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Photographic Technique for Estimating Skid Number and Speed Gradients of Pavements

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A technique has been developed for determining skid number and speed gradients of pavements from a moving vehicle. Photographs were made of the pavement by using a light at low-incidence angle to project shadows across the peaks and valleys of pavement macrotexture. The photographs were compared to standard photographs of pavements with known gradients. The ratings were converted to estimated skid number and speed gradient by using a regression equation. The technique is economical, valid, and reliable.

A study was made to determine the relations between skid number (coefficient of friction × 100) and wet-pavement accident rates. Wet-pavement accident records and the matching skid-number measurements provided by the states participating in the study were used. Skid number measurements are needed that correspond to the operating speed of the roadway.

The skid number data collected by the states are generally measured at a speed of 64 km/h (40 mph), and the skid number is known to decrease as speed increases. Thus, to determine skid number at the operating speed of the roadway at the time of the accident, we must know the skid number-speed gradient ($G = \Delta$ skid number/Δ speed). For example, if we know that the skid number at 64 km/h (40 mph) is 45 and the speed gradient is 0.50, then the skid number at an operating speed of 97 km/h (60 mph) is $45 - (0.50 \times 60 - 40) = 45 - 10 = 35$.

The most obvious method of obtaining the gradient for a section of pavement is to measure the skid number at various speeds and determine the gradient empirically. Because this is an expensive procedure and states have only limited budgets for skid measurement, the gradients have been determined for only a small number of pavement sections. A review of previous work was thus made to determine the technique best suited to estimate gradients.

PREVIOUS WORK

Several research projects have been directed toward alternate methods of determining the skid number-speed gradient of selected pavements. The most productive study was done by Schulze and Beckman (1), who found that the skid number-speed gradient from 20 to 60 km/h (12 to 37 mph) is correlated with the mean width of surface voids. The larger void width produces a flatter speed gradient primarily because of better water drainage.

The method for obtaining the mean void width is described by Schulze (2). Stereophotographs were taken of pavement sections and magnified 25 to 1. The outline of each individual void was then traced onto paper, and the width of each void was measured. Needless to say, this procedure would be much too expensive for any major speed-gradient inventory.

Gillespie (3) found mean void widths from pavement profile traces by using an electromechanical roughness meter. The mean void width was defined as the mean distance between peaks on the trace. When mean void width was compared to the known skid number-speed gradient from 60 to 80 km/h (37 to 50 mph), the comparison with the extrapolated Schulze and Beckmann curve was excellent.

Goodman (4) developed several techniques for measuring pavement texture from a moving vehicle; his validation, however, was limited to stationary, laboratory studies. One proposed technique involved photography. A narrow slit of light was projected vertically onto the surface of the pavement, and the resulting line was photographed from an angle of 30° to horizontal. In the resulting photograph, the strip of light delineated the peaks and valleys along the strip. The number of peaks per centimeter, inverse of mean void width, from this photographic technique agreed well with the results from an electromechanical roughness meter applied to the same strip of pavement.

Howerter and Rudd (5) developed a technique that uses stereophotography and computer interpretation to obtain skid-resistance parameters. However, the technique in its present form would be quite expensive for large pavement inventory projects.

After a thorough review of the literature, we elected to obtain the pavement-surface-texture data photographically because that approach appeared to offer the highest probability of success and liberal use could be made of off-the-shelf components.

PHOTOGRAPHIC EQUIPMENT AND TESTING

Photographs of pavement surfaces were made from a moving van at the same time other highway inventory data were being collected. Approximately 4 photographs were taken each 1.5 km (4 photographs/mile) of the left wheel track area, where most pavement skid number data are measured. The data were taken while the van was moving at 64 km/h (40 mph) because stopping the van on the highway was impractical.

Equipment

Figure 1 shows the configuration of the photographic equipment, which consists of a projection system, a camera system, and a light shroud.

The projection system projects a high-intensity, short-duration, shadow-bar pattern on the pavement surface. Since pictures were taken from a van moving at 64 km/h (40 mph), a flash duration of 0.5 to 1 μs was needed to stop the motion of the pavement relative to the camera. The shadow-bar pattern was projected on the pavement at a 20° angle with respect to the horizontal. This low-incidence light served to delineate the roughness of the pavement. On a smooth surface the interface between a band of light and dark was essentially straight. The rougher the surface became, the more crooked the interface line became because of the shadows cast by the peaks in the surface.

A camera system was needed with adequate format to portray salient surface texture features and durability to withstand several thousand kilometers of travel in the van. The system selected was composed of 35-mm data camera and magazine, 105-mm lens, electromechanical shutter, appropriate film, and combination housing and mounting structure.

A light shroud was provided to shield the pavement area illuminated by the projector from ambient light. The shroud was needed because ambient light reflecting from the surface would wash out the image of texture detail formed by the oblique lighting of the projection.

Equipment Testing

The complete photographic system was assembled, tested in the laboratory, and then installed in the van. Test photos were then taken for different pavement types, vehicle speeds, light-shroud position, time of day, and direction of travel (relative to the sun as ambient light source).

The developed test film showed that good, usable pictures could be obtained provided the light shroud was lowered to between 1 and 3 cm (0.5 and 1 in) above the pavement surface when the van was at a standstill. When the shroud was raised higher, ambient light effects obscured surface texture features. Vehicle speed and bouncing had no obvious effect. Pavement color change, e.g., portland cement concrete (PCC) to asphalt concrete (AC), altered the appearance of the photographs but visibility of surface texture was retained.

PRELIMINARY ANALYSIS OF PHOTOGRAPHS

The pavement was photographed from directly above and with oblique lighting. The spot of light contained shadow lines intended to delineate the peaks and valleys along a trace of the surface. The flash duration was sufficiently short to obtain streak-free photographs at 64 km/h (40 mph), but light leakage under the shroud produced minor streaking in most of the photographs.

The first nonlaboratory test of the photographic procedure was made while the vehicle was stationary. A photograph (Figure 2) was taken of a spot of open-textured asphaltic concrete in a parking lot. An impression of the surface was then made, and the surface texture was later duplicated with a plaster-of-paris replica.

The negative film photograph of the spot was placed on a standard library 35-mm film reader and magnified 2.2 times. The number of peaks per centimeter was determined by two methods. First, the shadow line was traced onto a piece of tracing paper and the number of peaks per centimeter were counted by hand. Second, a ruler was placed on the viewer screen and the number of peaks along the ruler edge was determined by changes in shades of gray. Then the number of peaks per centimeter in the same areas of the plaster-of-paris replica were counted by hand. For the shadow line trace, direct measurement, and plaster-of-paris replica there were 7, 6, and 4 peaks/cm (18, 15, 11 peaks/in) respectively. The oblique lighting in the photograph appeared to magnify the size of some of the microtexture, which was mistaken for macrotexture.

Another method used for analyzing the tracing paper outline of the shadow edge was to directly measure the mean void width. The width, parallel to the shadow bar, of each shadow projecting into a void was measured. This method produced unsatisfactory results for the same reasons as stated above, accumulated measurement errors, and was quite tedious and time consuming.

The analysis technique was then applied to the photographs taken from a moving vehicle in the field. Several of the macrotexture photographs were taken on pavement sections with known speed gradients. The film was reviewed and rated as to quality of photographs. (Quality indicates resolution or clarity of the photograph and was determined by comparison to reference photographs.) Rating was influenced primarily by motion streaking made visible by ambient light leaking under the light shroud. Experience showed that the minor streaking was helpful in interpreting the photograph; however, too much or too little streaking was undesirable. The average quality photograph is shown in Figure 3. A decision was made to test the film-reading procedure only on average quality photographs to avoid any bias that might be introduced by differences in photographic quality. Fortunately, 75 to 80 percent of all photographs were of the desired quality.

The known gradient photographs were analyzed by two methods. First, the shadow line was traced from the viewer screen onto tracing paper and the number of peaks per centimeter was counted by hand. Second, a ruler was placed in the lighted portion of the photograph, and the number of discernible changes in shades of gray along the ruler was counted. From this the number of peaks per centimeter was determined. A discernible peak on the negative film was defined as a darker area separated from the next darker area along the ruler by a lighter area. The two methods (tracing and direct reading) produced essentially the same results. Because the direct reading method was considerably faster, this method was selected as the primary reading method for subsequent work.

The number of peaks per centimeter on the known gradients was determined by the direct reading method described above. Only average quality photographs were read to prevent any bias that photographic quality might introduce. An average of six photographs was read for each known gradient and the mean of these readings was used. The mean number of peaks per centimeter was inverted to yield mean void width.

Mean void width may be converted to an index of speed gradient by using the Schulze and Beckman formula:

$$y = 13.5 - 72.6x + 103.6x^2 \tag{1}$$

where

y = mean width of surface voids (0.254 mm or 0.01 in) and

x = coefficient of friction at 20 km/h (12 mph) - coefficient of friction at 60 km/h (37 mph).

Solving the equation for x yields

Figure 1. Principal components of photographic system.

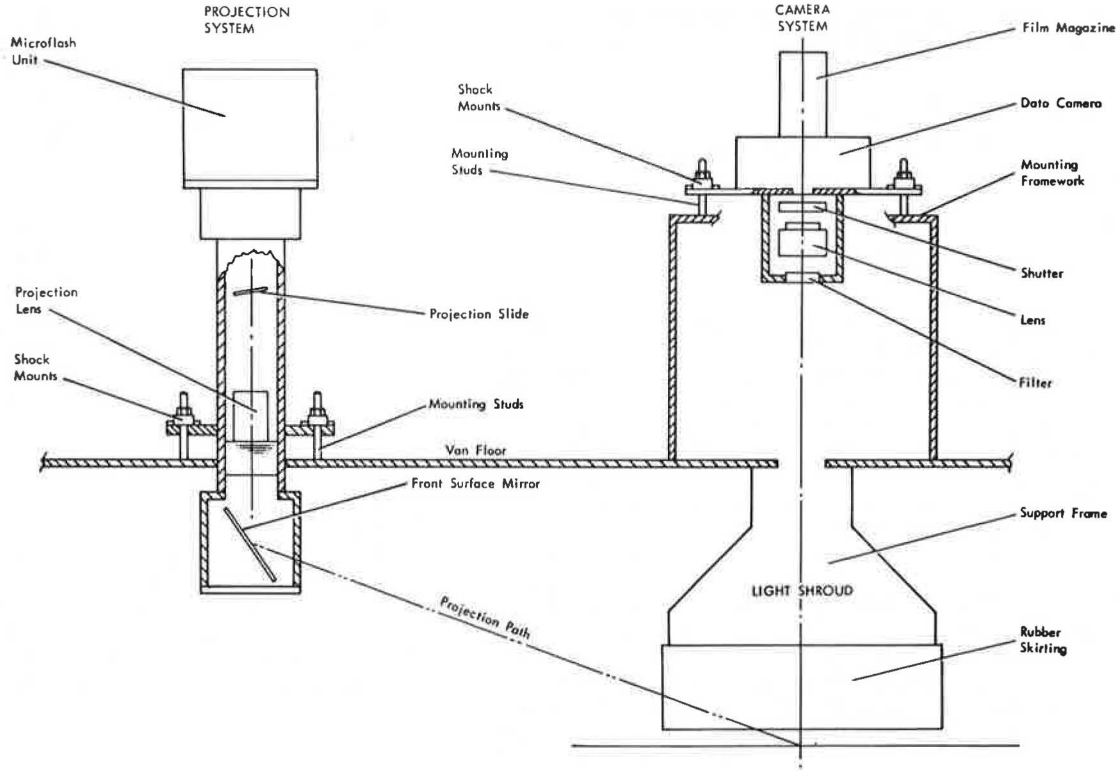


Figure 2. Photograph of pavement macrotexture from stationary vehicle.

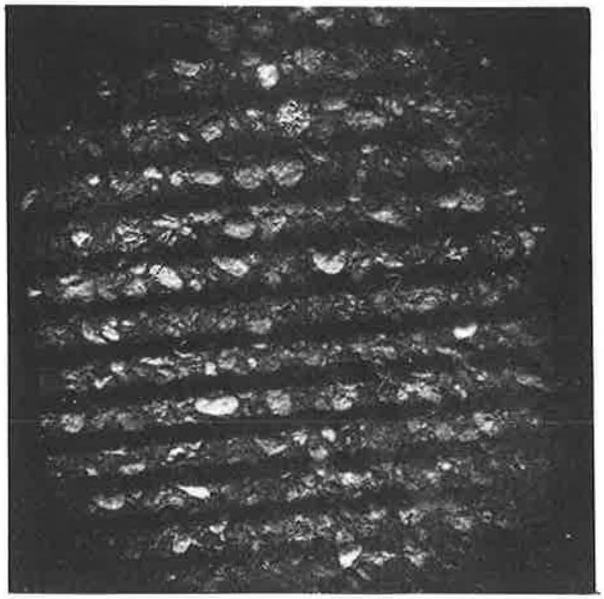
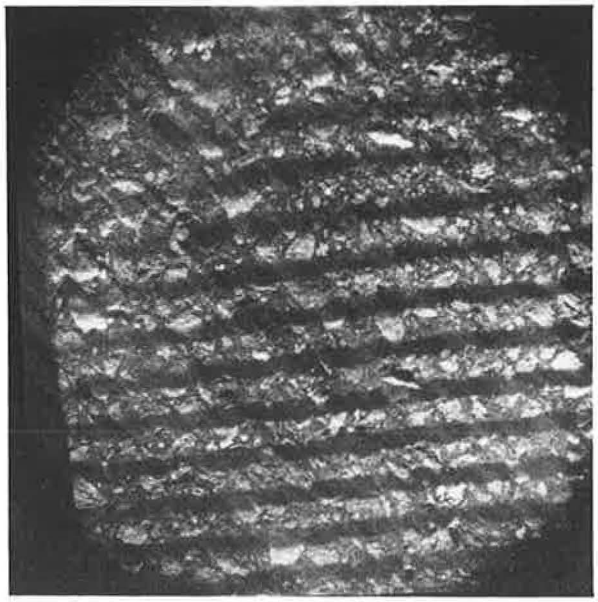


Figure 3. Photograph of average quality taken from moving vehicle.



$$x = 0.350\,38 - \sqrt{-0.007\,542\,86 + 0.009\,653y} \quad (2)$$

or the change (Δ) in coefficient of friction (CF) between 20 and 60 km/h. A much more useful term would be ΔSN/Δkm/h, where SN = 100 CF and 1 km = 0.62 mile. We multiply the right side of the above equation by [(100) (1.609)]/40 = 4.023 to yield

$$x = G = 1.4097 - \sqrt{-0.122\,077\,6 + 0.156\,229\,3y} \quad (3)$$

where G = ΔSN/Δkm/h. The curve in Kummer and Meyer (6) is based on this last equation.

The mean void width for each known gradient was converted to SN - G by using Equation 3. The G estimated from photographs and measured by skid trailer at various speeds are given below (1 km = 0.62 mph).

	Measured			
Estimated (km/h)	48 to 64 km/h	64 to 80 km/h	80 to 97 km/h	48 to 97 km/h
0.82	0.63	0.53	0.42	0.53
0.91	0.74	0.44	0.34	0.51
0.78	0.28	0.45	0.18	0.30
0.72	0.31	0.59	0.09	0.33

Based on this small sample, the method appeared to be accurate enough to be of value to the study. Considering the high variance in the known gradient data, the photo-estimated values appeared to be reasonable.

The film-reading method adopted for this study appeared to work better on photographs gathered in the field than on laboratory photographs. We believed this difference to be due to the light leakage under the shroud in the field. This light leakage created some streaking on the photograph and reduced the resolution somewhat. This loss in resolution obliterated the shadows cast on the microtexture (small irregularities in void surfaces that are not meaningful to drainage) by the oblique lighting, and only the macrotexture shadows could be seen. Consequently, the streaked photographs from the field produced better results than the laboratory photographs.

However, this photographic technique had limitations. We had field photographs of PCC pavement on which the sand patch test was done. Although mean texture depth is not synonymous with mean void width, one would expect them to be positively correlated.

Macrotexture photographic data were available for two pavements: The mean texture depth of one was 0.17 cm (0.066 in), and the other was 0.030 cm (0.012 in). The latter surface was considered very smooth. The field photographs of those pavements were read, and the mean void width on the first pavement was estimated to be 0.17 cm (0.07 in). The film reader reported that photographs of the smoother surface were unreadable. When told that the surface was very smooth and to try again, the reader was able to estimate the mean void width to be 0.18 cm (0.25 in). Based on these results, we assumed that our photo-estimation technique was not capable of determining the mean void width for very smooth pavements.

PRIMARY ANALYSIS OF PHOTOGRAPHS AND RELIABILITY OF MEASUREMENTS

For any measurement technique to be valid, it must yield essentially the same results from multiple measurements of the same data. This concept is known as test-retest reliability. A total of 83 photographs taken from a moving vehicle were read twice; a 2-month delay occurred between the first and second readings. The direct-measurement technique (using the ruler as described above) was used both times to determine the number of peaks per centimeter. The Pearson correlation coefficient (γ) between first and second reading on each photograph was found to be only 0.01. We then grouped the data into three classes as given in the table below (1 mm = 0.04 in, 1 km/h = 0.62 mph).

Class	Peaks (per mm)	Mean Void Width (mm)	Gradient (ΔSN/Δkm/h)
1	0.0 to 5.0	∞ to 2.0	0.0 to 0.21
2	5.1 to 8.0	2.0 to 1.3	0.21 to 0.37
3	>8	1.3 to 0.0	>0.37

The correlation coefficient between first and second reading in this case was 0.73. This finding indicated that the pavements could be reliably rated as to high, medium, or low gradients. When the readings were grouped into five classes, as given in the following table, the correlation dropped to 0.11, which indicated that the rater could not reliably rate the pavement into five classes.

Class	Peaks (per mm)	Mean Void Width (mm)	Gradient (ΔSN/Δkm/h)
1	0.0 to 4.5	∞ to 2.3	0.0 to 0.17
2	4.6 to 5.5	2.3 to 1.8	0.18 to 0.26
3	5.6 to 7.5	1.8 to 1.3	0.27 to 0.37
4	7.6 to 12.5	1.3 to 0.8	0.38 to 0.50
5	>12.5 +	0.8 to 0.0	>0.51 +

Subjective Rankings of Pavement Texture

At this point a decision was made to develop a method of ranking the photographs of pavements into several classes without directly counting peaks. Five studies were performed to determine how reliably a number of raters could rate pavement molds and photographs so that standards could be developed for the individual classes of pavement texture. One macrotexture photograph was selected as the standard for each class, and a photograph of a macrotexture of unknown gradient was compared to the standard to determine the gradient.

Study 1

The first study used 13 molds of pavement texture of known gradients, as follows:

Mold Number	Pavement Type	G (ΔSN/Δkm/h)	Mold Number	Pavement Type	G (ΔSN/Δkm/h)
1	AC	0.31	8	AC	0.12
2	PCC	0.24	9	Special	0.08
3	AC	0.27	10	Special	0.05
4	PCC	0.31	11	Special	0.18
5	AC	0.31	12	Special	0.15
6	AC	0.18	13	Special	0.09
7	AC	0.21			

Molds were positive duplications of the pavement surfaces and were molded from negative silicone impressions. The positive molds were made of white hydro stone. Gradients were calculated from multiple speed skid measurements provided by the states and the 64 to 97-km/h (40 to 60-mph) values were used when available. The raters consisted of 12 staff members, 6 of whom were primarily highway safety engineers and 6 stenographers and analysts.

Asphalt concrete (AC), portland cement concrete (PCC), and special pavement molds were hot mixed so that the rating would not be contaminated. The AC molds were rated first, the PCC molds second, and the special pavement third. Because some of the special pavement molds were exceptionally rough or smooth, extra rough and extra smooth were added to the classes of smooth, medium, and rough.

The relation between SN - G and mean texture rating (T) is shown in Figure 4; goodness of fit is described by the Pearson correlation coefficient (r). Except for one special mold, the relation between the two variables was good (r = -0.90). That pavement surface consisted of crushed sand in an epoxy overlay and was extremely smooth. The impression made of the surface contained air bubbles and produced a bad mold, which was eliminated from later studies. Since all of the surfaces seemed to fit the same general relation between gradient and mean texture rating, the molds were rated from all three surface types as a single group of 12 in the second study.

Study 2

In the second study the 12 molds were rated into five classes. Two of the original raters were unavailable for the second study, and the ratings were made by the remaining 10. The relation between gradient and mean texture rating in the second study is shown in Figure 5. Again, the relation is good (r = -0.92), and the coefficient of concordance (an index of how well the raters agreed on each mold) among raters was 0.90.

Study 3

In the third study, the individuals rated photographs of the pavement from which the molds had been made. The photographs were taken while the inventory van was stationary over the exact spot from which the molds had been made. The relation between gradient and mean texture rating for the still photographs is shown in Figure 6. The coefficient of concordance dropped to 0.75 for the still photographs.

Study 4

In the fourth study, the individuals rated the macrotexture photographs taken while the van was moving at 64 km/h (40 mph). The location of the pavement photographed was within 3 m (10 ft) of the spot of the impression in all cases. The relation between gradient and mean texture rating is shown in Figure 7. The coefficient of concordance increased to 0.92 for this group of photographs. At first, the result seems surprising. However, more reasonable results were attained when peaks per centimeter were counted on moving photographs because the streaking washed out the microtexture and made the macrotexture more visible. In study 4, however, the shadow bars in the photographs were more visible on the pavement because of the streaking, and judgment was easier by viewing the irregularities in the bars than by directly viewing the surface texture.

Study 5

An analysis was done to determine the rank-order agreement (Spearman correlation) for pavement texture ratings of molds and photographs taken while the van was stationary and moving. The results are as follows:

Combination	Correlation
Molds and still photographs	0.83
Molds and moving photographs	0.71
Still photographs and moving photographs	0.80

We concluded that raters could rate the photographs of macrotexture made while the van was moving into surface-texture classes with good interrater agreement. In addition, the mean ratings for the photographs formed a good relation with the known gradient.

However, two possibilities could have led to biased results. One possibility was that the raters used the photographs to remember the molds and did not actually rate texture based strictly on the information in the photographs. The other possibility was that the high interrater agreement on the moving photographs occurred because raters had become better through practice on the first three studies. Consequently, a fifth study was conducted.

Ten stenographers, none of whom had seen the pavement molds, were asked to rate the 12 still photographs and the 12 moving macrotexture photographs. Half of the individuals rated the still photographs first, and half rated the moving photographs first. The relation between mean rank and gradient is shown in Figure 8 for still photographs and in Figure 9 for moving photographs. By comparing the curve in Figure 6 with that in Figure 8 and the curve in Figure 8 with that in Figure 9, one can see that the agreement between the two groups was good. The Spearman rank-order correlation between the two groups for mean ranking of textures in moving photographs was 0.90. Consequently, previous knowledge of the molds did not seem to bias the ratings.

The coefficient of concordance was 0.48 for still photographs and 0.69 for moving photographs. Again, the concordance for moving photographs was higher than that for still photographs. Because the order effect was controlled in this study, the superiority of moving photographs was apparently real and not a result of learning. This conclusion was reinforced when a Bartlett's test was made on the variance data, and no significant difference was found between the variance for first and second readings.

However, the fact that the first group of raters (who had seen the molds) had a higher coefficient of concordance than the second group could indicate that the high concordance was due to experience with the molds. Another possibility is that a basic difference existed between the two groups of raters. Neither of these two possibilities could be ruled out.

Updated SN data were received from a skid test center at the completion of the five studies. The test center data used in the studies were preliminary results obtained shortly after the test surfaces had been laid, and the updated data were obtained after the surfaces stabilized. Two of the surfaces (molds 9 and 10) had a higher SN at 97 km/h (60 mph) than at 64 km/h (40 mph). Both had an epoxy overlay such that no aggregate directly contacted the tire. The surface in mold 9 had previously been eliminated because of a bad mold. The surface in mold 10 was then eliminated from further consideration. The updated gradients for the skid test center surfaces 3, 4, and 5 (molds 11, 12, and 13) are as follows (1 km/h = 0.62 mph):

Mold	Previous G (ΔSN/Δkm/h)	Updated G (ΔSN/Δkm/h)
11	0.18	0.16
12	0.15	0.10
13	0.09	0.03

Standards

After the known gradients were updated, we found that the correlation between mean texture rating and known gradient for the first group of raters (raters in studies 1 through 4) was better than the correlation for the second group. Consequently, the five standards were chosen in accordance with the ratings of the first group of raters. Figure 10 shows the relation between mean texture rating and known gradient for the first group of raters using updated gradients. Figure 11 shows the relation after the three outlying points were eliminated. Based on the least squares curve fit of the reduced data set, five standards were chosen that best represented the relation between mean texture rating and known gradient. The pavements selected as standards are as follows (1 km/h = 0.62 mph):

Standard	Mold	Known G (ΔSN/Δkm/h)	Standard	Mold	Known G (ΔSN/Δkm/h)
1	4	0.31	4	8	0.12
2	2	0.24	5	13	0.04
3	7	0.21			

We now had five standards for estimating SN - G, but the photo-estimation technique had not been tested to determine its accuracy. Fortunately, gradient data were

Figure 4. Mean texture rating versus known gradient—sequential ratings.

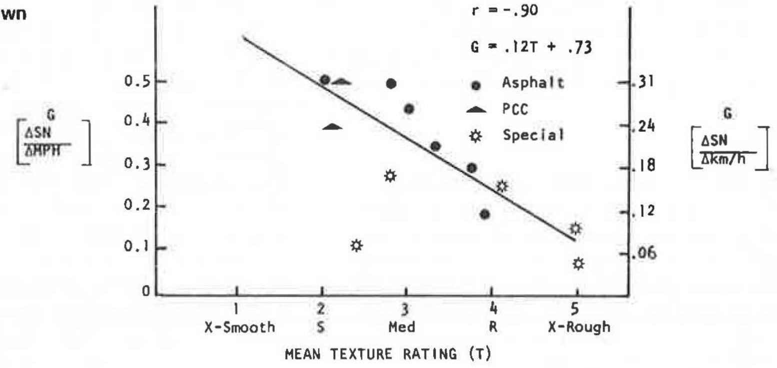


Figure 5. Mean texture rating versus known gradient—12 molds together.

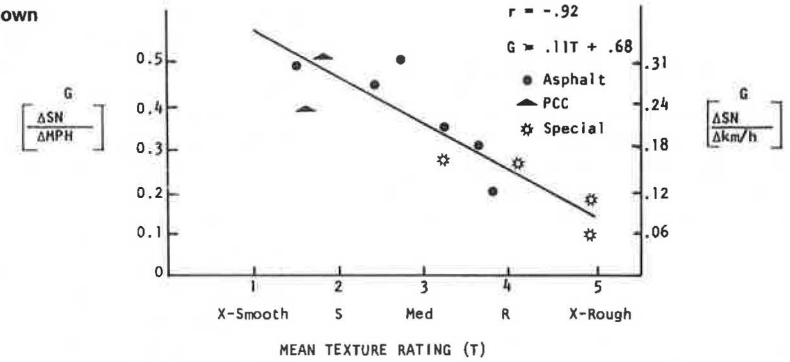


Figure 6. Mean texture rating versus known gradient—still photos, first group.

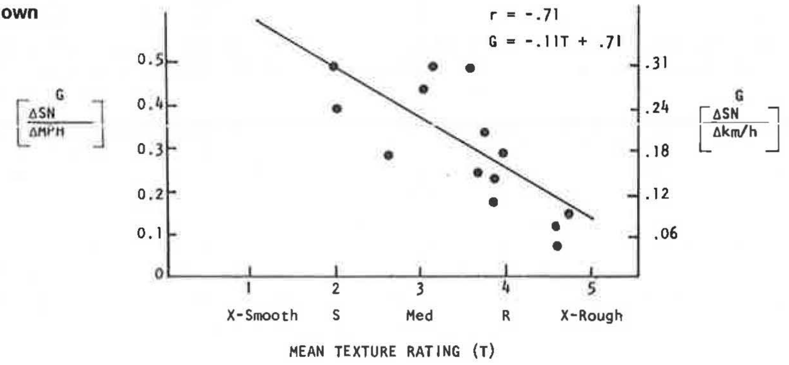
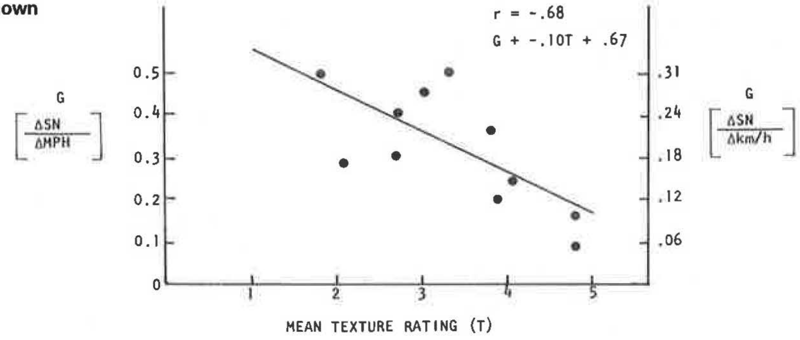


Figure 7. Mean texture rating versus known gradient—moving photos, first group.



available on nine sections of pavement that had not been used in the earlier studies to develop the standards. A total of 208 photographs had been taken in the nine sections.

Negatives of the photographs of the five standards were cut into strips so that all five could be mounted on one 35-mm slide. This set of standards was projected onto half of a rear-projection screen. Then the 208 frames of negative film were each projected on the screen next to the standards. A photograph of the actual split projection is shown in Figure 12. The rater compared the pavement photograph with the five standards and then judged which standard the pavement photograph most resembled.

The ratings were converted into estimated gradient by the following procedure. The mean rating for each section of pavement was found. If the mean rating was an integer number, the known gradient of that standard was assigned to the pavement section as the estimated gradient. For example, if the mean rating was found to be

Figure 8. Mean texture rating versus known gradient—still photos, second group.

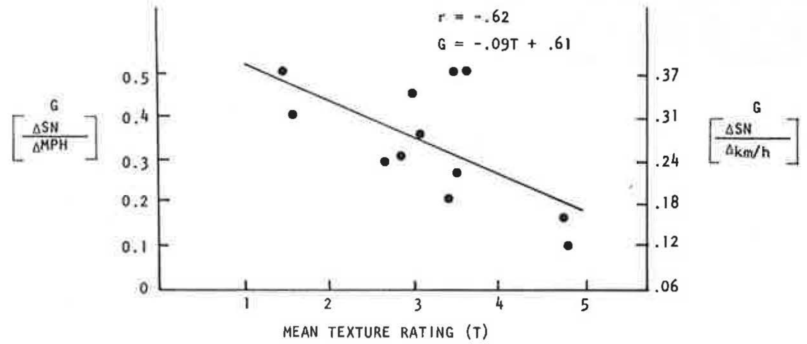


Figure 9. Mean texture rating versus known gradient—moving photos, second group.

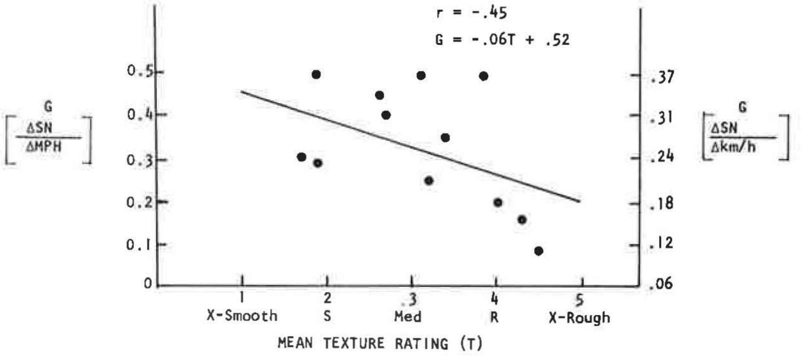


Figure 10. Mean texture rating versus known gradient—updated gradients.

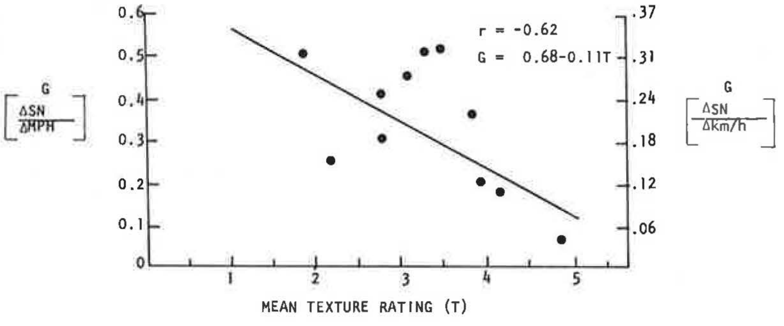
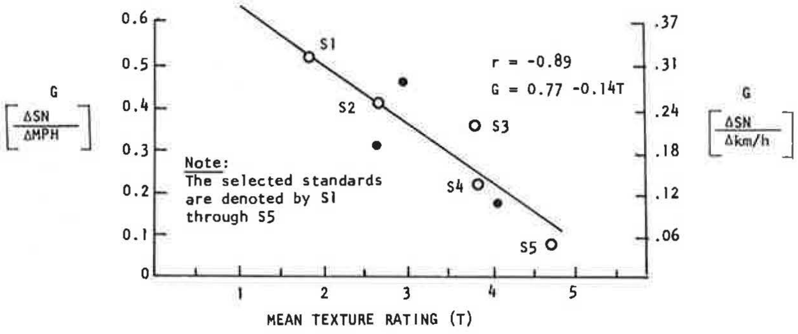


Figure 11. Mean texture rating versus known gradient—outlying points eliminated.



Note: The selected standards are denoted by S1 through S5

Figure 12. Negative photograph of pavement projected next to five standards.

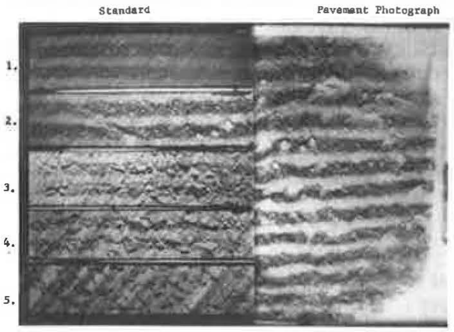


Figure 13. Relation between photo-estimated and known gradient.

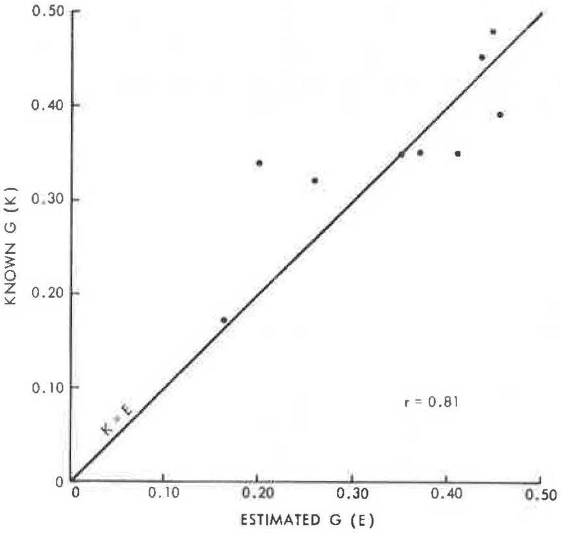
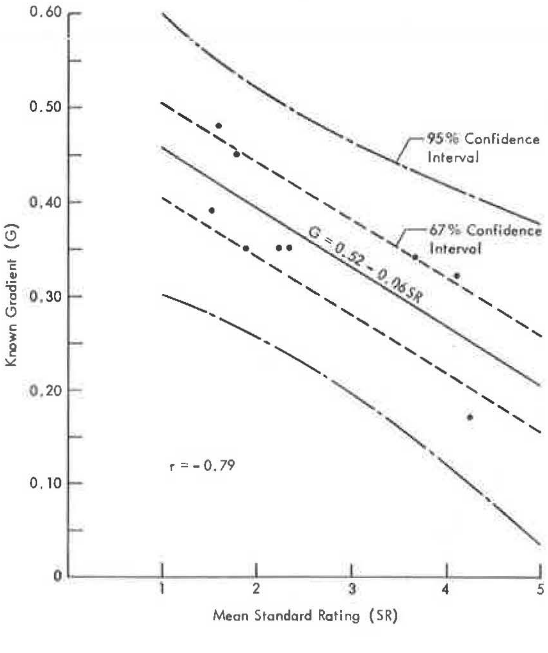


Figure 14. Relation between mean standard rating and known gradient.



3.0, the known gradient (0.35) of standard 3 in the above table was assigned to the pavement section. If the mean rating was a fractional number, the estimated gradient was found by linearly interpolating between the two bordering known gradients. For example, if the mean rating was 1.5, the estimated gradient of 0.45 was assigned to the pavement section.

The relation between estimated and known gradients that was made by using the above procedure appears in Figure 13. The line represents where the points would fall if perfect correlation existed between estimated and known gradients. The points fall fairly close to the line, and the Pearson correlation coefficient between estimated and known gradient is 0.81.

Rating Conversion Equation

Once we observed that the technique was valid, we decided to improve the linear interpolation technique of converting standard ratings into estimated gradient. The relation between mean standard rating (SR) in the validation study and known gradient for each of the nine highway sections is shown in Figure 14. The best fit, least squares linear regression line for the points had the equation G = 0.52 - 0.06 SR. The correlation coefficient was -0.79, and the standard error of the estimate was 0.0578. The 95 and 67 percent confidence intervals are shown in dashed lines. The equation above then became the equation for converting mean SR to estimated SN - G.

Reliability

The technique described above was used to estimate SN - G on 580 sections of highway in 14 states. The standard ratings for each of 28 000 frames of film were placed on punched cards for later conversion to estimated gradient by the above equation.

The film-reading process took approximately 2 months of half-time work for two technician-level readers. At the end of the 2-month period the 208 photographs used in the validation study were reread. The mean standard rating for each of the nine sections of highway was found, and the Pearson correlation coefficient between first and second reading was +0.94, indicating high reliability of the technique.

As a further check, 168 frames of film for a section of highway (with unknown gradient) were reread. The standard ratings for each frame were compared to ratings given the frames when they were read along with the other 28 000 frames. The correlation between the first and second reading was +0.69, which is reliable. Mean rating was 1.82 on first reading and 2.37 on second reading. These ratings convert to estimated gradients of 0.38 and 0.41 respectively. An error of this magnitude is deemed acceptable when one considers the variance of the skid number data with which we were working.

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Relation of Accidents and Pavement Friction on Rural, Two-Lane Roads

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Friction measurements were made with a skid trailer at 50 km/h (40 mph) on 2350 km (1460 miles) of rural, two-lane roads (U.S. routes) in Kentucky. Maintenance sections or subsections were treated as test sections. Accident experience, friction measurements, traffic volumes, and other available data were obtained for each section. Various expressions of wet-pavement accidents and pavement friction were related and analyzed. Averaging methods were used in developing trends and minimizing scatter. A moving average for progressively ordered sets of 10 test sections and test sections grouped by skid numbers and peak slip numbers yielded more definite results. The expression of accident occurrence that correlated best with skid resistance and peak slip resistance was ratio of wet- to dry-pavement accidents. Wet- to dry-pavement accident ratios increased greatly as skid number decreased from approximately 40 and as peak slip number decreased from approximately 71.

To ensure safe highway travel in wet weather, pavements must have sufficient and enduring skid resistance to enable drivers to perform driving tasks without risk of skidding and loss of vehicle control. Investigations to establish minimum friction requirements in Kentucky have focused on analysis of accident experience as related to pavement friction (1). The primary objective of this study was to discern a relationship between accident experience and pavement friction for principal, two-lane roads (U.S. routes) in rural areas of Kentucky. Evaluation of such a relationship in conjunction with economical and technical considerations will guide the establishment of minimum friction requirements for pavements.

To define a relationship between accidents and pavement friction, we must know or hold constant the effect of all pertinent parameters to the extent possible. By limiting this study to the principal, two-lane roads in rural areas, we were able to assume that parameters such as highway geometrics, access, and traffic speed would remain within reasonable bounds. Traffic characteristics (volume and density) and pavement-surface condition (wet or dry and pavement friction when wet) are respectively the regenerative and causative factors.

Annual average daily traffic volumes were obtained for 1969 and 1971. Accident data were those reported during 1969, 1970, and 1971. Pavement friction measurements were made between June and December 1970 on 2350 km (1460 miles) of the principal, two-lane roads. Both locked-wheel and peak slip resistances were measured. The measurements that best correlate with wet-pavement accidents remain to be established.

DATA ACQUISITION AND COLLATION

Measurements of annual average daily traffic (AADT) are generally available biennially. AADT data for 1969 and 1971 were averaged and used in these analyses.

Friction measurements were obtained by using a surface dynamics pavement friction tester. The two-

Figure 1. Relationship between skid numbers measured at 63.4 and 96.6 km/h.