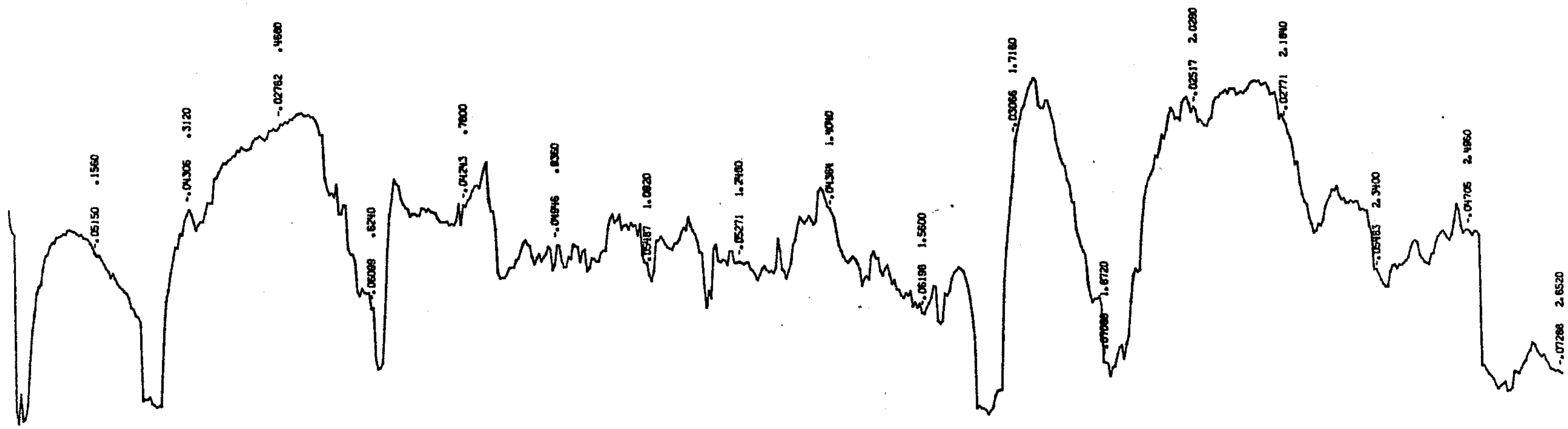
LIMESTONE ROCK ASPHALT

SCALES: 0 0.08 HOR. 0 0.00833 VERT.



CONTROL-SECTION-JOB 37-3-1
C_{20} 0.790
C_{50} 0.514
MICRO HEIGHT 0.001807
MACRO HEIGHT 0.005759
MAX. HEIGHT 0.039200
AVERAGE NUMBER OF PEAKS 2707
AVERAGE HEIGHT 0.001492
LIMESTONE ROCK ASPHALT

SCALES: 0 0.08 HOR. 0 0.00833 VERT.

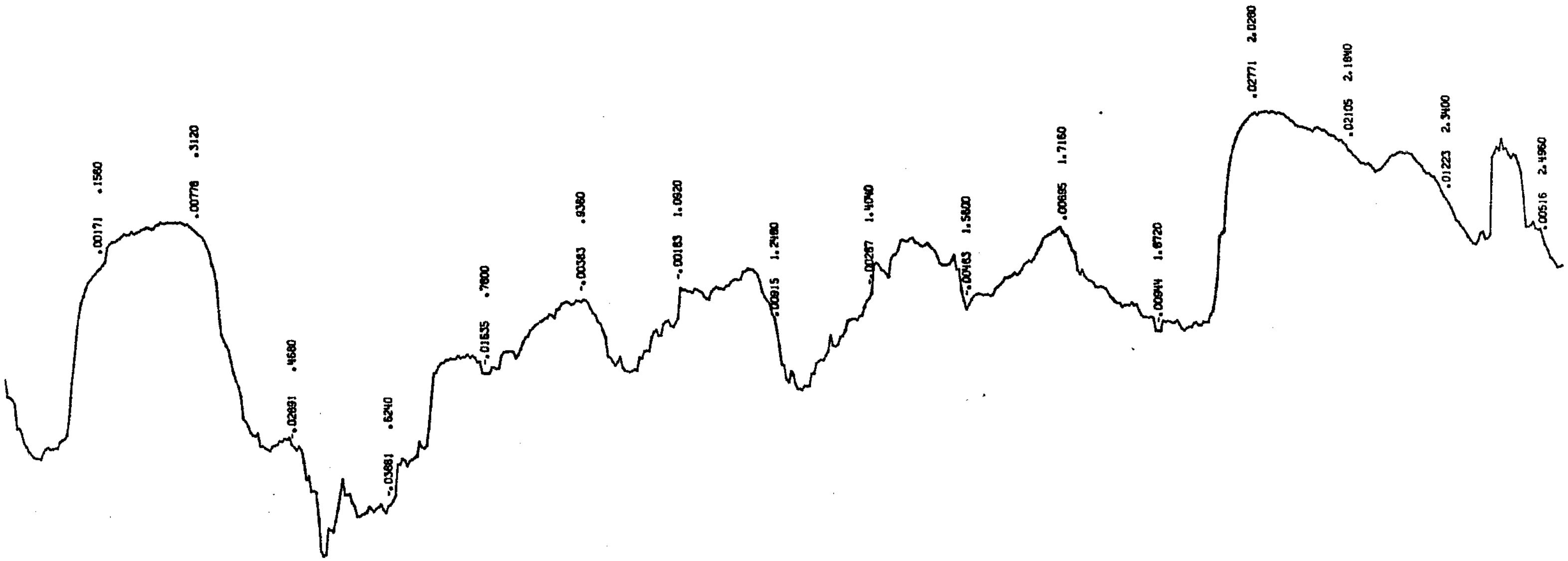


CONTROL-SECTION-JOB 425-1-1

C_{20}	0.622
C_{50}	0.527
MICRO HEIGHT	0.002827
MACRO HEIGHT	0.007181
MAX. HEIGHT	0.058700
AVERAGE NUMBER OF PEAKS	1751
AVERAGE HEIGHT	0.003633

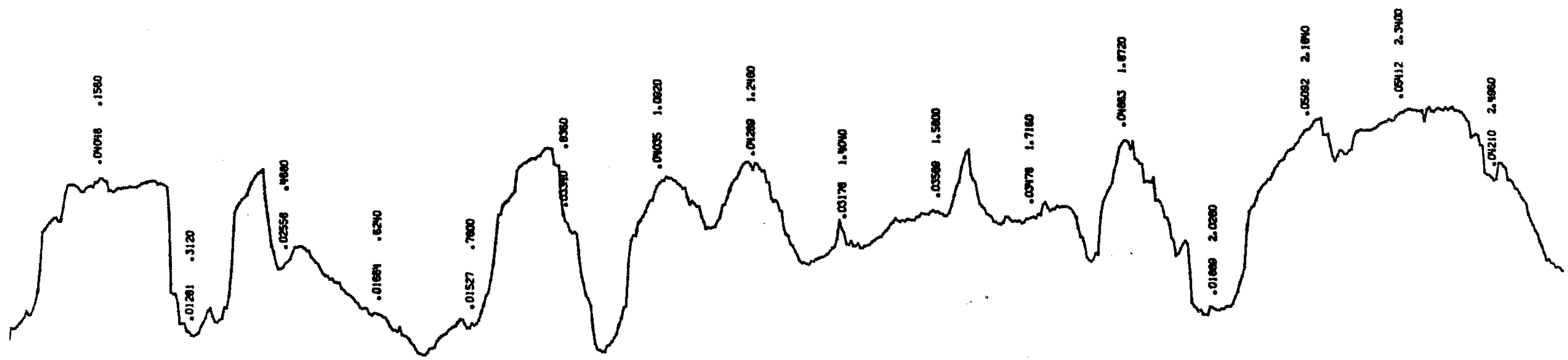
SURFACE TREATMENT-CRUSHED SILICIOUS

SCALES: 0 0.08 HOR. 0 0.00833 VERT.



CONTROL-SECTION-JOB 1-2-1
C_{20} 0.593
AVERAGE NUMBER OF PEAKS 1272
AVERAGE HEIGHT 0.002182
ASPHALTIC CONCRETE-ROUND SILICIOUS

SCALES: 0 0.08" HOR. 0 0.00833" VERT.



CONTROL-SECTION-JOB 1978-1-1

C_{20} 0.545

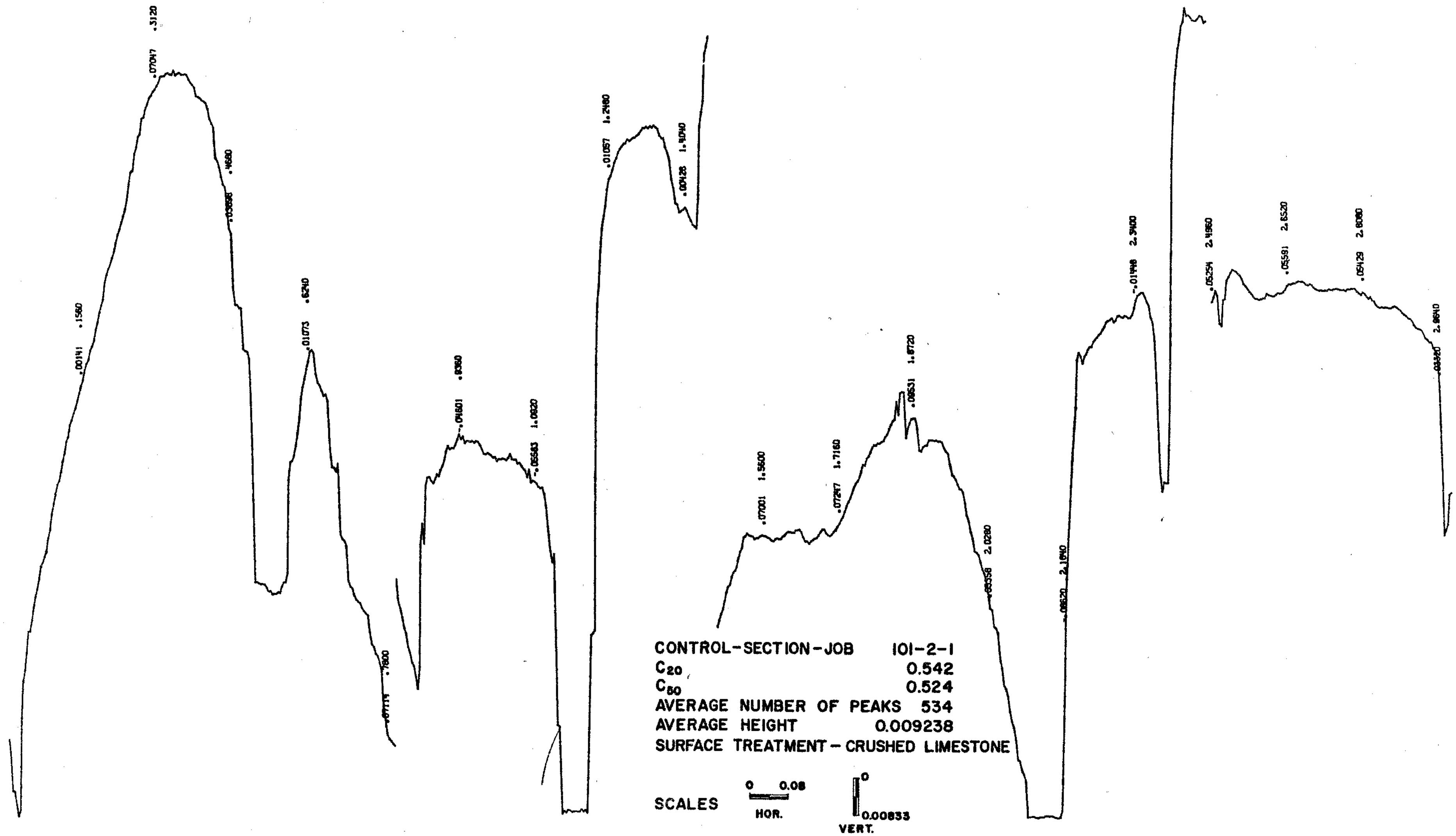
C_{50} 0.438

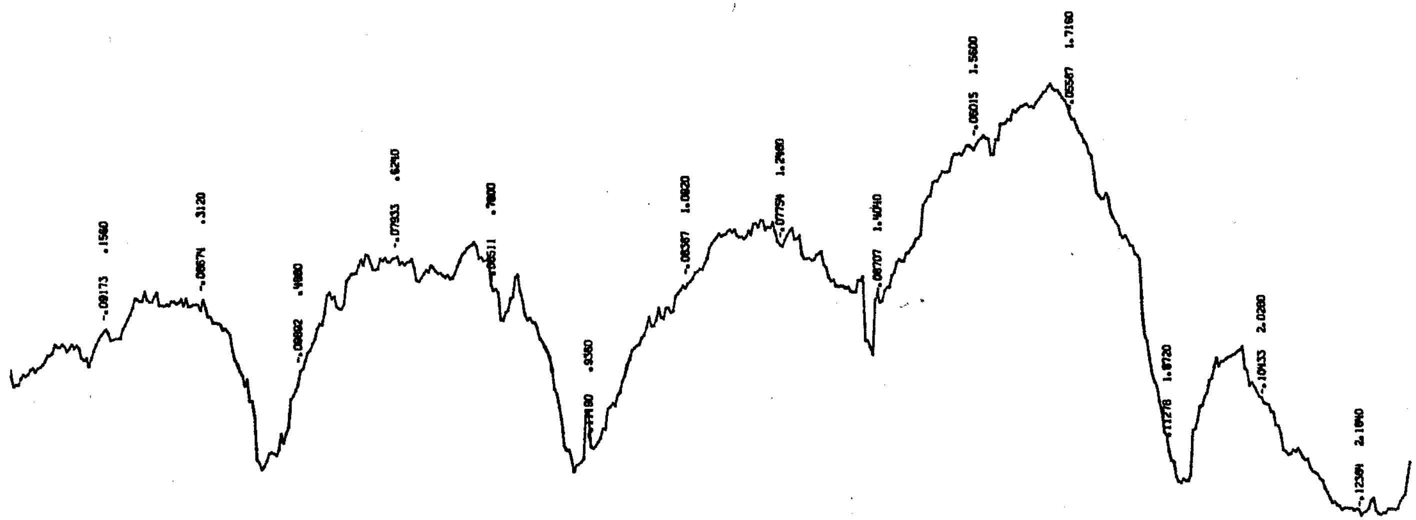
AVERAGE NUMBER OF PEAKS 904

AVERAGE HEIGHT 0.004613

ASPHALTIC CONCRETE-CRUSHED LIMESTONE

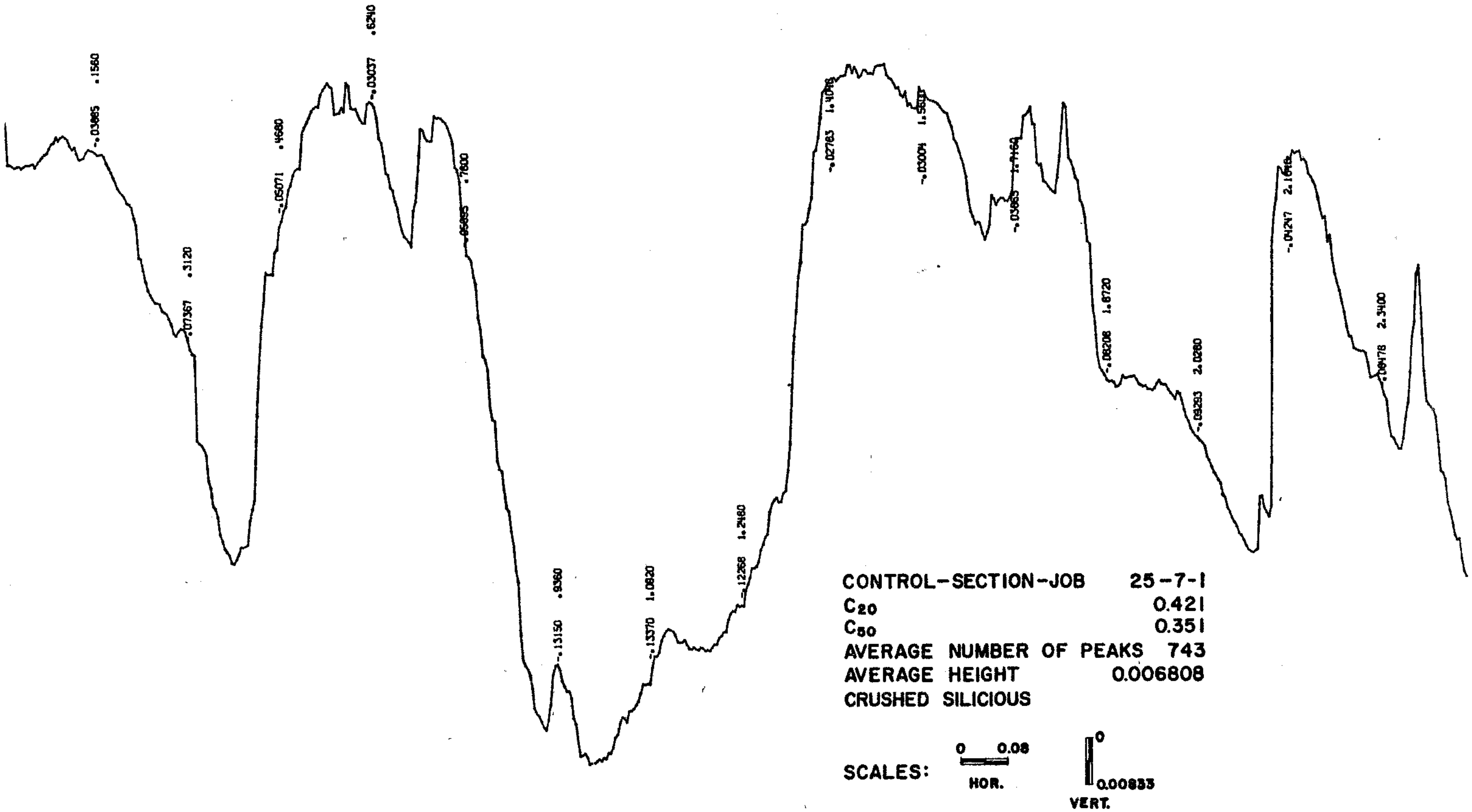
SCALES: 0 0.08" HOR. 0 0.00833" VERT.

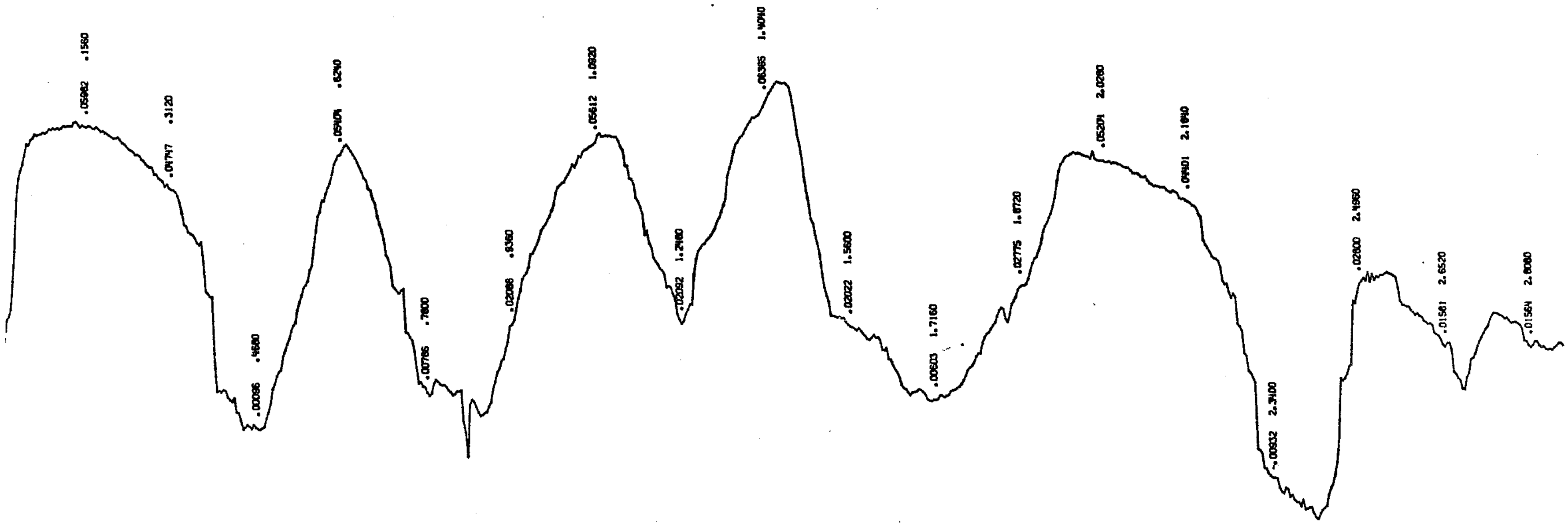

CONTROL-SECTION-JOB 101-2-1
C_{20} 0.542
C_{50} 0.524
AVERAGE NUMBER OF PEAKS 534
AVERAGE HEIGHT 0.009238
SURFACE TREATMENT - CRUSHED LIMESTONE
SCALES
0 0.08
HOR.
0
0.00833
VERT.



CONTROL-SECTION-JOB 613-2-1
C_{20} 0.519
C_{50} 0.490
AVERAGE NUMBER OF PEAKS 2073
AVERAGE HEIGHT 0.002452
LIMESTONE ROCK ASPHALT – POLISHED

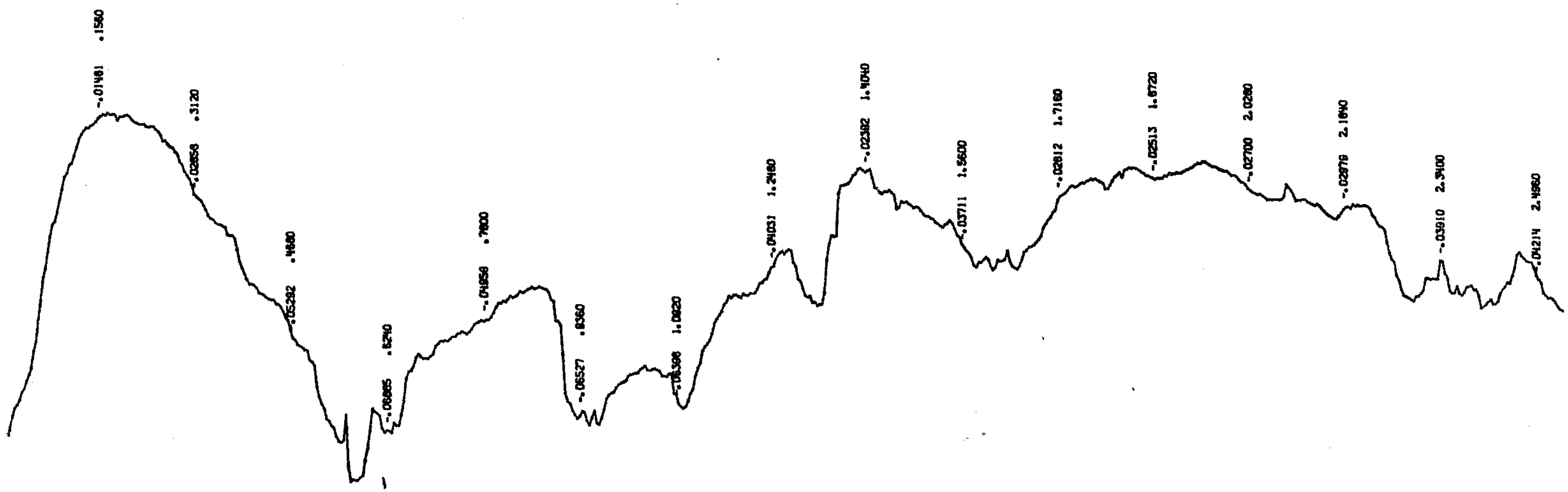
SCALES: 0 0.08 HOR. 0 0.00833 VERT.


CONTROL-SECTION-JOB 25-7-1
C_{20} 0.421
C_{50} 0.351
AVERAGE NUMBER OF PEAKS 743
AVERAGE HEIGHT 0.006808
CRUSHED SILICIOUS
SCALES:
0 0.08
HOR.
0
0.00833
VERT.



CONTROL-SECTION-JOB 356-1-1
C_{20} 0.376
C_{50} 0.273
MICRO HEIGHT 0.000734
MACRO HEIGHT 0.008277
MAX. HEIGHT 0.040200
AVERAGE NUMBER OF PEAKS 562
AVERAGE HEIGHT 0.004039
SURFACE TREATMENT – CRUSHED LIMESTONE

SCALES: 0 0.08 HOR. 0 0.00833 VERT.



CONTROL-SECTION-JOB 508-4-1

C_{20} 0.324

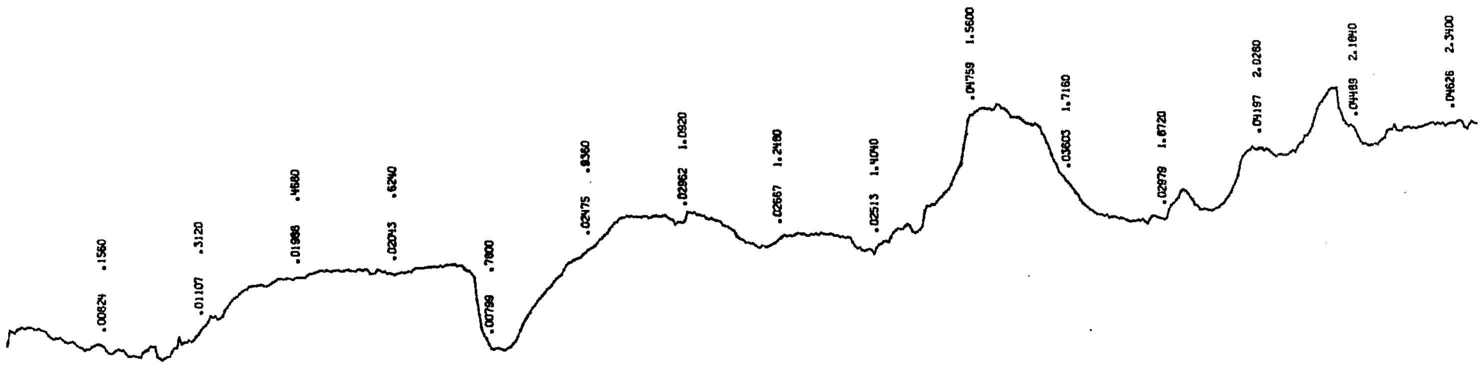
C_{50} 0.300

AVERAGE NUMBER OF PEAKS 1098

AVERAGE HEIGHT 0.001788

ASPHALTIC CONCRETE-CRUSHED LIMESTONE

SCALES: 0 0.08" HOR. 0 0.00833" VERT.



CONTROL-SECTION-JOB	5-7-1
C_{20}	0.222
C_{50}	0.167
AVERAGE NUMBER OF PEAKS	1766
AVERAGE HEIGHT	0.000808

ASPHALTIC CONCRETE-SEALED WITH EMULSION

SCALES: 0 — 0.08 HOR. 0 — 0.00833 VERT.

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