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Seasonal and Short-Term Variations in Skid Resistance

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Preliminary results of a three-year program to investigate possible causes of seasonal and short-term variations in skid resistance are presented. The program was initiated in 1976 at the Pennsylvania State University to develop a method for predicting the lowest skid number a pavement is expected to attain during the year from a skid-resistance measurement made at any time during the year. Results of two years of testing indicate that skid-resistance variations of 15-30 SN_{40} occur at the changes of season from early to late fall and early to late spring. Higher numbers occur in the winter season. Skid numbers vary by about 25 percent between rainfall periods whether or not the surface is subject to significant traffic. Higher skid numbers are observed after heavy rainfall. Where traffic is low (average daily traffic < 1000), only minor macrotexture changes are noted from one season to another. On these pavements, therefore, microtexture changes are expected to cause the variations in skid resistance. Bituminous surfaces containing sandstone gravel aggregate are subject to small variations in skid resistance over time, whereas surfaces containing limestone and dolomite are subject to large variations. Temperature has been found to have insignificant effects on skid resistance.

Seasonal and short-term variations in skid-resistance measurements made according to the ASTM E 274 test method have been observed on Pennsylvania and other public highways (1, 2). These variations make it difficult to establish a maintenance management program in which skid resistance is an important factor. Day-to-day variations, apparently caused by rainfall patterns and local weather conditions, are superimposed on an annual cycle. At least in northern states, this annual cycle tends to be higher in winter through spring than in summer through fall. Frequent tests during the period from spring through fall reveal that the skid resistance of pavements may vary by as much as 25 percent during a single week.

To establish a means of interpreting skid-resistance data subject to seasonal and short-term variations, in 1976 the Pennsylvania Department of Transportation (PennDOT) initiated a three-year research program at the Pennsylvania Transportation Institute (PTI). The primary objective of the research is to investigate the possible causes of the variations and to develop a method for predicting the lowest skid number a pavement is expected to attain during the year from a skid-resistance measurement made at any time during the year. This paper summarizes the data and preliminary findings obtained during the first two years of the study.

TEST SITES

Six pavements on public roads in the State College, Pennsylvania, area were selected for the study according to the following criteria:

1. The pavements should be in a sufficiently small geographic area so that each could be tested within a short period of time by using the same skid tester.
2. As far as possible, the pavements should be subject to the same weather conditions.
3. The pavements should be at least three years old so that their surface characteristics would have stabilized.
4. The pavements should contain a variety of aggregates and mix designs and include at least one portland cement concrete pavement.
5. The pavements should have as wide a range of average daily traffic (ADT) as possible.

The selected pavements met all of these criteria. Their characteristics are summarized in Table 1.

During the 1976 test season, local weather conditions were monitored by rain gauges that were read at the time of skid tests. Since weather variations among the sites were small, the weather records provided by the Pennsylvania State University weather station were subsequently used as representative of the weather at all sites. Available daily weather data include the amount of rainfall, maximum and minimum temperatures, relative humidity, wind speed and direction, and cloud cover. In addition, the temperature of the pavement and the tire and ambient temperatures are measured at the time of skid testing.

Five test locations at each site are marked with a fluorescent orange square to assist the driver in conducting the daily skid tests at the same locations each day. A series of three nails have also been placed in the surface at each location so that pavement texture can be measured at the same spot each month.

At all locations, skid tests are made in the wheel tracks. At one site, skid tests are also made between the wheel tracks to verify whether skid-resistance variations occur where no significant tire traffic passes. Although skid resistance is expected to be higher between the wheel tracks, the behavior of short-term variations between the wheel tracks may provide further insight into the mechanisms involved.

DATA COLLECTION AND ANALYSIS

Daily Skid Testing

Skid-test measurements according to ASTM E 274 are made on all days when the pavement is dry. In addition, tire and pavement temperatures are continuously monitored by using radiometers mounted on the tester. Ambient and water temperatures are measured with appropriate thermometers. Skid tests are made at each of five marked locations at each site. The data are reported as the average of the five tests. Locked-wheel skid numbers at 64.5 km/h (40 mph) (SN_{40}) are shown in Figures 1-4. Also shown in the figures are the daily rainfall (in millimeters per 24-h period) and a five-day weighted rainfall function (WRF), which is defined as

$$WRF = R_1 + (R_2/2) + (R_3/3) + (R_4/4) + (R_5/5) \quad (1)$$

where

R_1 = rainfall on the day in question (mm),
R_2 = rainfall on the previous day (mm), and
R_n = rainfall (n - 1) days before the day in question ($1 < n < 5$).

From Figures 1-4, it can be seen that the short-term skid-resistance variations have a behavior qualitatively similar to that of the WRF. During the testing season, the variations between wheel tracks, where traffic is light, followed a pattern similar to that of variations in the heavily traveled wheel tracks (see Figure 5).

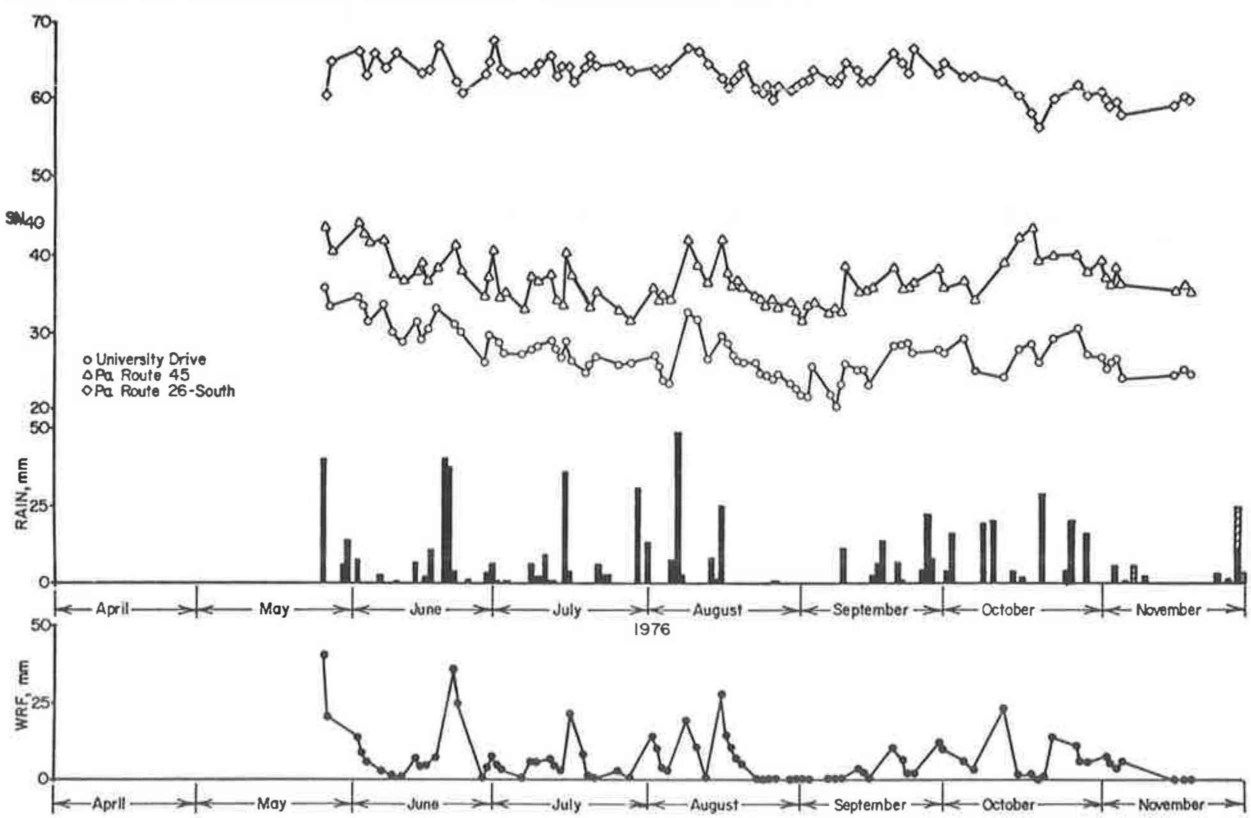
During the 1977 test season, skid tests were performed in the transient slip mode (3). Although this method provides SN_{40} data according to the ASTM E 274

Table 1. Description of road surfaces selected for testing.

Item	Test Section: University Drive	PA-45E	US-322N	PA-26N	PA-26S	PA-871
April 1976 ADT	6500	800	7000	2500	2500	1200
Construction year	1966	1961	1968	1969	1969	1973
Pavement						
Description	Base 20 cm limestone, surface 5 cm limestone	Pennsylvania 1B limestone, natural sand	Pennsylvania 1B limestone, natural sand	Pennsylvania 1B limestone, natural sand	Gravel, natural sand	Reinforced cement concrete, silica sand, 2B limestone, PDH design
Type	ID-2	ID-2	ID-2	SR-1A	SR-1A	Class AA RCCP
Asphalt (%)	6.2	6.2	5.8	6.0	7.5	
Percentage passing 2.36-mm sieve	45	45	45	17	17	
Sand-patch texture depth (mm)	0.50	1.35	0.46	1.4	1.6	0.69

Notes: 1 cm = 0.39 in; 2.36-mm sieve = no. 8 sieve.
PDH = Pennsylvania Department of Highways.

Figure 1. Skid-test and rainfall data for 1976 test season: University Drive, PA-45, and PA-26S.



test method, it also provides brake slip numbers at 16, 32, and 48 km/h (10, 20, and 30 mph) that can be used to approximate SN_{10}, SN_{20}, and SN_{30}. These data, together with the locked-wheel skid number SN_{40}, were regressed to the Penn State model for the behavior of skid resistance (SN) with speed (V) (4):

$$SN = SN_0 \, e^{(-PNG/100)V} \qquad (2)$$

where SN_0 is the zero-speed intercept of a curve for skid number versus velocity and PNG is the percentage normalized gradient (4). The daily values for SN_0 and PNG are plotted versus rainfall data in Figures 6 and 7, respectively.

Figure 2. Skid-test and rainfall data for 1976 test season: PA-871 (concrete), US-322, and PA-26N.

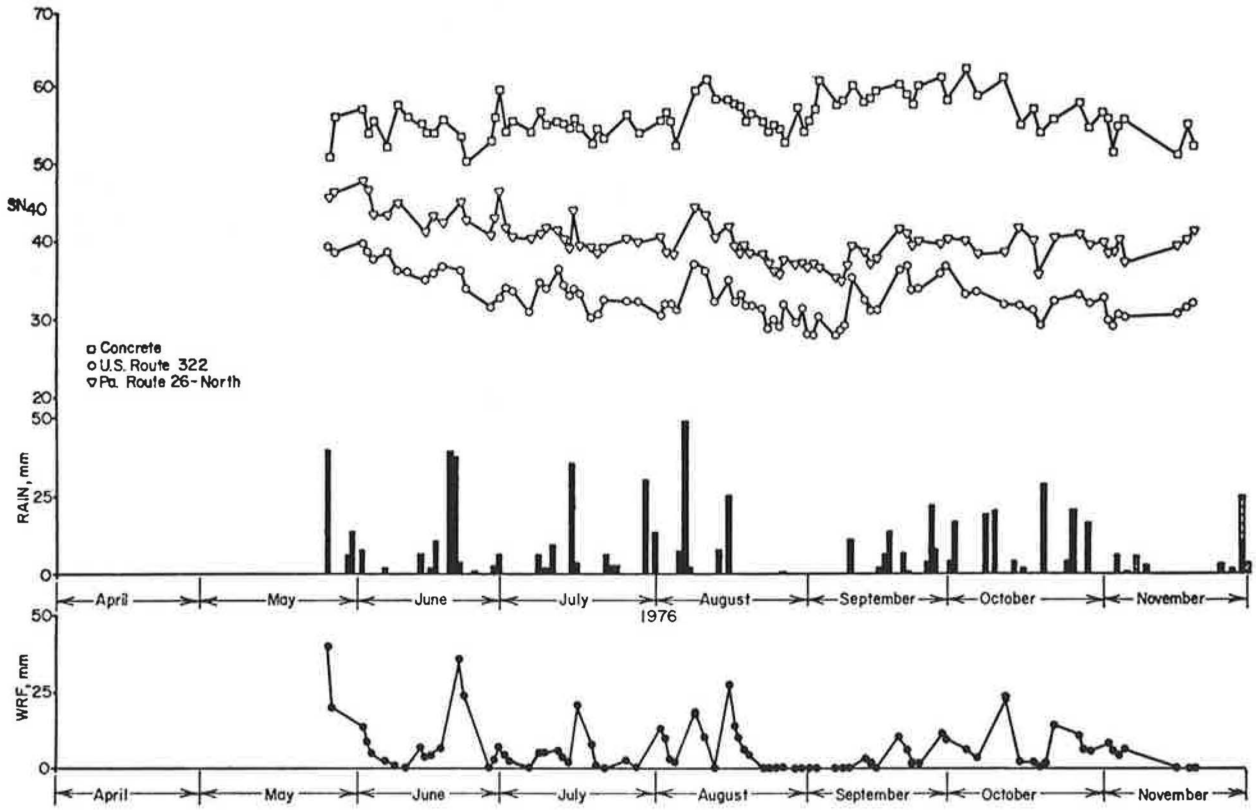


Figure 3. Skid-test and rainfall data for 1977 test season: University Drive, PA-45, PA-26S, and US-322 (between wheel tracks).

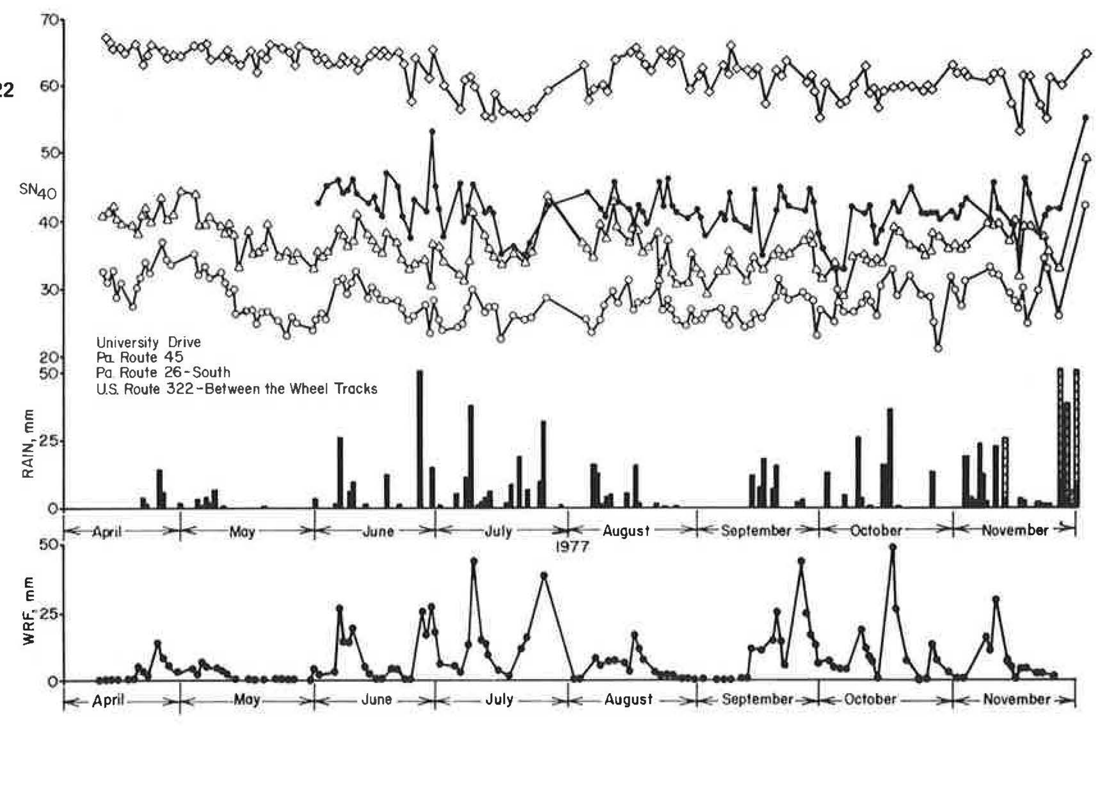


Figure 4. Skid-test and rainfall data for 1977 test season: PA-871 (concrete), US-322, and PA-26N.

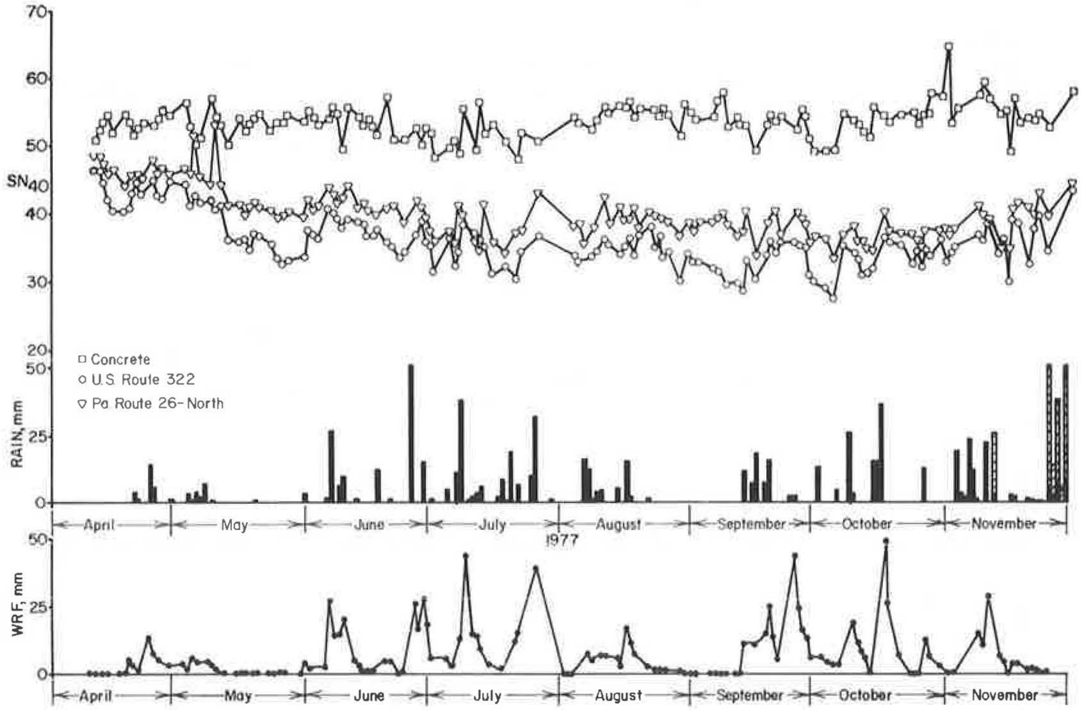
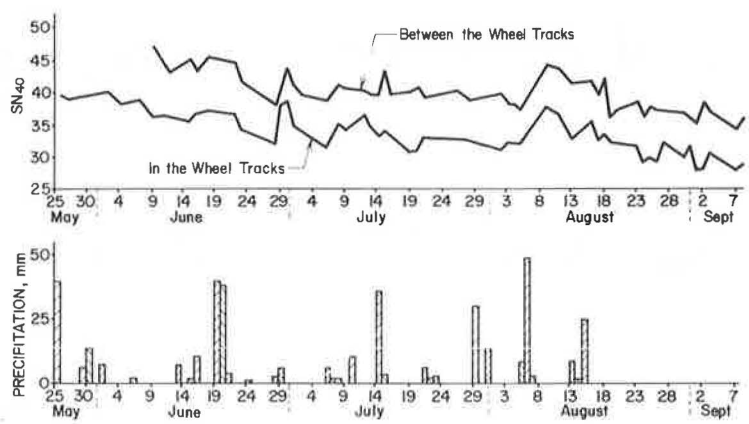


Figure 5. Skid-number history (1976) for US-322 between and in wheel tracks.



It is significant that the short-term variations of SN_0 amplify the variations noted in SN_{40}. In addition, the level of SN_0 decreases from early spring to a more or less stable level by mid-July for the seven surfaces tested. Since SN_0 correlates well with microtexture, one can conclude that early-season polishing for the pavements in this study reaches its terminal level by mid-July. The time required to reach terminal polishing is expected to depend on ADT and type of aggregate.

The variations in PNG that do exist have not yet been explained but, unlike the variations in SN_0, they do not appear to be related to rainfall history.

Texture Measurements

Texture measurements and other examinations of each test pavement have been conducted on a monthly schedule during the test season. During the 1976 season, four sets of measurements were obtained from July to October; in the 1977 season, six measurements were made from May to November. Two days were required to complete these measurements; each pavement section was closed to traffic for about 2 h each day. The tests were performed at the same spots on the pavements each month by referring to nails driven into the pavement during the first test session.

The following data were obtained on a monthly basis:

1. Macrotexture profile recordings;
2. Microtexture profile recordings;
3. Sand-patch texture depth;
4. British pendulum data (a) in the wheel track, (b) out of the wheel track before polishing, and (c) out of the wheel track after polishing with various abrasives;
5. Stereophotographs; and
6. Extracted aggregates for petrographic analysis and observation of particle surface changes.

The texture recordings were made by using PTI profile tracers that produce electrical signals proportional to the profile height. These signals were recorded on magnetic tape and were subsequently processed to provide data on root-mean-square profile height (RMSH). It has been determined that, for purposes of skid-resistance prediction, microtexture is best defined as consisting of asperities that have a wavelength of less than 0.5 mm (0.02 in) [or a space frequency greater than 2000 cycles/m (600 cycles/ft)] (4).

During the first two seasons, sand-patch tests were performed according to the American Concrete Paving Association method (5) but by various operators, and there is considerable variation in the data because of differences in operator technique. During 1978, these tests were performed by a single operator in strict adherence to the method.

British pendulum tests were performed according to ASTM E 303 in and out of the wheel tracks. In addition, the PTI modified portable reciprocating pavement

Figure 6. SN_0 data for 1977.

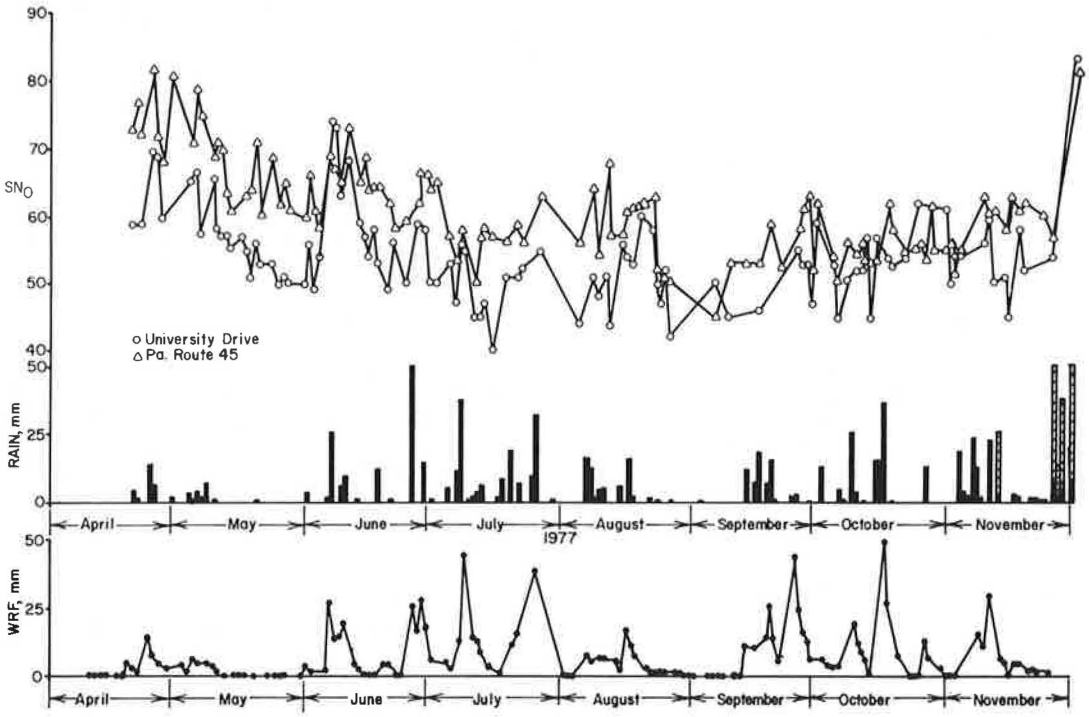
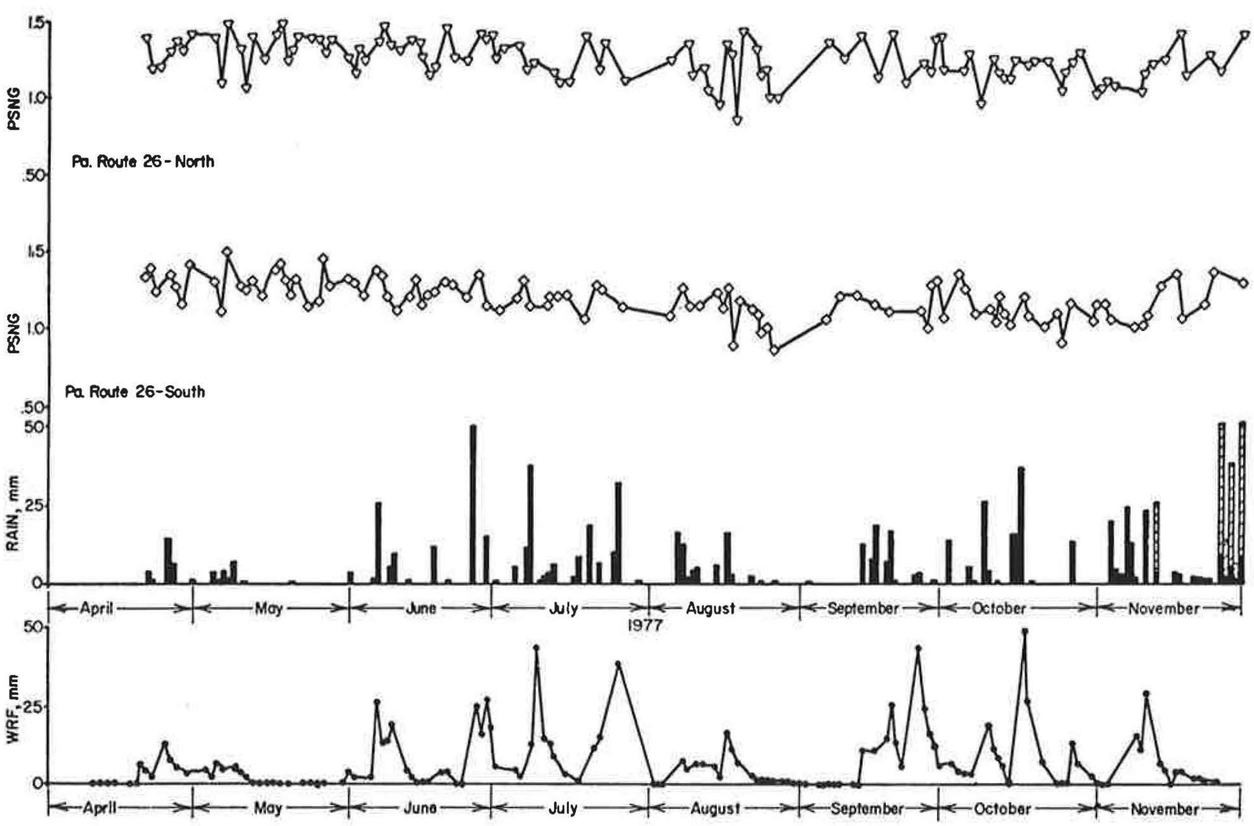


Figure 7. PNG data for 1977.



polisher (6) was used to polish spots on the pavement out of the wheel track with abrasives of various sizes. The polishing data are discussed later in this paper.

Stereophotographs of 35-mm slide pairs were taken by using the Schonfeld procedure as described in ASTM E 559. The stereophotographs provide a record of the surface condition. Although they are interesting and provide qualitative insight into pavement weathering and polishing, no quantitative analysis of these photographs appears promising at this time.

Visual Inspection and Petrographic Analysis of Aggregates

Individual stones taken from the five bituminous sections were inspected under magnifications of 4X and 10X. Stones taken from the same road section but in different months of the same year and in different months a year apart were compared, as were stones from different locations. The stones were inspected for (a) type, (b) appearance and cleanliness, and (c) texture and texture changes.

After many hours of inspection, it was difficult to detect any systematic, significant changes in texture. The stones did appear to have relatively clean surfaces in May but in June or July were fully or partially coated with an asphalt film. The surfaces tended to be cleaner but more shiny in August and September and still cleaner but less shiny in November. Based on this experience, it appears that quantitative texture information cannot be obtained through visual inspection of individual stones lifted from the pavement.

After inspection of the stones under magnification, thin sections were prepared from each set of stone samples. At least two thin sections from the stones taken from each of the five bituminous test locations were prepared and analyzed.

The petrographic analysis showed that the sandstone gravel used in the PA-26S section is superior to the limestone and dolomite used in the other sections. The gravel contained about 60 percent quartz grains and 40 percent sericite, clay, and other rock fragments. This combination permitted the gravel to maintain a high level of skid resistance after nine years in service (average SN_{40} = 63). An adjacent test section (PA-26N), in which the coarse aggregate was 30 percent dolomite, 5-10 percent quartz, and 60 percent limestone, had an average SN_{40} of 40. Both sections PA-26S and PA-26N were placed simultaneously, and the same design—an open-graded friction course—was used. The other three bituminous sections that contained limestone coarse aggregate averaged SN_{40} = 36, 35, and 27. The lowest value was on the surface where the coarse aggregate was practically pure limestone and contained only 10-15 percent dolomite but no hard siliceous minerals. In addition, the grain size was small: 10-100 μm (0.0004-0.004 in). These results confirmed previous observations on the polishing characteristics of surface aggregates (7).

Table 2. Results of 1977 pavement polishing.

Test Surface	Date	Particle Size at 3000 Cycles (μm)	Polished BPN	Actual Wheel-Track BPN (11/1/77)
University Drive	6/28	5	65	58
PA-45	6/28	15	59	58
PA-871	6/28	105	71	77
US-322	6/28	30	64	57
PA-26N	7/27	44	70	66
PA-26S	7/27	44	82	84

Note: 1 μm = 0.039 × 10^{-3} in.

Pavement Polishing

The British portable tester (ASTM E 303) was used to take measurements on the test sections in the wheel path and outside the wheel path next to the shoulder. The location out of the wheel path was then polished by using the Penn State portable pavement polisher (6) and water and silica abrasives of varying gradations to aid in the polishing process. Generally, 3000 cycles of the polisher were used. After polishing, the British portable number (BPN) was measured again, and the change from the prepolished number was observed. In addition, the BPN on the polished surface was compared with the BPN taken in the adjacent wheel path. The size of abrasive that caused the polished surface to attain a BPN close to that measured in the wheel path was assumed to be the abrasive closest in gradation or effect to the road dust that was causing the polishing by tires in the wheel path.

Abrasive sizes found in 1976 to produce polished-pavement BPNs close to those caused by tire polishing in the wheel path were retested on June 28, 1977. The abrasive sizes and their results are given in Table 2, where the BPN of the polished pavement in June is compared with the BPN measured on November 1, 1977, in the wheel path. The BPN of the polished pavement was used to predict terminal polish by traffic, which was assumed to have been reached by November 1.

Road Contamination

The friction characteristics of the road surface vary throughout the year because of factors such as pavement polishing and wear, amount of precipitation, and road-surface contamination. The size of contamination particles is mostly in the microtexture range, and they provide a form of lubrication for the road surface by preventing intimate tire-pavement contact. During rainfall, the action of water escaping from the tire-pavement interface causes a cleansing of the road surface. This cleansing washes away the fine dust created by road polishing and, soon after a heavy rainfall, increases the skid resistance of the road surface.

To determine the nature of pavement contamination, a vehicle-mounted device was designed and constructed to collect the loose contamination particles and classify them according to size. In 1977, the particles were collected daily, weather and equipment permitting, during the last week in September and through the month of October. The vacuum device was attached to the front bumper of the PTI road-friction tester. Collection was carried out in the inner wheel track of a 150-m (500-ft) section of the PA-45 test pavement, on which daily skid tests were conducted. The dust-collection data are given in Table 3.

Before the dust collection started, four impaction collection filters, a backup filter, and a preseparator cup were weighed to the nearest 10 000 th of a gram on a Mettler balance. After they were weighed, the filters were placed in the cascade impactor, and the collection device was assembled on the truck. The speed was maintained at 20 km/h (12.5 mph) through the test area. At the end of the test section, the impactor was removed from the bumper and stored in the truck. The impactor was then taken to the laboratory, where the filters and preseparator were weighed.

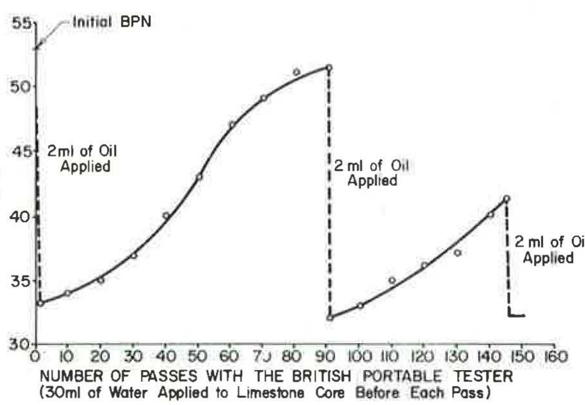
In addition to loose particulate contamination, which can be removed and analyzed, there were oils or lubricants, which cannot be easily removed. The effect of oils was investigated in the laboratory by using the British portable tester. A small amount [2 ml (0.0005 gal)] was applied to a Society of Automotive Engineers

Table 3. Data on 1977 dust collection on PA-45.

	Weight (g)						
Date	Preseparation Stage	First Stage	Second Stage	Third Stage	Fourth Stage	Backup	SN_0
9/21	0	0.087	0.030	0.028	0.007	0.021	58.7
9/29	0	0.147	0.049	0.034	0.007	0.061	53.2
9/30	0	0.115	0.056	0.033	0.011	0.035	58.8
10/3	0.27	0.101	0.033	0.025	0.007	0.028	58.5
10/4	0.518	0.140	0.048	0.025	0.009	0.043	53.6
10/5	0.314	0.122	0.036	0.022	0.007	0.027	54.6
10/7	0.525	0.104	0.033	0.021	0.006	0.029	58.6
10/10	1.545	0.189	0.046	0.038	0.010	0.041	53.2
10/11	0.491	0.049	0.025	0.014	0.003	0.016	60.6
10/12	1.481	0.181	0.053	0.027	0.009	0.038	52.5
10/13	0.696	0.154	0.052	0.033	0.014	0.029	52.2
10/14	0.188	0.066	0.027	0.022	0.009	0.011	60.3
10/17	0.320	0.050	0.032	0.016	0.007	0.025	61.4
10/18	0.451	0.051	0.030	0.018	0.014	0.023	59.7
10/21	0.602	0.126	0.052	0.033	0.010	0.033	55.9
10/24	1.014	0.239	0.083	0.052	0.033	0.058	54.4
10/25	0.782	0.254	0.080	0.050	0.015	0.052	54.2
10/26	0.486	0.213	0.073	0.046	0.011	0.032	53.5
10/28	0.249	0.082	0.032	0.018	0.007	0.013	56.7
10/31	0.195	0.109	0.049	0.023	0.009	0.015	56.2
11/2	0.211	0.092	0.022	0.013	0.003	0.011	60.1
11/14	0.471	0.296	0.091	0.048	0.014	0.051	53.7

Note: Particle sizes = preseparation stage, 50 μm; first stage, 7-50 μm; second stage, 3.3-7 μm; third stage, 2-3.3 μm; fourth stage, 1-2 μm; backup, $\ll$1.1 μm.

Figure 8. Effects of SAE 30 oil on BPN.



SAE 30 oil of 150-mm (6-in) diameter core sample, which dramatically reduced the BPN. Subsequent repeated tests were made until the oil was removed by the action of the slider and water. Reapplication of oil reproduced the low value. The results of the experiment are shown in Figure 8.

By cleaning the surface and by "conditioning" the slider when BPN is measured in accordance with ASTM E 303, the effects of contaminants can be eliminated. During the 1978 season, British pendulum tests were conducted on a monthly schedule, and the values obtained before the cleaning and conditioning of the pavement were also recorded. Only "clean" BPN values are available for 1976 and 1977. One would expect them to be related to the skid resistance of the clean pavement after a rainfall. To test this hypothesis, the mid-summer high levels of SN_0 for each pavement were noted from the data in Figure 4. These high levels were reached after rainfall during the months after the pavements were polished to a stable level. The BPN data from September 1977 and the high-level SN_0 data for the seven test sites are correlated in Figure 9. A high coefficient of correlation (r = 0.97) was obtained.

Temperature Effects

To investigate the effects of temperature, a test was performed in September 1976 in which the skid resistance

Figure 9. High-level SN_0 versus September BPN for 1977.

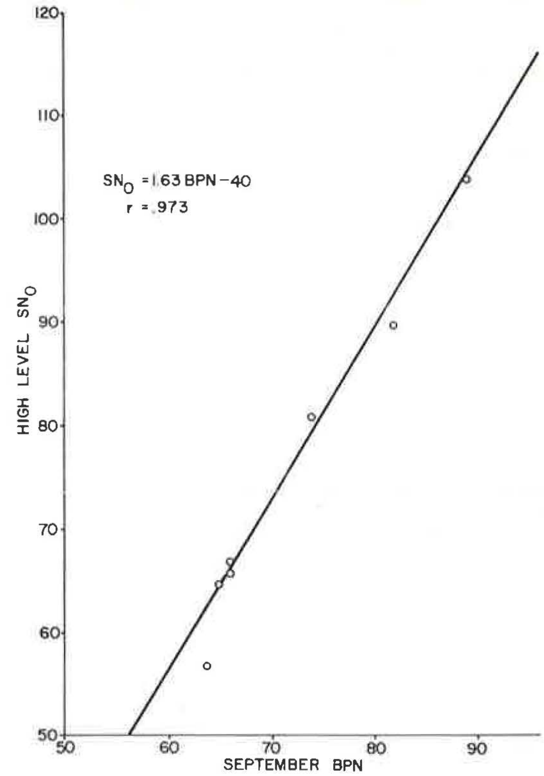
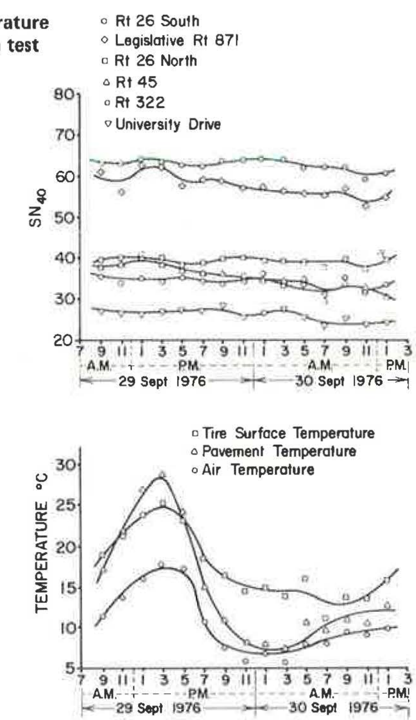


Figure 10. Temperature effects of SN_{40} on test surfaces.



of each test surface was measured every 2 h for a period of 30 h. During such a short period of time, the only major test parameters that are expected to change significantly are the temperatures of the air, the pavement, and the tire. Air, pavement, and tire temperatures measured during this test are shown in Figure 10. The pavement shows a temperature variation of about 22°C (40°F); the air and tire temperatures vary by about 11°C (20°F). But the skid resistance (also plotted in Figure 10) shows a very slight, insignificant variation. From these results it may be concluded that temperature variations of the magnitude experienced in the tests do not significantly affect skid-resistance measurements.

CONCLUSIONS

Based on the findings of the first two years of the test program, the following preliminary conclusions have been reached.

1. Significant variations in the skid resistance of pavement surfaces (15 to 30 SNs) occur in Pennsylvania from one season to another, particularly as the seasons change from early fall to late fall and from early spring to late spring. Periods of cold, rainy, and snowy weather improve skid resistance, whereas warm, dry periods reduce the friction characteristics of the surface. The zero-speed skid-number intercept SN_0, which is related to microtexture, appears to be highest in early spring and to decrease gradually to a stable level by mid-July, after which its level remains fairly constant until the next cold, snowy season starts in late November or early December. This behavior would indicate that the test pavements reach a stable level of polishing by July.
2. Within any season, particularly within the period from April to December, daily or weekly variations in skid resistance of as much as 25 percent occur according to changes in rainfall. Higher skid numbers follow an abundance of rainfall whether traffic is heavy or light. In addition, the greatest changes appear to be caused by the amount and/or the duration of rainfall immediately before a measurement. The proposed WRF appears promising as a predictor of short-term cycles.
3. Temperature changes within short periods—e.g., within 30 h—appear to have little or no effect on pavement skid resistance.
4. Minor changes in the macrotexture may occur from one season to the next, but on stable pavements (three years or older) these changes and their effects appear to be negligible.
5. Surfaces made from aggregates that exhibit differential wear (sandstone gravel, for example) exhibit relatively small variations in skid resistance. Surfaces made from polish-susceptible aggregates such as limestones and dolomites undergo pronounced seasonal and short-term, rain-related variations in skid resistance.
6. BPN values are strongly correlated with values of the zero-speed skid-resistance intercept SN_0 measured after periods of rain. It is believed that the BPN conditioning procedure (ASTM E 303) produces data that correspond to the clean condition of the pavement.

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The contents of this paper reflect our views, and we are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Pennsylvania Department of Transportation or the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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