PHOTO-INTERPRETATION OF PAVEMENT SKID RESISTANCE IN PRACTICE

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A standard texture classification procedure has been formulated that views the pavement surface as a geometric structure expressed by 6 parameters: height, width, angularity, distribution, harshness of projections above the matrix, and harshness of the matrix itself. The function of the classification method is primarily to identify pavement surfaces and to correlate textures with the accumulated test results and experience of skid testing devices. A simple stereophotographic technique was used. Regression analyses of photo-interpreted skid numbers and skid trailer test results indicated that the coefficient of correlation ranged from 0.8 to 0.9. Examples are reported of the method's applications for examining the reason for pavement slipperiness, for obtaining skid resistance information in locations where skid test vehicles cannot operate, for investigating the skid resistance of laboratory samples of pavement textures, for easing the work load of skid trailers engaged in skid resistance surveillance, and for determining the need for correcting deficient pavement skid resistance.

•THE HIGHWAY engineer, to manipulate the surface texture in order to control the pavement's skid resistance, must have a geometric concept of the pavement surface. Pavement surface textures have been stereophotographed and studied on a macroscopic and microscopic scale by several research workers (1, 2). Real pavement surface texture includes sediments of pavement, tire, windblown debris, and other contamination. There is evidence that the real pavement texture at the microscopic end of the scale is volatile and that transitory sediments are responsible for the seasonal fluctuations of skid resistance that coincide with precipitation and change of seasons (3). The texture classification system given in Table 1 deals with surface textures as perceived by the human eye at a magnification of approximately 6. The function of the classification method is twofold:

1. To classify pavement textures by identifying the 6 geometric features of the pavement surface that are known to influence skid resistance by using the simplest means possible and
2. To use texture classification for correlating the pavement surface textures with the accumulated test results of skid testing devices.

EQUIPMENT FOR PAVEMENT SURFACE TEXTURE ANALYSIS

A 35-mm single-lens reflex camera with a focal length of 55 mm was used for taking pairs of stereophotographs. The camera was mounted on a box (Figs. 1 and 2) 457 mm above the pavement. The box was equipped with an electronic flash unit that illuminated the photographed area at an angle of approximately 45 deg. The camera was attached to a sliding seat and took pavement photographs from 2 positions 95 mm apart. The stereophotographs covered a pavement surface area approximately 10 cm square. The camera box was placed in the middle of the wheel track with the light source side of the box facing to the right of the traffic direction.

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Table 1. Surface texture classification.

	Macrotexture of Projections				Microtexture	
Number	Approximate Height, A[a] (mm)	Approximate Width, B (mm)	Angularity, C[b]	Density of Projections as Percent of Total Area, D	Projection Harshness, E[b]	Background Harshness, F
0	0	16		0 to 12		Cavity in matrix surface
1	¼	8	Round	13 to 37	Polished[c]	Polished[c]
2	½	4	Subangular	38 to 62	Smooth[d]	Smooth[d]
3	1	2	Angular	63 to 87	Fine grained[e]	Fine grained[e]
4	2	Less than 2 is background		88 to 100	Fine grained[f,g]	Fine grained[f,g]
5	4	Less than 2 is background			Coarse grained, subangular[f,h]	Coarse grained, subangular[f,h]
6	8	Less than 2 is background			Coarse grained, angular[f,i]	Coarse grained, angular[f,i]

[a]A texture element has a height dimension only if the surrounding area below its peak is drained.
[b]To use this chart for asphalt pavements the following adjustments should be made: If the C-parameter number is 2, then the E-parameter number should be raised by 1; if the C-parameter number is 3, then the E-parameter number should be raised by 2.
[c]No texture visible.
[d]Texture visible but microprojections too small for visual estimate of height.
[e]Height of microprojections less than ¼ mm and less than ½ their width.
[f]Microprojections must protrude by not less than ½ their width.
[g]Microprojections approximately ¼ mm high.
[h]Microprojections approximately ½ mm high or higher.
[i]Microprojections approximately ½ mm high or higher.

Figure 1. Camera box.

Figure 2. Camera box showing flash.

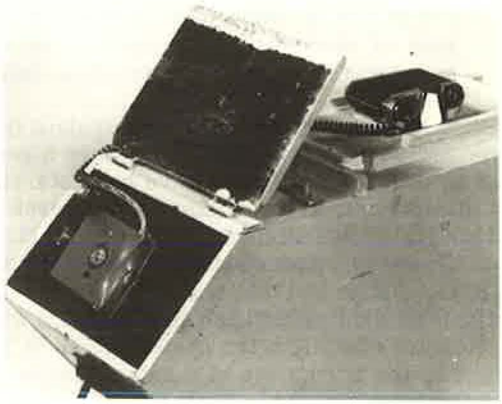
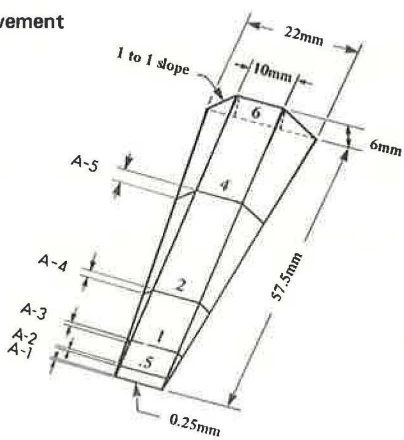


Figure 3. Vertical-scale wedge for pavement surface texture analysis.



Because pavement stereophotographs show reference scales for estimating texture dimensions, a horizontal reference scale with 1-mm divisions was attached to the light box at approximately pavement surface level. A vertical reference scale also was attached to the light box at approximately the same level. The vertical scale was wedge shaped, $\frac{1}{4}$ mm high at 1 end and 6 mm high at the other end and had 45-deg side slopes. Heights were indicated at increments of the texture height parameter (Fig. 3).

Pavement stereophotographs are viewed under a mirror-stereoscope or under a microstereoscope. If a mirror-stereoscope is used, the 35-mm pavement photographs are first enlarged into natural-scale prints. These are viewed at a magnification of 6. A microstereoscope with a magnification of 25, mounted on a light table, may be used for viewing 35-mm color transparencies (Fig. 4).

A more detailed account of pavement surface texture analysis is available (4).

TEXTURE PARAMETERS

The surface texture of a pavement was defined in terms of 6 texture parameters (Table 1).

1. Parameter A denotes the height above the matrix of projections on the pavement surface.
2. Parameter B denotes the width of the surface projections at the top of the matrix.
3. Parameter C denotes the shape of the projection, for example, round, subangular, or angular (Fig. 5). Round projections have curved sides and no edges or nearly plane sides and well-rounded corners and rounded edges. Subangular projections have somewhat blunted edges. Angular projections have sharp edges and pointed corners.
4. Parameter D denotes the density of distribution of the projections as the proportion of the whole surface area occupied by projections.
5. Parameter E denotes the harshness (microtexture) of the projections' surfaces in terms of apparent height and angularity of the microprojections, for example, polished; smooth; fine grained; coarse grained, subangular; and coarse grained, angular. A polished surface has no visible texture. A smooth surface has a visible texture, but the microprojections are too small for a visual estimate of height. A fine-grained surface has microprojections that are approximately $\frac{1}{4}$ mm high. Microprojections must protrude by not less than half their width. A coarse-grained, subangular surface has blunt microprojections that are approximately $\frac{1}{2}$ mm high or higher. Microprojections must protrude by not less than half their width. A coarse-grained, angular surface has sharp microprojections that are approximately $\frac{1}{2}$ mm high or higher. Microprojections must protrude by not less than half their width.
6. Parameter F denotes the harshness of the texture of the background surface between projections in terms of apparent height and angularity of microprojections, for example, smooth; fine grained; coarse grained, subangular; and coarse grained, angular. A cavity is an undrained area below the surface of the matrix.

The surface texture of a pavement is classified by the texture code number, which is the complete set of the 6 texture parameter numbers, for example, 2.7-1.4-1.8-55-2.1-3.0. For heterogeneous surface textures, when part of the photographed surface has been expressed in terms of 1 microtexture parameter and the other part by the full set of 6 parameters, 2 texture code numbers and their proportion are stated: 30 percent × 0-0-0-100-3.4-0 + 70 percent × 2.7-1.4-1.8-55-2.1-3.0.

ANALYSIS

A transparent grid, equivalent to 1 cm square, was placed over 1 stereophotographic print or under 1 color transparency, depending on whether a mirror-stereoscope or a microstereoscope was used. On the grid, 10 random centimeter squares were marked and numbered (Fig. 6). Each of the numbered centimeter squares of pavement surface was examined under the stereoscope, and the number of each of the 6 texture parameters was assessed according to Table 1. The numerical average of the parameter numbers of the centimeter squares was the parameter number of the photographed surface area.

Figure 4. Microstereoscope.

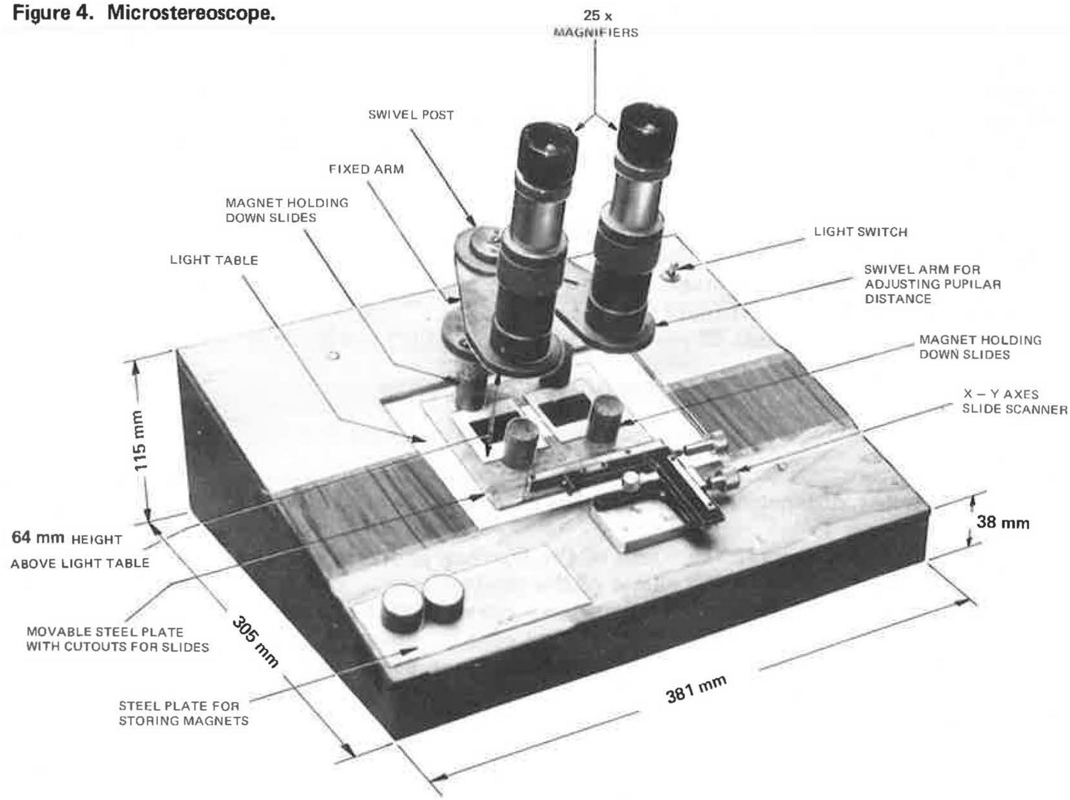


Figure 5. Angularity of projections.

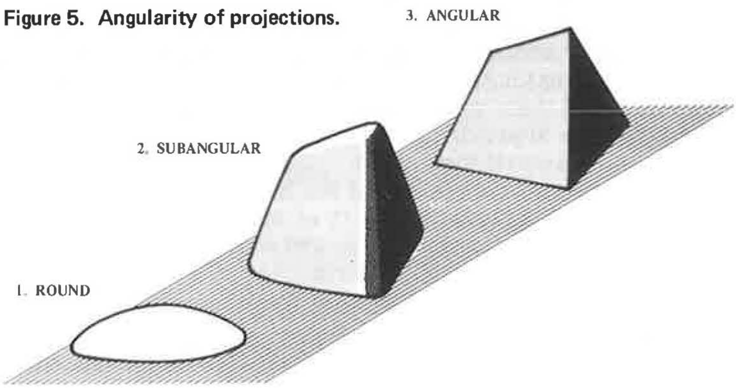


Figure 6. Transparent grid.

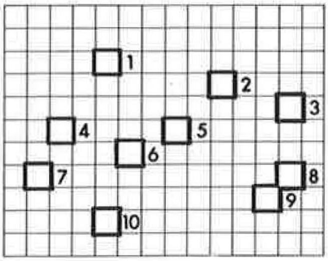
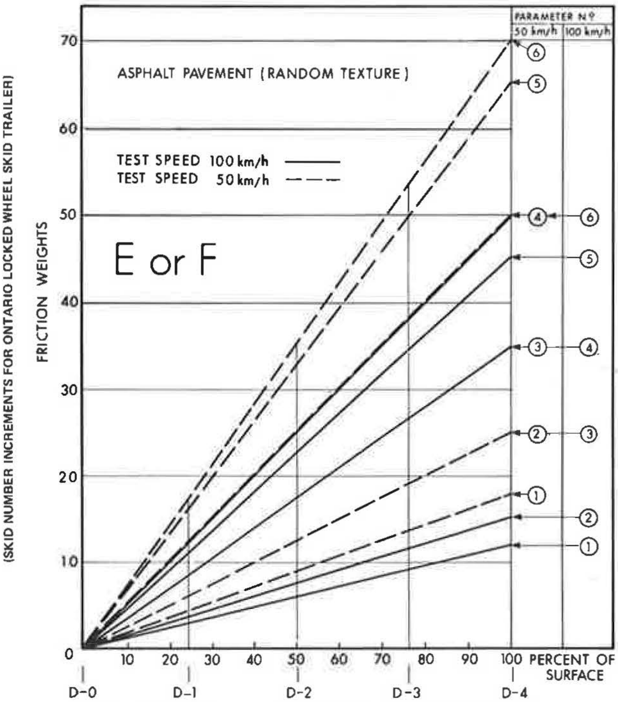


Figure 7. Friction weights of pavement texture parameter E or, if macroprojections are absent (D0), parameter F.



Note: If the density parameter is D-1, D-2, or D-3, add to the friction weight for parameter E (obtained from this graph) the friction weights for parameters A, B, and F (obtained from Figures 8, 9, and 10 respectively).

In the case of parameter C only, the average parameter number was rounded to the nearest whole number. The set of the 6 average parameter numbers was the texture code number of the photographed surface area.

SAMPLING PAVEMENT TEXTURE IN TEST SECTIONS

At least 3 pavement stereophotographs were taken in each test section. A test section is a section of pavement of uniform age and general composition that has been subjected to essentially identical wear throughout. Sharp curves and steep grades should not be included in the same test section with level tangents, nor should passing lanes be included with driving lanes.

PHOTO-INTERPRETING SKID RESISTANCE AND COMPUTING SKID NUMBERS

Correlation charts of texture code numbers and skid test results on asphalt pavements of an ASTM 2-wheel trailer were prepared (Figs. 7, 8, 9, and 10). Similar charts based on regression analyses of texture code numbers and test results of other skid testing devices may be prepared. The photo-interpreted skid number of a pavement surface is the sum of the texture parameters' friction weights obtained from photo-interpretation charts. The photo-interpreted skid numbers can either be abstracted from the charts in the ordinary way or calculated by computer. In the latter case, the computer input should consist of (a) the identification number of the pavement photograph; (b) the type of pavement; (c) the texture parameters; and (d) skid trailer test skid numbers, if available, at test speeds of 50 km/h and 100 km/h. The program should contain an option for performing a linear regression of the test skid numbers (independent variable) and photo-interpreted skid numbers (dependent variable). The output should consist of 2 listings: (a) the photo-interpreted skid numbers together with the input parameters for each photograph and the test skid number and (b) the regression analysis, namely, constant, a, and regression coefficient, b, in the equation $y = a + bx$; the coefficient of correlation; and the standard error of estimate.

EXAMINING CAUSE OF PAVEMENT SLIPPERINESS

The photo-interpretation method can throw light on the reasons for the existence of a slippery pavement condition. In the course of analyzing the pavement surface, some of the following defects became apparent:

1. Polished aggregate (texture parameter E1),
2. Excess binder or fines in matrix (texture parameter F1 or F2),
3. Excessive wear of pavement aggregate (angularity parameter C1), and
4. Stripping of aggregate (distribution parameter D1 or D2).

Example 1

The test site was located on Highway 9, with the town of Arthur to the west. The texture code number was 1.7-1.3-1.7-25 percent-2-2.7. The skid number at 50 km/h was 41; at 100 km/n, it was 26. The stone projections on the surface were low (0 to 0.5 mm), subangular to round, sparsely distributed, and smooth (partly asphalt coated). The matrix was fine grained to smooth. Therefore, skid resistance at low speed was adequate but relatively low at high vehicle speeds. Scattered flushing in the wheel paths was in evidence. Traffic will wear off the stones' asphalt coating, which will raise skid resistance. However, present flushing in the wheel tracks will probably spread and will further aggravate the friction deficiency at high speeds.

Example 2

The test site was located on Highway 6 with Rickman's Corners approximately 8 miles to the south. The texture code number was 1.5-1-1-25 percent-3.3-3. The skid number at 50 km/h was 45; at 100 km/h, it was 28. A large proportion of stone projections on the surface appeared to have broken off at, or even below, the matrix level

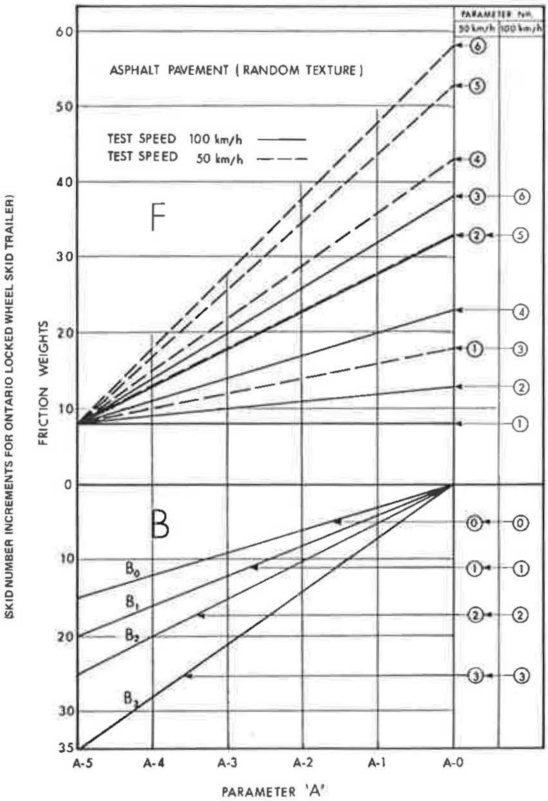


Figure 8. Friction weights of pavement texture parameters A, B, and F for D1.

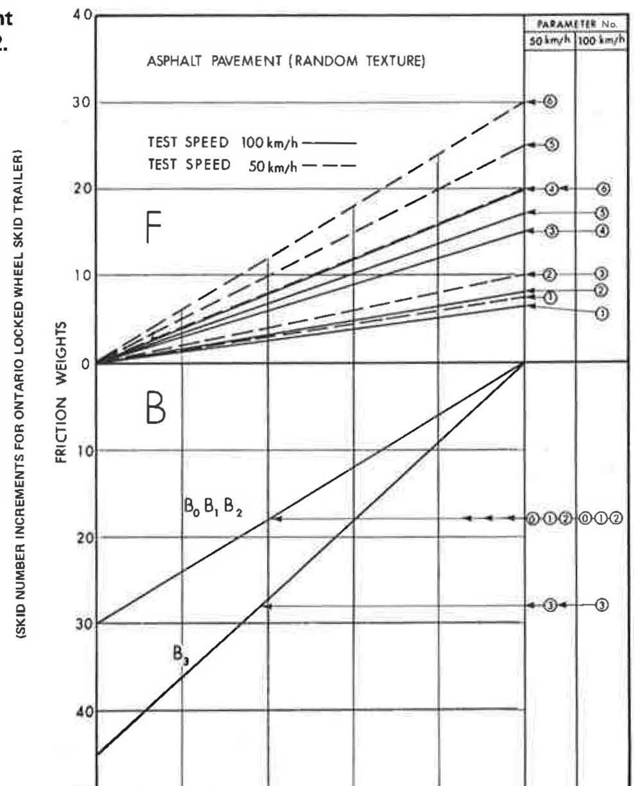


Figure 9. Friction weights of pavement texture parameters A, B, and F for D2.

Figure 10. Friction weights of pavement texture parameters A, B, and F for D3.

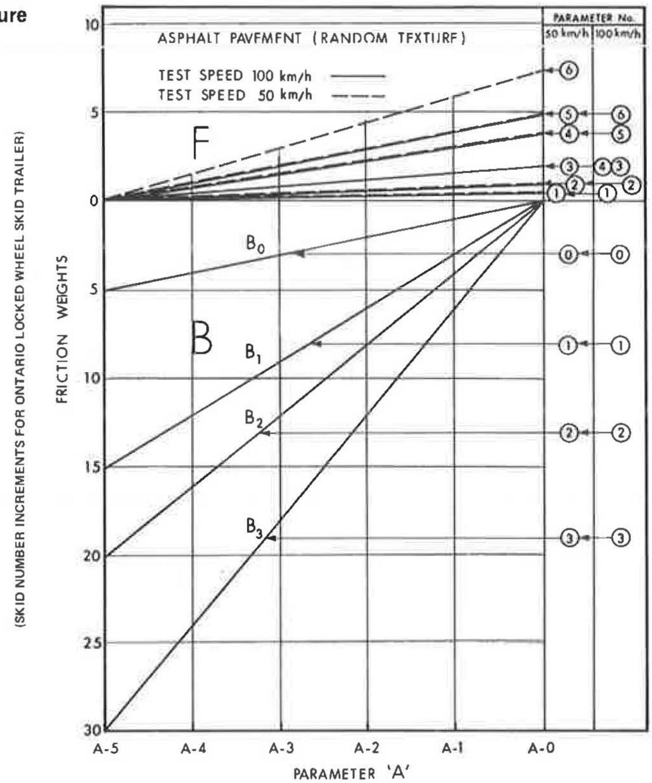


Table 2. Texture and skid-resistance changes caused by PCA wear machine, 1973.

Section Number	Pavement Wear	Parameter A: Before PCA Wear	Parameter A: After PCA Wear	Parameter E: Before PCA Wear	Parameter E: After PCA Wear	Parameter E: Skid Resistance Change 50 km/h	Parameter E: Skid Resistance Change 100 km/h	Parameter F: Before PCA Wear	Parameter F: After PCA Wear	Parameter F: Skid Resistance Change 50 km/h	Parameter F: Skid Resistance Change 100 km/h	Total Change in Skid Resistance Caused by Wear Test 50 km/h	Total Change in Skid Resistance Caused by Wear Test 100 km/h	Skid Num[ber] After PC[A] Wear 50 km/h	Skid Num[ber] After PC[A] Wear 1[00] k[m/h]
1	Normal sand, normal limestone	2	2	3	2	-8	-5	0/3	0/3	Nil	Nil	-8	-5	24	[illegible]
2	Normal sand, normal limestone	1	1	3	2	-8	-5	0/3	0/4	+2	+3	-6	-2	23	[illegible]
3	100 percent silica, normal limestone	2	2	3	2	-8	-5	3	3	0	0	-11	-5	28	[illegible]
4	67 percent silica, 33 percent normal limestone	0	0	3	3	Nil	Nil	3	2/3	-5	-3	-5	-3	40	[illegible]
5	33 percent silica, 67 percent normal limestone	2	2	3	2	-8	-5	3	0/3	-5	-3	-13	-8	25	[illegible]
6	100 percent silica, slag	3/2	0	3	3	Nil	Nil	3.5	0/7	+3	+5	+3	+5	42	[illegible]
7	67 percent silica, 33 percent sand, slag	0	0	3	3	Nil	Nil	3	0/4/7	+7	+7	+7	+7	41	[illegible]
8	33 percent silica, 67 percent sand, slag	3	3	3	3	Nil	Nil	0/3	0/3	Nil	Nil	Nil	Nil	45	[illegible]
9	100 percent silica, traprock	3	3	3	3	Nil	Nil	3	3	Nil	Nil	Nil	Nil	46	[illegible]
10	67 percent silica, 33 percent sand, traprock	3	3	3	3	Nil	Nil	3	3	Nil	Nil	Nil	Nil	52	[illegible]
11	33 percent silica, 67 percent sand, traprock	3	3	3	3	Nil	Nil	3	3	Nil	Nil	Nil	Nil	46	[illegible]
12	Normal sand, normal limestone	1	1	3	2	-8	-5	3	3	Nil	Nil	-8	-5	28	[illegible]

so that the height of stone projections was generally low (0 to 0.5 mm). The damaged stones were light colored and probably soft. Their presence in an HL1 (traprock) pavement was not expected. The surface of the matrix was gritty. The skid resistance of the examined section of Highway 6 met the minimum requirements at low traveling speeds but fell short of the high-speed friction needs of a curved alignment with numerous driveways. The relatively low skid resistance may be attributed to the fact that the coarse aggregate in the pavement mix had a significant proportion of white stone particles sheared off at the base. Only the traprock particles provided the desirable texture relief. The mineral composition of the coarse aggregate in this section of highway should be investigated.

EVALUATING SKID RESISTANCE OF LABORATORY AND FIELD SAMPLES

Core samples of 12 experimental concrete pavement sections containing different aggregates and mix proportions were subjected to wear under the PCA wear machine. The changes in the surface texture and consequent changes in the skid resistance of the concrete surfaces brought about by the lab test are given in Table 2. The surface changes consisted of the following:

1. Downgrading of parameter E3 (fine grained) of the coarse aggregate to E2 (smooth) in test sections 1, 2, 3, 4, and 12, in which the coarse aggregate was local limestone;
2. Downgrading of matrix parameter F3 to F1.5 and F2.5 in test sections 4 and 5 respectively; and
3. Improved skid resistance in slag sections 6 and 7, in which the slag appears to have been worn down enabling the silica-sand matrix to make contact with the tire.

ESTIMATING SKID RESISTANCE IN A CURVED ALIGNMENT

The skid trailer in a curved test path cannot be expected to realistically reflect the skid resistance of the pavement because of the lateral (centrifugal) force exerted on the test wheel's torque sensor.

The third test site was located in the eastbound collector lane on the exit ramp to Warden Avenue on Highway 401. The texture code number was 0-0-0-100-2.0-0. The skid number at 40 km/h was 27; at 50 km/h, it was 25; and at 100 km/h, it was 15. The posted speed limit was 25 mph (40 km/h). The skid resistance at this speed was extrapolated from the speed skid resistance gradient obtained from the photo-interpretation chart. The coarse aggregate was highly polished and the texture relief was less than ¼ mm. The matrix was mainly smooth; only a small proportion of it was fine grained. Therefore, skid resistance was extremely low for the friction requirement on a curved ramp.

EASING WORK LOAD OF SKID TRAILER

When only 1 skid trailer is used for extensive highway mileages (as was the case in Ontario), promptly satisfying all requests to examine highway sections separated by considerable distances is often not possible. Use of the photo-interpretation method eases the pressure exerted on the skid trailer by allowing quick diagnoses to be made from pavement stereophotographs. It can be determined whether the texture of a pavement surface

1. Excludes the possibility of a slippery condition;
2. Indicates the certainty that a slippery condition exists; or
3. Leaves doubt about the friction level, indicating that skid testing should be conducted.

DETERMINING NEED FOR CORRECTING DEFICIENT PAVEMENT

Corrective action is often undertaken when skid resistance is below the level representing the minimum frictional requirement. The list of guidelines currently used by state highway departments and the British illustrates the variety of norms (5, 6).

Determining the pavement friction coefficients required for driving tasks was undertaken in NCHRP Rept. 154 (7) with the objective of providing highway agencies with methods to determine minimum skid resistance, allowing for driver behavior. A tape switch system was developed for roadside instrumentation to measure longitudinal and lateral accelerations of vehicle maneuvers. However, it is uncertain when reliable friction requirements for traffic locations will be obtainable and whether tailor-made skid resistances will be feasible. A statistical evaluation of skid tests demonstrated that a great deal of skill and sophistication is needed to extract from survey test data results suitable for use with minimum skid resistance standards (8).

Identifying and classifying pavement surface textures and their suitability for specified traffic conditions in different climates holds the prospect of raising the skid resistance standard of our highways by eliminating those textures that have proved to have low resistance to skidding and hydroplaning. Pavement texture selection will be based on those combinations of texture parameters that must be incorporated in the surface to achieve skid resistance in the intermediate or upper scale. Therefore, determining the skid resistance standard of a pavement should be based not exclusively on a skid test result but on the accumulated testing of a particular pavement surface texture. Pavement texture can be divided into 6 groups with interpreted skid numbers in the lower, intermediate, and upper range of the known skid resistance spectrum, as follows:

1. $SN_{100\ km/h} < 20$,
2. $20 \le SN_{100\ km/h} < 30$,
3. $30 \le SN_{100\ km/h} < 40$,
4. $40 \le SN_{100\ km/h} < 50$,
5. $50 \le SN_{100\ km/h} < 60$, and
6. $60 \le SN_{100\ km/h}$.

The 6 skid resistance ranges would be in line with the categories of friction needs which, hopefully, will be identified for different traffic situations (7). A pavement surface will be considered in need of correction if its texture has an interpreted skid resistance potential below the range of the location's friction needs.

CONCLUSION

The photo-interpretation skid resistance method has been in use in Ontario for the past 2 years in investigating highway pavements on which a skidding problem was suspected. By focusing on pavement surface geometry and by combining it with skid testing experience, the engineer is in a better position to understand the cause, prevention, and remedy of particular skidding problems.

ACKNOWLEDGMENT

Allan Ma, of the Ministry of Transportation and Communications, contributed the statistical analysis of correlated photo-interpreted skid numbers and skid trailer test results. Graham Musgrove, of the Ministry of Transportation and Communications, supplied field data and valuable advice from the beginning of the work on pavement texture classification.

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