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SURFACE TEXTURE MEASUREMENTS
BY THE PUTTY IMPRESSION METHOD

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SURFACE TEXTURE MEASUREMENTS
BY THE PUTTY IMPRESSION METHOD

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Summary

In negligence cases involving wet pavement skidding accidents and alleging hydroplaning, equations relating water depths to such factors as rainfall intensity, cross-slope, drainage path, and surface texture have been used by some plaintiffs. This report investigates the relative precision of texture depth measurements as used in the TTI (Texas Transportation Institute) model for estimating water depths. This limited testing, done in the laboratory where conditions are to be expected to be less susceptible to variations than in the field, showed testing errors in texture measurements by the putty impression method can result in 20 to 200 percent variations in the calculated values of water depth obtained by the TTI equation. It is recommended that a field testing program be initiated to establish practical limits for sampling and testing error in texture depths as measured by the putty impression method.

Introduction

Surface texture measurements by the 'putty impression method' have been extensively used by the Texas Transportation Institute (TTI) to appraise the macroscopic roughness or macrotexture which affects the friction level of pavement surfaces (1, 2). The method was also used to determine texture depth for use in an empirical equation that relates several variables and their relative effects to rainwater depths on pavement surfaces (3). The TTI equation has been frequently referred to in court during negligence actions against the Department, brought as a result of wet pavement skidding accidents. Therefore, a detailed analysis of the relationship between rainwater depth on pavements and surface texture will be an important part of this report.

The laboratory experiment reported here had three specific objectives:

1) to measure surface texture on three slab samples constructed for laboratory experiments,

2) to study the relative variability among three selected operators and their experimental errors in measuring macrotexture by the putty impression method on three slab specimens, and

3) to study the influence of macrotexture measurement error on the behavior of the TTI empirical equation that relates water depth on pavement with geometric factors (drainage path, and cross-slope or superelevation), rainfall, and surface texture depth measurements obtained by the putty method.

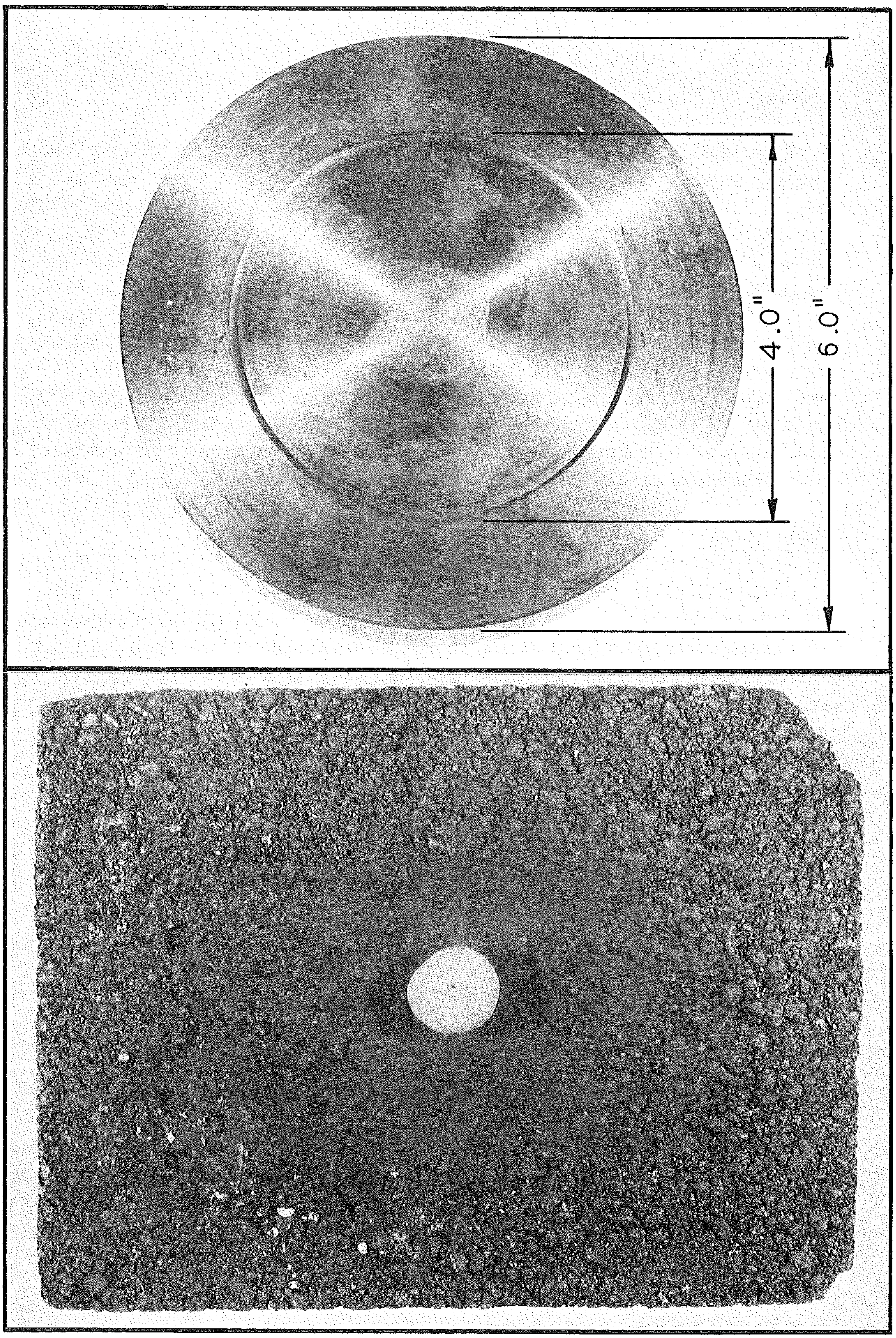

Figure 1. Surface texture measurements by the putty method consisted mainly of an 8-lb circular metal plate (top) and a 14.2 gm specimen of fresh glazing compound shaped like a sphere and placed on a bituminous concrete surface to be tested (bottom).

Macrotexture Measurements

Macrotexture is the 'roughness' of a pavement surface that provides channels for surface water to escape under the rubber tire when rain falls over a highway pavement (4, 5). For this experiment, the putty impression method used by the TTI was modified slightly. Instead of silicone putty, an elastic glazing compound manufactured by Perm-E-Lastic, Inc., was used to fill the cavities and channels of the slab surfaces under test.* Test equipment consisted of an 8-lb circular metal plate, 6 in. in diameter by 1 in. thick, with a circular recess, 4 in. in diameter by 1/16-in. deep, machined into one surface (Fig. 1). A known weight of glazing putty was shaped into a sphere and placed on the surface of the test slab (Appendix A). The plate recess was centered over the spherical putty and the metal plate was pressed down to firm contact with the slab surface. The putty was thereby pressed into a pancake shape and forced into surface voids in the specimen surface. Four diameter measurements spaced at 45° angles were taken from the resulting pressed-down circular putty (Fig. 2). The average of these four readings was used to calculate texture depth according to the following equation (Appendix A).

$$T = \left(\frac{1}{D^2} - 0.0625\right) \qquad (1)$$

where: T = average texture depth, in.
D = average putty diameter, in.

Laboratory Experiment

To accomplish the first two objectives, the experimental design called for three operators (O_1, O_2, O_3) selected from laboratory personnel; three slab specimens (S_1, S_2, S_3) for texture measurements and two measuring scales—a dial caliper (M_1) scaled to 0.001 in. and a ruler scaled in sixty-fourth's of an inch (M_2). This was a completely replicated three-factor experiment, easy to set up and suitable for a randomized sequence of texture

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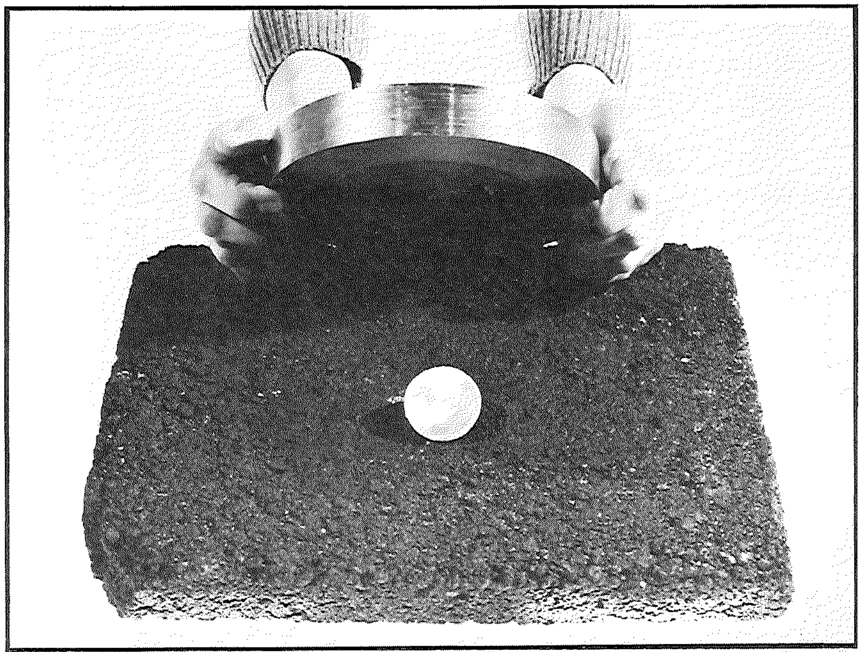
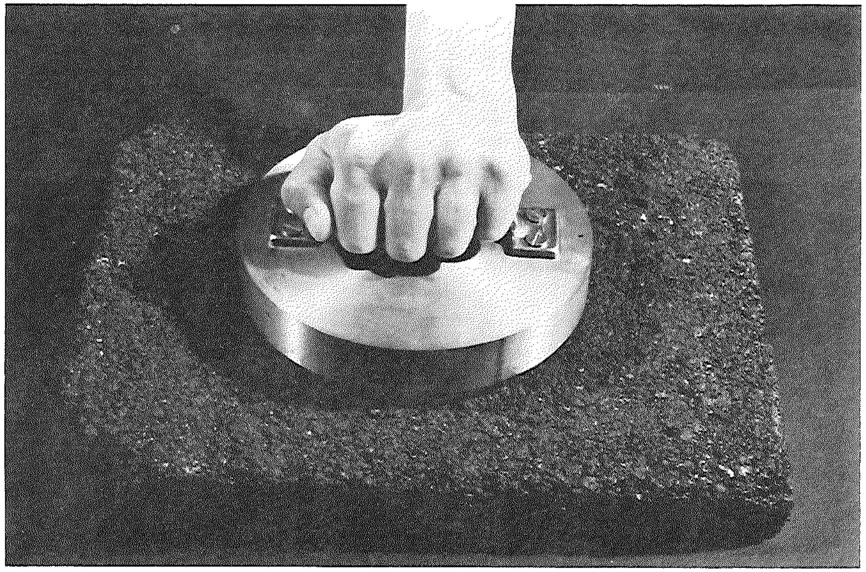
* Glazing Compound No. 0110 manufactured by Perm-E-Lastic, Inc., Aurora, Illinois, 60506. This material is used for patching and filling in cracks, for glazing wood and metal sash. It is easily applied and mended and it molds like clay. Unlike silicone putty, it does not bounce like a rubber ball, neither cracks nor crumbles. The preweighed compound samples should be kept in covered 8-oz tin cans ready for macrotexture measurements.

Figure 2. At the location selected for texture measurements, proceed as follows:

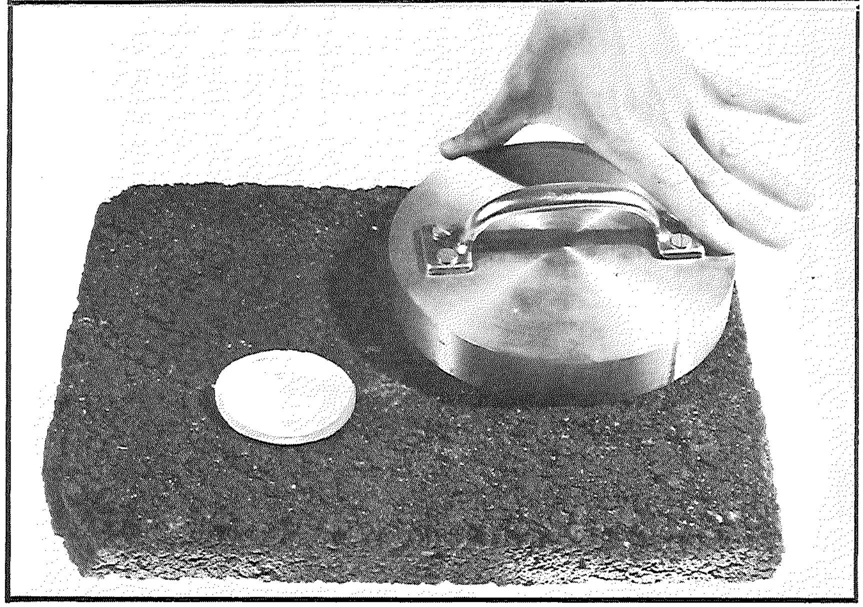
Clean and sweep surface to remove all foreign matter. Shape glazing compound into a ball and place it on the surface to be tested.



Center the metal plate recess over the spherical putty and press the plate down in firm contact with the surface under test.



Take four diameter readings spaced at 45° angles with a dial caliper scaled to 0.001 in. Use the average of these four readings to calculate average texture depth according to Eq. (1).



measurements. The three operators were properly instructed in the texture putty method and each took 18 texture readings for each slab specimen. After a test was completed, the putty compound was completely removed from the slab surface and fresh putty material was used in subsequent tests. Thus, 54 putty specimens were preweighed and kept ready in covered 8-oz tin cans. When weighed-out correctly and tested on a smooth, flat surface with no texture, the putty specimen should completely fill the test plate recess with a circular diameter of 4 in. For each texture test, a decrease in diameter of the pressed-down putty was related to an increase in texture depth according to Eq. (1). All 54 texture tests involved in the experiment were completed the same day.

Results

The laboratory findings (Fig. 3) are summarized as follows:

1) For a brush textured portland cement concrete slab (S_1), texture depth based on 18 tests ranged from 0.099 to 0.114 in., averaging 0.107 in.; for a smooth finished portland cement concrete slab (S_2), texture values ranged from 0.031 to 0.043, averaging 0.038 in.; and for a bituminous concrete slab (S_3), texture values ranged from 0.032 to 0.081, averaging 0.046 in.

2) The relative variability among the three selected operators indicated the following: for the experimental operator O_1, errors in sampling and testing were 0.079 and 0.011 in., respectively; for operator O_2, errors involved were 0.079 in. for sampling and 0.017 in. for testing; and for operator O_3, 0.083 in. for sampling and 0.005 in. for testing error.

3) The data show also that operator O_2 had some difficulties in taking diameter readings with the standard rule M_2, while testing asphalt concrete slab S_3 (Fig. 3).

The testing error S_e as used here, is a measure of the uncontrolled sources of variation in the texture experiment, such as inaccuracies of both the operator and the test method and the external influences beyond control of the experimenter. The size of the testing error depends on the type of experimental design being used for data acquisition. In statistical analysis, it is called residual or error variance S_e^2 or standard deviation S_e. The sampling error S_s is a measure of the combined effects of the sampling plan selected for data acquisition and the local variations of surface texture being measured. The size of the sampling error depends also on the experimental design being used. It is usually called sample variance S_s^2 or sample standard deviation S_s. In this report, the term 'error' means the

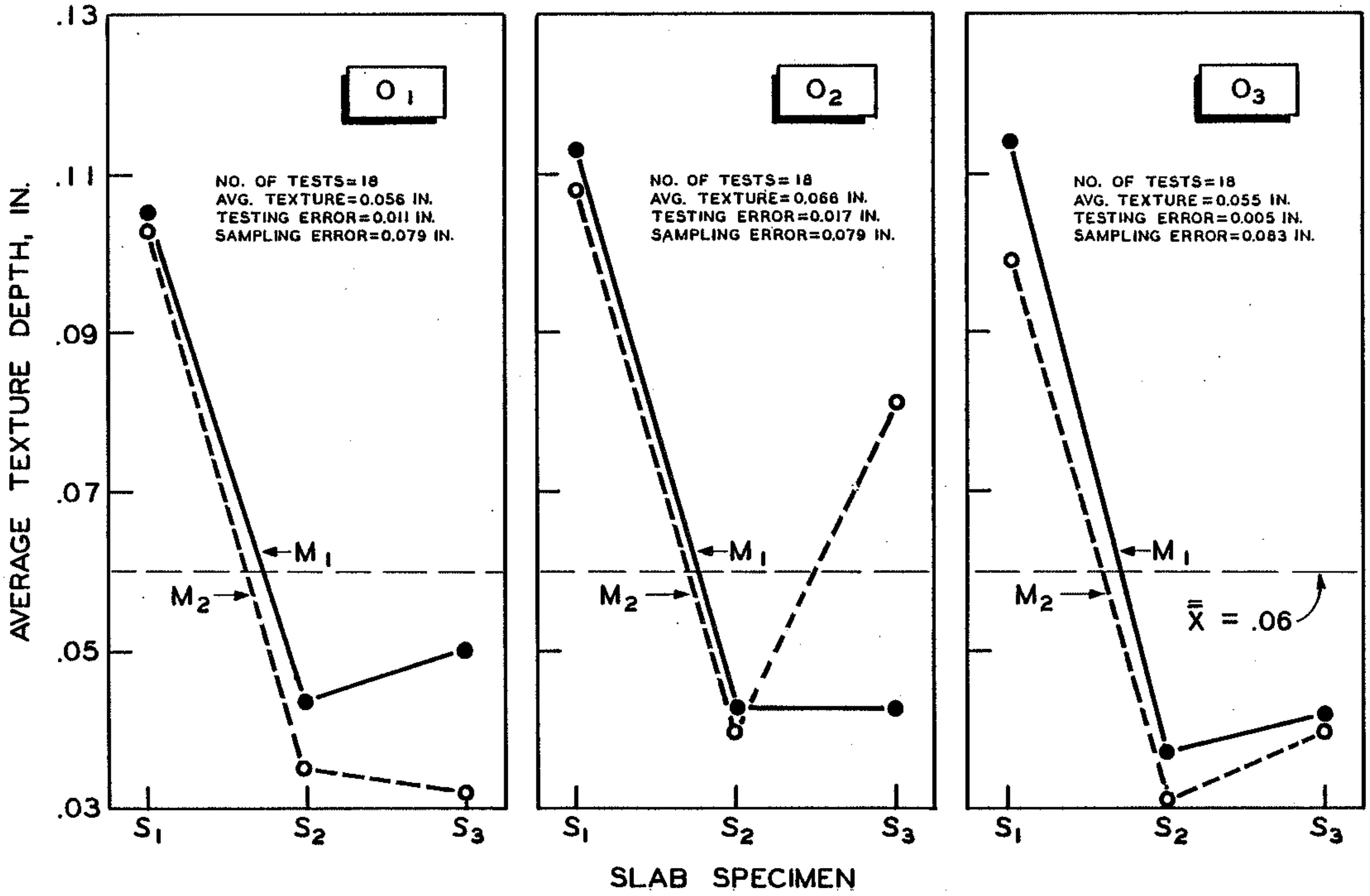


Figure 3. Relative performance of experimental operators (0_1, 0_2, 0_3) using two different measuring scales M_1 and M_2. Each plotted point represents the average of three texture readings—18 for each operator.

error variance denoted by S_e^2 or the square root of this variance called the error standard deviation S_e.

Propagation of Errors

The third specific objective of this study was to study the influence of error in texture measurements on the behavior of the empirical equation developed by the TTI to predict water depth on pavement surfaces (3, 6).

$$W = 3.38 \times 10^{-3}\left(\frac{1}{T}\right)^{-0.11}\left(L\right)^{0.43}\left(I\right)^{0.59}\left(\frac{1}{e}\right)^{0.42} - T \qquad (2)$$

where: W = average water depth, above the surface texture, in.
T = average texture depth, in.
L = drainage length or path, ft
I = rainfall intensity or rate, in./hr, and
e = superelevation or transverse slope, ft/ft.

When a dependent variable W is calculated as a function of four independent variables: W = f (L, I, e, T) the resulting error S_W associated with the four independent errors S_L, S_I, S_e, and S_T can be expressed as follows (7, 8, 9):

$$S_W^2 = \left(\frac{\partial w}{\partial L}\right)^2 S_L^2 + \left(\frac{\partial w}{\partial I}\right)^2 S_I^2 + \left(\frac{\partial w}{\partial e}\right)^2 S_e^2 + \left(\frac{\partial w}{\partial T}\right)^2 S_T^2 \qquad (3)$$

where the partial derivatives $\left(\frac{\partial w}{\partial L}, \frac{\partial w}{\partial I}, \frac{\partial w}{\partial e}, \text{and } \frac{\partial w}{\partial T}\right)$ are obtained from Eq. (2) (Appendix B). Based on this principle, the sources of errors were as follows:

1. Drainage length. With most engineering work, the maximum error, in feet, over a line should be kept within ± 0.05 $\sqrt{\text{distance, in miles}}$ for accurate leveling (10, 11). Thus, for a drainage length of 24 ft, the estimated error was $S_L = 0.0034$ ft and the calculated $\left(\frac{\partial w}{\partial L}\right)^2 S_L^2 = 0.0008 \times 10^{-8}$ is an estremely small quantity which can be neglected when used in Eq. (3).

2. Rainfall intensity. Records from the Capital City Airport and the National Weather Service show hourly precipitation data to the nearest 0.01 in./hr. According to the approximation's rule for numerical operations with decimals if a single reading is rounded off to two decimal places,

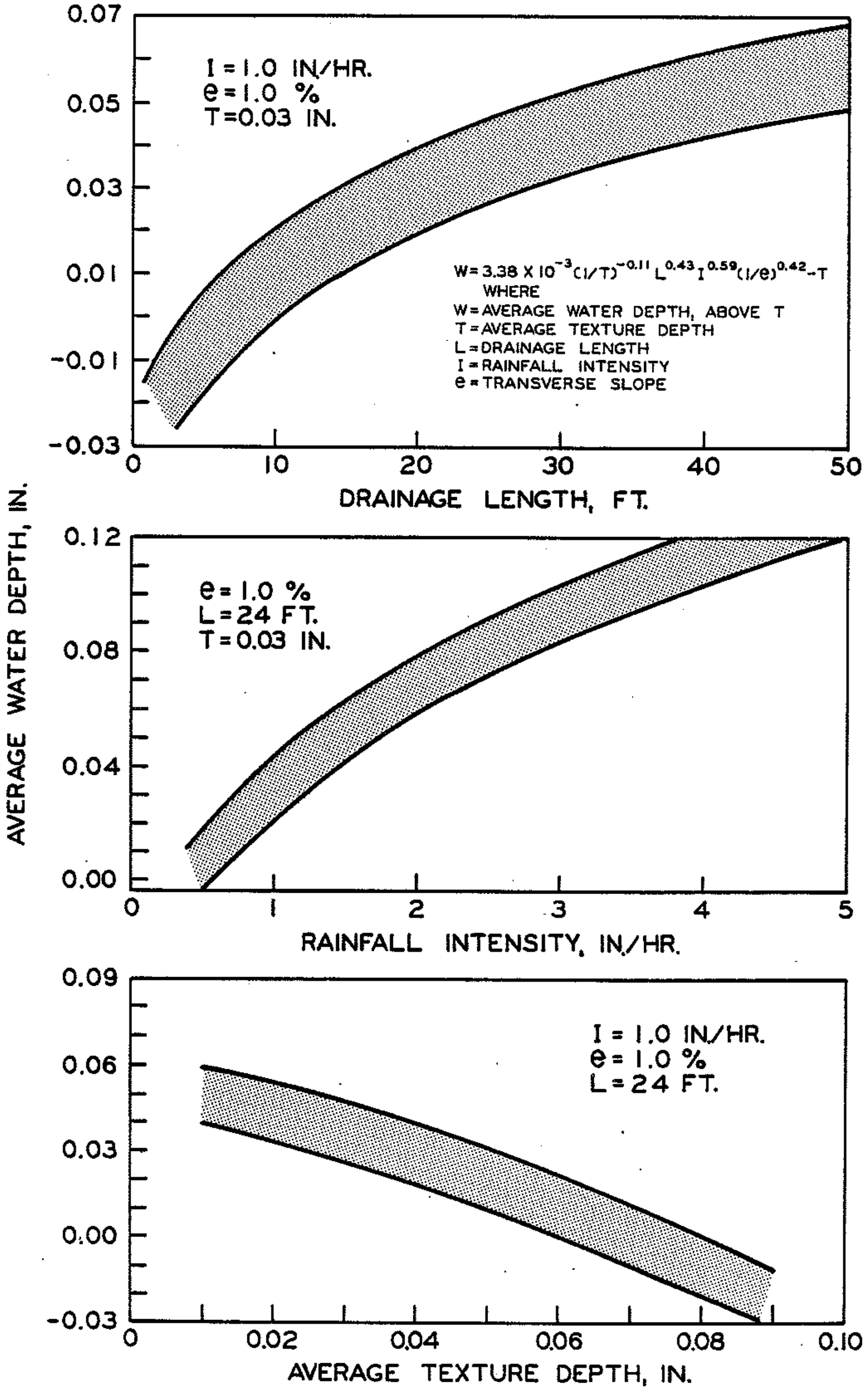


Figure 4. Three specific diagrams showing the estimated limits of uncertainty (dark bands) for calculated values of water depth.

the second digit following the decimal point may be in error by ± 0.005. Therefore, an estimated error of $S_I = 0.005$ in./hr was used in Eq. (3). The calculated quantity $\left(\frac{\partial w}{\partial I}\right)^2 S_I^2 = 2 \times 10^{-8}$ is also a small value that can be neglected.

3. Transverse slope. For a two-lane pavement, 24 ft wide, the calculated error in slope distance in ft/100 ft was $S_e = 0.00028$ or 0.028 percent (10, 11). The calculated quantity $\left(\frac{\partial w}{\partial e}\right)^2 S_e^2 = 8 \times 10^{-8}$ is also a negligible factor.

4. Average texture depth. The macrotexture experiment by the putty method showed testing errors among three operators ranging from 0.005 to 0.017 in. for an average texture error of $S_T = 0.012$ in. Since errors in texture measurements produced the largest error in S_W, Eq. (3) was reduced to:

$$S_W^2 = \left(\frac{\partial w}{\partial T}\right)^2 S_T^2 \tag{4}$$

which gave a resulting error in water depth of $S_W = \pm 0.01$ in. (Appendix B). This result based on the macrotexture laboratory experiment indicates that the resultant water depth calculated by Eq. (2) may be in error ranging from 20 to 200 percent.

For example, Figure 4 shows three specific diagrams with the estimated limits of uncertainty (dark bands) within which the calculated values W might be expected to fall. Probably, these limits of uncertainty arising from laboratory testing errors might become wider if field texture measurements were taken from highway pavements opened to traffic.

Conclusions and Recommendations

Briefly, the results of the laboratory experiment are as follows:

1) Test operators measuring average surface texture depth by the putty impression method showed testing errors ranging from 0.005 to 0.017 in. with slab specimens made for laboratory work. Sampling errors among operators were more uniform ranging from 0.079 to 0.083 in.

2) Normal errors in texture measurements by the putty impression method can result in 20 to 200 percent errors in the calculated values of water depth obtained by the TTI equation. Furthermore, since environmental factors (temperature, humidity, wind, rain, vibration, traffic

hazards) and operator performance are better controlled in the laboratory than in field testing, larger errors may be expected from field texture measurements on typical highway pavements opened to traffic. It is recommended that these possibilities be tested in a field experiment.

3) Test operators showed more uniformity in measuring putty diameters with a dial caliper scaled to the nearest 0.001 in. than with a standard ruler scaled in 1/64 of an in.

4) Test operator O_2 had some difficulty in taking diameter readings with the standard ruler while testing the asphalt concrete slab.

Since this laboratory experiment alone would be insufficient to adequately evaluate the variability of surface texture measurements by the putty method, a planned field experiment including several typical highway pavements is recommended. The field study may include six highway pavements (three concrete and three bituminous roads). At least eight random locations should be selected from each pavement area which appear to be most representative of the surface texture of the pavement project. Each random location should be divided into two portions as nearly identical in surface texture as possible. All duplicate portions should be tested within a short time in the same manner by the same operator using the same circular metal plate, but with fresh preweighed glazing compound after each test. For diameter readings, a dial caliper scaled to 0.001 in. is also recommended. This field experiment probably should be continued until at least 200 test results are collected for each pavement project before practical limits for sampling and testing errors in texture measurements are established.

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APPENDIX A

1. Glazing compound weight. Specific gravity, ρ, of the glazing compound was determined according to a displacement method similar to ASTM D 71-72a for solid pitch and asphalt material. Specific gravities ranged from 1.102 to 1.116 g/cu cm.

The weight W of the glazing compound was calculated by Equation 5.

$$W = \frac{\pi D_0^2 \ h_0 \rho}{4} \tag{5}$$

where the plate diameter, $D_0 = 4$ in., the recess depth, $h_0 = 1/16$ in., and $\pi = 3.1416$ when used in Eq. (5), it shows:

$$\begin{aligned} W = 12.87\rho &= 12.87\ (1.102) = 14.183\ \text{gm} \\ &= 12.87\ (1.116) = 14.363\ \text{gm}. \end{aligned}$$

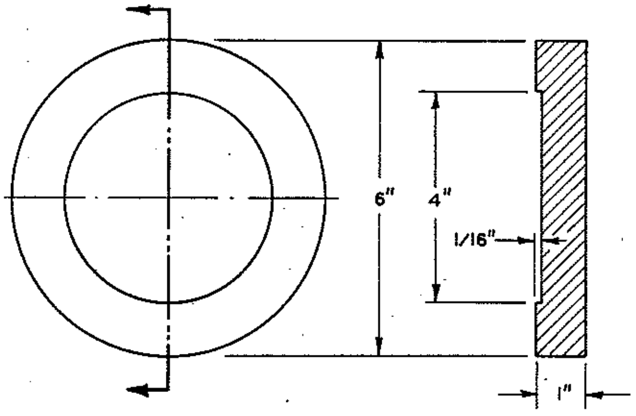
Thus, the weight of glazing compound specimens ranged from 14.183 to 14.363 gm.

2. Texture depth Equation 1. From Eq. (5), let $k = \frac{4W}{\pi\rho}$, then $h_0 = \frac{k}{D_0^2}$ and $h_1 = \frac{k}{D_1^2}$. Use the ratio $\frac{h_1}{h_0}$ to obtain $h_1 = \frac{1}{D_1^2}$ and

$$T = \left(h_1 - \frac{1}{16}\right) = \left(\frac{1}{D_1^2} - 0.0625\right) \tag{1}$$

where: T = average texture depth, in.
D_1 = average putty diameter, in.

For a flat surface with no texture, the Eq. (1) shows: $T = 0$ and $D_1 = 4$ in. Furthermore, a decrease in diameter ($D < 4$ in.) results in an increase in texture ($T > 0$) according to Eq. (1).



Metal Plate

APPENDIX B

Water depth Equation 2. This equation developed by the TTI to predict water depth on pavement surfaces (3, 6) may be rewritten as follows: $W = (KT^c - T)$ where $K = \frac{K_0\, L^a\, I^b}{e^a}$; and the partial derivatives become:

$$\left(\frac{\partial w}{\partial L}\right)^2 = \left(\frac{a}{L}\right)^2 K_1^2 \qquad \left(\frac{\partial w}{\partial e}\right)^2 = \left(-\frac{a}{e}\right)^2 K_1^2$$

$$\left(\frac{\partial w}{\partial I}\right)^2 = \left(\frac{b}{I}\right)^2 K_1^2 \qquad \left(\frac{\partial w}{\partial T}\right)^2 = \left(\frac{c}{T} K_1 - 1\right)^2$$

where: $K_1 = KT^c$
$K_0 = 3.38 \times 10^{-3}$
$a = 0.425$
$b = 0.59$, and
$c = 0.11$.

EXAMPLE

Let $L = 24$ ft, $I = 1.0$ in./hr, $e = 2.0$ percent, $T = 0.03$ in.

then: $K_1 = 0.046779$

$$\left(\frac{\partial w}{\partial L}\right)^2 S_L^2 = 0.0008 \times 10^{-8}, \quad \left(\frac{\partial w}{\partial I}\right)^2 S_I^2 = 2.0 \times 10^{-8}$$

$$\left(\frac{\partial w}{\partial e}\right)^2 S_e^2 = 8.0 \times 10^{-8}, \quad \left(\frac{\partial w}{\partial T}\right)^2 S_T^2 = 1.0 \times 10^{-4}$$

and either Eq. (3) or (4) gives a resulting error in water depth of $S_W = \pm 0.01$ in. under laboratory controlled conditions. Probably, larger errors may be expected from field texture measurements on typical highway pavements opened to traffic.