Use of Smooth-Treaded Test Tire in Evaluating Skid Resistance

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Since its first use in the 1960s, the locked-wheel skid testers have used the ribbed (ASTM E501) rather than the smooth (ASTM E524) tire. The early history of the ASTM E274 locked-wheel testers is discussed, and reasons the ribbed tire was originally the standard tire are explained. The use of smooth versus ribbed tires is also examined. First the effect of film thickness on the two tires is reviewed; then the use of each or both tires is discussed in the evaluation of accident data. Finally, the relationship of skid measurement using one or both tires with texture is reviewed. It is concluded that both current research and current use would recommend that the use of both tires produces the best data; however, if a single tire is to be used, then the smooth tire would be recommended because it gives more-useful data than the ribbed tire.

Since the early 1960s, the locked-wheel skid tester has been the predominant instrument in the United States for evaluating pavements for their skid resistance under wet conditions. The publication of the ASTM Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire in 1965 further encouraged the adoption of the locked-wheel method in the United States as well as other countries (ASTM E274-70, ASTM E274-90).

The original ASTM standard specified the use of a bias-ply test tire with five circumferential ribs (ASTM E249-66). The standard for the tire preceded the standard for the test method, because the standard tire had been developed for and used on a two-wheel trailer on which both wheels were locked and the hitch force was measured (*1*). The lateral stability problem resulting from locking both wheels on the trailer was alleviated to some degree when a ribbed test tire was used. In 1961, the development of torque-measuring locked-wheel trailers in California and Tennessee allowed locking only one of the wheels and was a forerunner of the system described in the E274 standard.

In developing the standard for the test tire, the sensitivity to water flow rate was also a concern. It was noted that the ribbed tire was less sensitive to water flow rate than a smooth tire, hence the data would be more reproducible with unsophisticated water delivery systems. The NCHRP report on the correlation and calibration of skid testers concluded: "The ribbed tire, because of its lesser sensitivity to water-film thickness, is therefore the preferred choice for skid-resistance measurement, which ideally is insensitive to all operational factors" (*2*).

The tolerance on water flow rate was large: 3.6 ± 10 percent gal/min/in. of wetted width at 40 mph. The corresponding equivalent water film thickness is 0.023 in. Because the water flow rate is specified to be directly proportional to speed, the effective water film thickness should be independent of speed. However, the effective water film thickness is somewhat artificial because the water is not deposited in a uniform sheet, as anyone who has observed a skid test would know.

In 1973 the E249 tire was superseded by a seven-ribbed bias-belted tire (ASTM E501-88). The nominal water flow rate was increased slightly, but the tolerance remained 4.0 ± 10 percent gal/min/in. of wetted width. This corresponds to an effective water film thickness of 0.025 in.

In 1975 the standard for a smooth-tread companion to the E501 tire was developed and issued as the Standard Specification for Standard Smooth-Tread Tire for Special-Purpose Pavement Skid-Resistance Tests (ASTM E524). In 1988 its name was amended to Standard Specification for Standard Smooth Tire for Pavement Skid-Resistance Tests. In 1990 the E274 standard was amended and the E501 and E524 were given equal status, whereas previous versions of the standard had referred to the smooth tire as used in "alternative testing for special purposes." The current version, E274-90, also specifies that the data be reported as SN40R for a 40-mph test with the ribbed E501 tire and as SN40S for a 40-mph test with the smooth E524 tire.

This background demonstrates the increased awareness that the smooth tire has significant advantages for skid testing. As stated earlier, the ribbed tire is less sensitive to water film thickness and therefore is insensitive to macrotexture while being mostly sensitive to microtexture. In the past, some agencies were reluctant to use the smooth tire, stating that their skid numbers would be lower. Another reason for resistance was that the historical data are important, and changing to a smooth tire would produce data that could not be compared with the histories of pavement performance. At present, as a result of voluntary consensus through the ASTM procedures, the two tires have equal standing. Both tires have their merits in the evaluation of skid resistance, but the information they provide must be interpreted correctly. The use of both tires provides the most information; however, if only one tire is to be used, experience has shown that the smooth tire should be used because of its equal sensitivity to micro- and macrotexture.

SKID RESISTANCE AND ACCIDENT DATA

It has long been argued that the smooth tire produces more-significant results for evaluating wet pavement safety. Early attempts to relate accident data to skid resistance measured

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with a ribbed tire were frustrating. Rizenbergs et al., using accident data from Kentucky, plotted the ratio of wet- to dry-accident frequency against skid number (Figure 1;*3*). It is evident from this plot that there is no direct correlation between this measure of wet pavement safety and skid number measured with the ribbed tire.

During the late 1970s after the smooth-tread tire standard was issued, there was increased interest in its use for skid resistance surveys, particularly with respect to its relationship to accidents. In Connecticut one study included an inventory survey along Route 15 (*4*). This study reported that "a good correspondence between low smooth-tire skid numbers and accident experience can be seen" and that "ribbed-tire correspondence was quite poor." It was concluded that areas that had smooth-tire skid numbers (SN40S) greater than 25 were areas where no wet skidding accidents occurred, but that there was no corresponding cutoff in terms of the ribbed-tire skid numbers (SN40R).

In 1984 the Florida Department of Transportation began collecting smooth- and ribbed-tread tire data at wet-accident sites (L. Hewlett and G. C. Page, unpublished report). It reported the data for two categories: pavements having more than 50 percent of accidents in wet weather and pavements having less than 25 percent. Pavements having between 25 and 50 percent were not reported. These data are tabulated in Table 1 and plotted in Figure 2. Referring to Table 1, note that the normalized separation of the means for the smooth tire is nearly twice that of the ribbed tire, where the normalized separation of the means is defined here as

$$\Delta m = (X_{\text{high}} - X_{\text{low}})/{}^1\!/_2(X_{\text{high}} + X_{\text{low}}) \qquad (1)$$

where X_{high} is the mean value of the high-accident skid numbers and X_{low} is the mean value of the low-accident skid numbers. This is a measure of the difference of the ability of the two data sets to distinguish between the high-accident population and the low-accident population. The values are .63 for the smooth tire data and .33 for the ribbed tire data. Therefore, the smooth tire sees a much greater difference between the high- and low-accident sites.

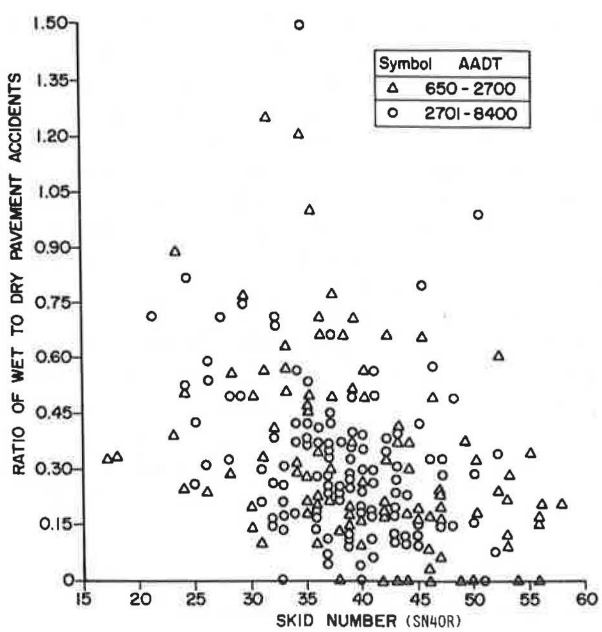

FIGURE 1 Ratio of wet- to dry-pavement accidents versus skid number for a 3-year period in Kentucky (AADT = annual average daily traffic).

A useful way to examine the two-tire data is to plot them as shown in Figure 2, with the SN40S on the vertical axis and the SN40R on the horizontal axis. The data for most of the sites will fall below the line of equality, because the smooth-tire skid numbers are usually lower than the ribbed-tire numbers. However, this is not always true, particularly when the macrotexture is very high and the microtexture is low, which happens when the texture depth is good but the aggregate is polished. The data close to the line of equality generally have good macrotexture. The significance of the data with respect to texture is discussed further.

It is noteworthy that the level on the vertical axis that separates most of the high wet-accident rate sites from the low wet-accident rate sites is 25. In other words, sites with an SN40S greater than 25 are low wet-accident sites, and sites with an SN40S less than 25 are high wet-accident sites. No value on the horizontal axis separates the high- and low-accident sites, which means that one cannot select a level of SN40R that separates the high- and low-accident sites.

A project was conducted in Pennsylvania from 1981 through 1983 to collect data at wet-accident sites using the two tires (*5*). The project team was notified of all wet-weather accidents by local police agencies in selected communities in central Pennsylvania. The sites were tested with both tires within 2 days after the accidents. The data set included 79 sites, 21 of which had multiple accidents. At the time the accident sites were tested, control sites no more than 1.6 km (1 mi) from the accident site were also tested. The data for the accident sites were compared with the data from the control sites. The results were not enlightening, because the skid resistances of the control sites were not significantly different from the accident sites with either tire. The control sites had, on average, a skid resistance of only about 2 skid numbers (SN) higher than the accident sites for both the smooth and ribbed tires. This experiment demonstrates the difficulty of working with accident data, because many factors other than skid resistance should be considered in an analysis of wet accidents. Although the data were not statistically significant, the trends were consistent with other experiences indicating a slightly higher sensitivity of the blank tire to distinguish high-accident sites.

Wet-pavement accidents are caused by complex interactions among many roadway, vehicle, human, and environmental factors. Accidents also occur because of unpredictable factors such as inattentiveness, misjudgment, recklessness, and random variables such as unforeseeable events or obstacles. In a research project for Pennsylvania (*6*), various models were developed to determine a relationship between wet-weather accidents involving injuries or fatalities and

- Total number of accidents,
- Skid number (SNR only),
- Rutting,
- Roughness,
- Surface type and age,
- Posted speed limit,

TABLE 1 SKID NUMBERS MEASURED AT ACCIDENT SITES IN FLORIDA (*10*)

PVT. TYPE ACC. RATE	DENSE GRADED GREATER THAN 50%		FLORIDA DATA DENSE GRADED LESS THAN 25%		OPEN GRADED LESS THAN 25%	
SKID NO.	SN40S	SN40R	SN40S	SN40R	SN40S	SN40R
	33.5	43.5	48.5	49.0	36.5	39.0
	30.5	41.5	47.0	57.0	36.5	37.0
	27.5	22.0	42.5	51.0	35.5	39.0
	27.5	20.5	41.5	51.5	35.5	35.5
	26.5	32.0	40.0	46.0	35.5	34.5
	23.5	28.5	38.5	51.0	34.5	35.5
	21.5	38.0	37.5	50.0	34.5	33.5
	20.5	40.5	37.5	46.0	33.5	37.0
	19.5	38.5	35.5	43.5	33.5	34.5
	19.5	30.5	35.5	46.0	30.0	33.0
	19.5	28.0	34.5	41.5	30.0	31.0
	14.5	33.5	34.5	51.5	28.0	31.0
	14.5	29.0	32.5	46.0	28.0	29.5
	14.5	27.0	32.5	40.5		
	13.5	34.0	31.5	42.0		
	13.5	33.0	30.5	43.5		
	13.5	24.0	30.5	39.5		
	13.5	20.5	30.0	46.5		
	12.5	35.0	29.0	45.5		
	12.5	33.0	27.0	45.5		
	12.5	27.0	26.0	45.5		
	12.5	22.0	25.0	40.5		
	12.5	20.0	25.0	41.5		
	11.5	31.0	25.0	42.5		
	10.5	26.0	23.0	45.0		
	10.5	29.5				
	9.0	27.0				
MEAN	17.4	30.2	33.6	45.9	33.2	34.6
STD. DEV.	6.8	6.6	6.9	4.3	3.1	3.0
COMBINED DATA FOR LESS THAN 25%				SN40S	SN40R	
MEAN				33.5	42.1	
STD. DEV.				5.8	6.7	

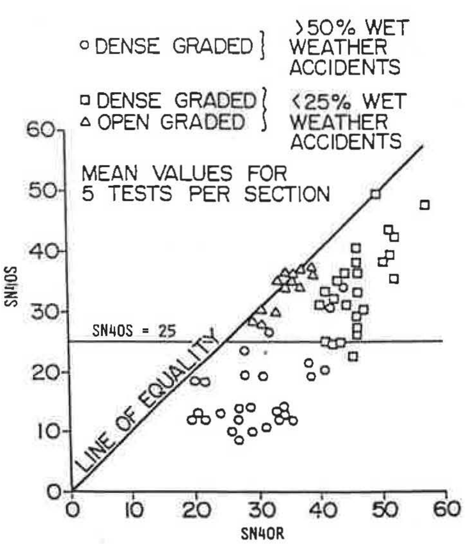

FIGURE 2 Skid numbers SN40R and SN40S measured at accident sites in Florida; mean values for five tests per section.

- Percentage wet time,
- Horizontal curvature,
- Vertical alignment, and
- Driving difficulty (number of signals, turn lanes, cross-roads, land use, etc.).

Stepwise regression reduced the independent variables to two: driving difficulty index (DDI) and SNR, where

$$DDI = 1/3 * (\text{curvature} + \text{grade} + \text{driving difficulty}) \quad (2)$$

However, the regression coefficients found in the Pennsylvania Department of Transportation study for 308 sites were found to be 14.4 for the DDI, compared with 0.62 for the SNR. This relative insignificance of the treaded-tire skid resistance data in accident prediction is not surprising. Unfortunately, smooth-tire data were not available for this study; it would be interesting to conduct a similar study for which both ribbed- and smooth-tire data were available.

EFFECT OF WATER FILM THICKNESS ON SKID NUMBERS

As noted, the concern that variations in water flow rates through the nozzle of a skid tester may cause excessive var-

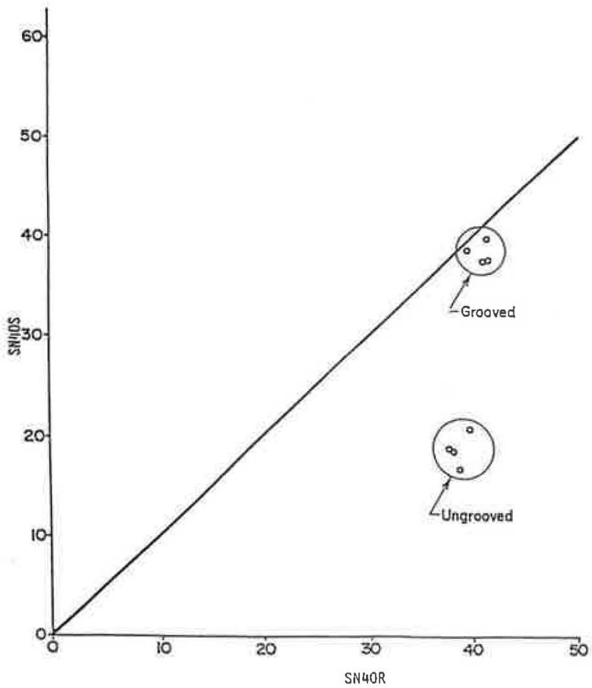

FIGURE 3 Skid numbers of grooved and ungrooved PCC pavements [test speed = 65 km/hr (40 mph)].

iations in skid number was one consideration that led to the selection of the ribbed test tire. Another consideration in the selection of the test tire was that the tire have little sensitivity to temperature. This consideration was well founded, and a compound that produces little variation over a wide temperature range was specified. The ribs of the test tire provide a significant path for water to escape from the interface between the pavement and the tire sliding over it. The additional drainage path provided by the pavement macrotexture is fairly small, even for pavements with high levels of macrotexture.

An example of the ability of the ribbed tire to mask the benefits of macrotexture is its recognized inability to distinguish between longitudinally grooved and ungrooved portland cement concrete (PCC) pavements. If ribbed-tire skid numbers were the meaningful measure of safety, no longitudinal grooving would be performed. A study of four sites on Interstate 80 in Pennsylvania shows this effect well (*7*). Longitudinal grooving was done over sections several miles long, leaving ungrooved sections that otherwise had similar characteristics. Measurements were made with both tires at the grooved and ungrooved sections. The results are shown in Figure 3, in which the data are plotted on the SN40S/SN40R coordinates. Note that there is no significant difference in the ribbed-tire data, whereas the smooth-tire skid numbers of the grooved sections are more than twice as high as those for the ungrooved sections. An idealized cross section of the tire-pavement interface is shown in Figure 4, using the grooving geometry and the tire design geometry. Note that even when the test tire is fully worn, it provides as much drainage capacity as the grooves.

In the NCHRP study on the correlation and calibration of skid testers, tests were performed on one coarse-textured surface with varying amounts of water flow corresponding to effective film thicknesses ranging from 0.005 to 0.030 in. (*2*). Neither the new nor the worn ribbed test tire showed the effect of water film thickness between 0.020 and 0.030 in., so the choice of the effective water film thickness of 0.025 in. was reinforced. This corresponds to a flow rate of 4.0 gal/min/in. of wetted width, which is the nominal value for the E274 standard. It was also noted that the smooth tire decreased significantly over the range of water film thickness of the test, as shown in Figure 5.

To further address the concern that the smooth tire might be too sensitive to water film thickness to provide reliable data, a study with conducted at the Pennsylvania Transportation Institute in 1981 (*8*). The water flow rate delivered through the skid tester nozzle was varied from 7.5 to 22.5 m^3/hr (30 to 100 gal/min). This corresponds to 3.7 to 12.5 gal/min/in. of wetted width, while E274-90 requires 4 ± 10 percent gal/min/in. of wetted width. Four sites were measured with both tires at three water flow rates. The results shown in Figure 6 indicate that the smooth tire is definitely more sensitive to water flow than the ribbed tire is. However, the insensitivity of the ribbed tire to the water flow further shows that the tire can handle excessive amounts of water with relatively little effect on the skid number regardless of the level of macrotexture.

Another difficulty in the use of a treaded test tire is that variations due to tread depth over the useful life of the tire must be insignificant. One could argue that the test tire should have a tread depth so large that as it reaches its wear limit it still has a tread depth large enough so that it does not affect the measurement. In fact, in a study comparing the test tires with a new commercial tire of the same size and construction, the ribbed tire produced higher friction than the new commercial passenger-car tire (*9*). For the commercial tire worn to the legal limit, it was hypothesized that its performance would degrade toward the smooth-tire performance.

If reasonable care is exerted to control the water flow rates of a skid tester, the effect on SN40S data is not a problem. The largest effect in the data in Figure 6 is 1 SN/10 gal/min. Therefore, using the tolerance required in the ASTM E274 test method, the resulting variation is only ± 0.3 SN.

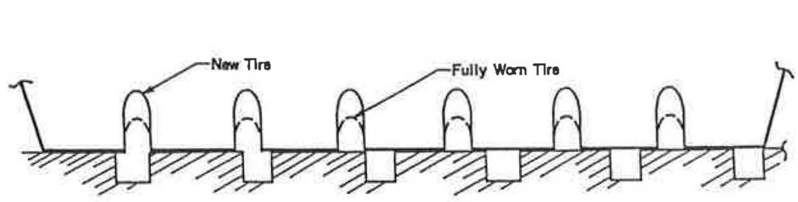

FIGURE 4 Idealized geometry of interface between ribbed tire and grooved PCC pavement (0.65- × -0.65-mm grooves on 25-mm spacing).

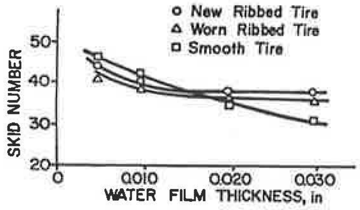

FIGURE 5 Skid resistance with ribbed and smooth tires on coarse-textured bituminous concrete pavement.

RELATIONSHIPS BETWEEN SKID RESISTANCE MEASUREMENTS AND TEXTURE

It is easier to generate meaningful quantitative data for texture and skid resistance studies than for accident and skid resistance studies. Several recent studies have attempted to develop statistical models relating skid resistance to texture parameters.

An early attempt to relate skid resistance to observations of texture was made in Virginia (*10*). Unfortunately, only qualitative descriptions of the texture of the sites were given, but when the data are plotted on SN40R/SN40S coordinates, the groupings fall into cluster according to the qualitative descriptions (see Figure 7). Note that, with the exception of one data point, the clusters can be separated by levels of

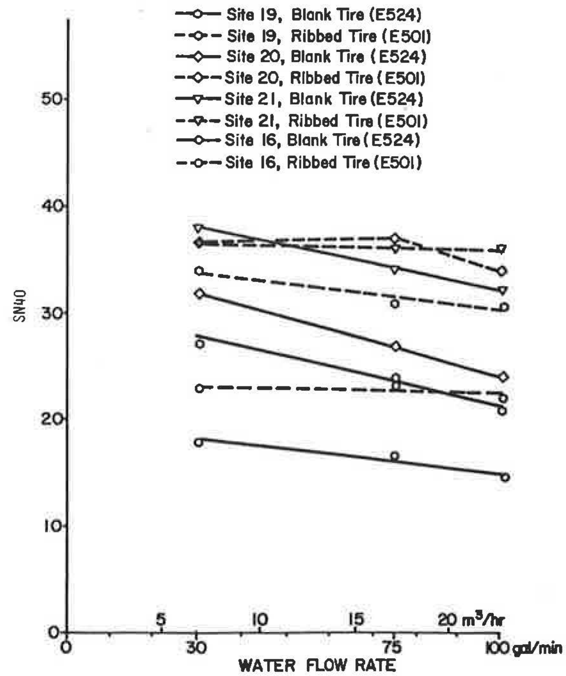

FIGURE 6 Effects of water flow rate on skid resistance measurements.

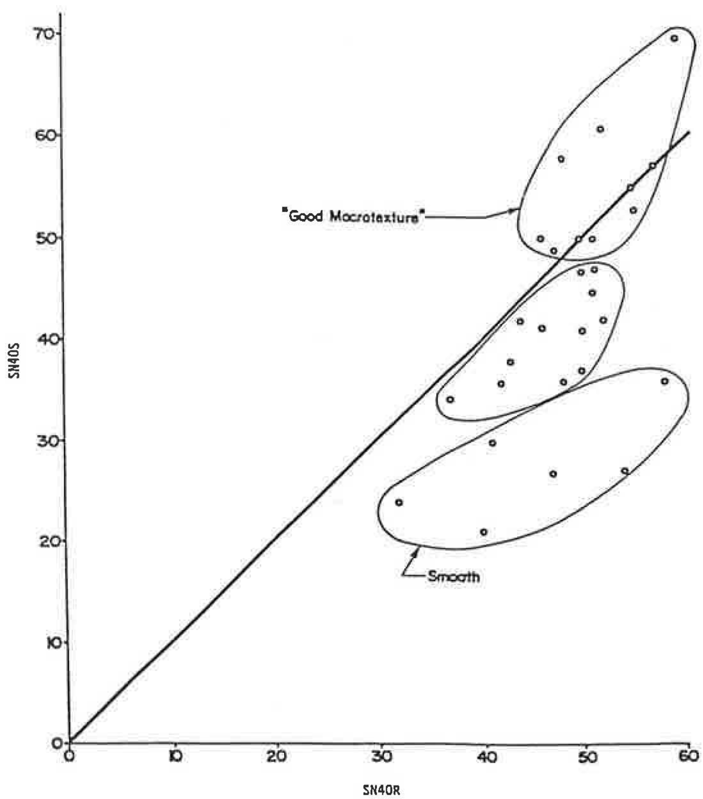

FIGURE 7 Skid numbers for sites in Virginia [test speed = 65 km/hr (40 mph)].

SN40S. The "good macrotexture" sites are above 47, and the "smooth" sites are below 30.

Data from a Pennsylvania study conducted from 1978 through 1979 included both skid resistance with the two tires as well as pavement texture measurements (*7*). The texture data were sandpatch mean texture depth (MTD) and British pendulum numbers (BPN), which serves as a surrogate for microtexture. The data are presented in Table 2. Initially, 23 sites were included in the study, which began in the fall of 1978. Two of the sites (20 and 23) were dropped from the study early in the program because they were too inhomogeneous. Sites 5 and 6 were severely damaged by winter maintenance and were replaced by Sites 24 and 25 in spring 1979. With these exceptions, the same sites were used in the fall of 1978 and the spring of 1980. Figures 8 and 9 are plots of the data showing the site number, MTD, and BPN data for each point.

Linear multiple regressions were run with the skid numbers as dependent variables and MTD and BPN as the independent variables. For the spring and the fall data sets, the improvement resulting from including the MTD in the regression for SN40R was negligible. For the SN40S data, however, the MTD and BPN were equally significant. The fall data produced the following results:

$$SN40R = -6.1 + 0.72\ BPN \qquad R^2 = .74 \tag{3}$$

$$SN40S = -20.5 + 0.65\ BPN + 16.4\ MTD \qquad R^2 = .82 \tag{4}$$

where MTD is expressed in millimeters. The spring data produced higher correlation coefficients:

$$SN40R = -10.5 + 0.83\ BPN \qquad R^2 = .90 \tag{5}$$

$$SN40S = -16.9 + 0.54\ BPN + 19.6\ MTD \qquad R^2 = .91 \tag{6}$$

Although the intercepts and the coefficients of BPN and MTD are different for the two data sets, they are similar in magnitude. The excellent correlation coefficients, especially of the spring 1979 data, confirm the insensitivity of the ribbed tire to macrotexture and the approximately equal sensitivity of the smooth tire to the macro- and microtexture.

The skid resistance data may also be used to predict macro- and microtexture from skid resistance measurements by performing regressions for BPN and MTD as the independent variables and SN40S and SN40R as the independent variables.

$$MTD = 0.59 - 0.036\ SN40R + 0.053\ SN40S \qquad R^2 = .86 \tag{7}$$

$$BPN = 10.33 + 1.62\ SN40R - 0.49\ SN40S \qquad R^2 = .93 \tag{8}$$

TABLE 2 SKID NUMBERS MEASURED AT ACCIDENT SITES IN PENNSYLVANIA

	FALL 1978				SPRING 1979						
SITE	SNR	SNB	MTD (mm)	BPN	SNR	SNB	MTD (mm)	BPN	CONSTRUCTED	TYPE	ADT
1	32.4	22.8	0.41	50.7	31.7	22.7	0.36	46.3	1970	DG	6630
2	28.2	19.0	0.36	59.0	27.4	14.7	0.41	51.7	1950	PCC	7700
3	49.4	28.4	0.33	69.9	38.0	19.7	0.38	68.1	1973	PCC	3640
4	39.4	25.6	0.30	58.7	35.0	23.3	0.33	50.1	1972	DG	3640
5	53.0	56.0	1.30	86.0					1976	OG	7700
6	52.5	42.5	0.56	81.1					1976	DG	7700
7	48.5	27.2	0.41	70.4	40.4	23.4	0.38	64.0	1973	PCC	1820
8	46.2	44.2	0.74	59.3	32.2	26.7	0.71	52.0	1972	DG	1820
9	52.2	46.8	0.69	66.0	43.2	34.6	0.79	56.9	1972	DG	1710
10	48.4	26.2	0.36	73.0	43.2	22.7	0.33	70.1	1973	PCC	1710
11	30.2	21.6	0.36	59.9	27.3	18.8	0.48	47.8	1963	DG	4490
12	39.8	34.8	1.02	67.7	40.6	31.0	0.79	57.6	1970	DG	4490
13	60.0	61.4	1.04	94.2	64.5	60.7	1.32	88.7	1969	OG	7920
14	37.0	24.8	0.41	63.8	37.9	21.4	0.46	61.1	1967	PCC	8770
15	62.6	61.6	1.30	96.9	68.6	62.2	1.37	86.6	1969	OG	7920
16	25.4	17.8	0.66	55.5	24.1	14.7	0.58	44.1	1966	DG	6500
17	35.8	33.0	1.02	58.0	35.4	29.4	1.12	50.0	1961	DG	800
18	50.6	37.8	0.51	69.5	47.6	34.0	0.53	67.0	1973	PCC	1200
19	37.4	26.6	0.43	63.0	30.3	19.5	0.51	49.1	1968	DG	7000
21	36.2	36.6	1.24	70.0	36.2	32.3	1.22	53.2	1969	OG	2500
22	57.6	61.4	1.40	87.5	60.2	56.2	1.63	87.7	1969	OG	2500
24					26.1	14.4	0.41	46.2	1963	DG	4490
25					53.8	40.8	0.69	76.7	1969	OG	7920

NOTE: OG = open graded, DG = dense graded, ADT = Average daily traffic, and SNB = skid number for smooth (blank) tire

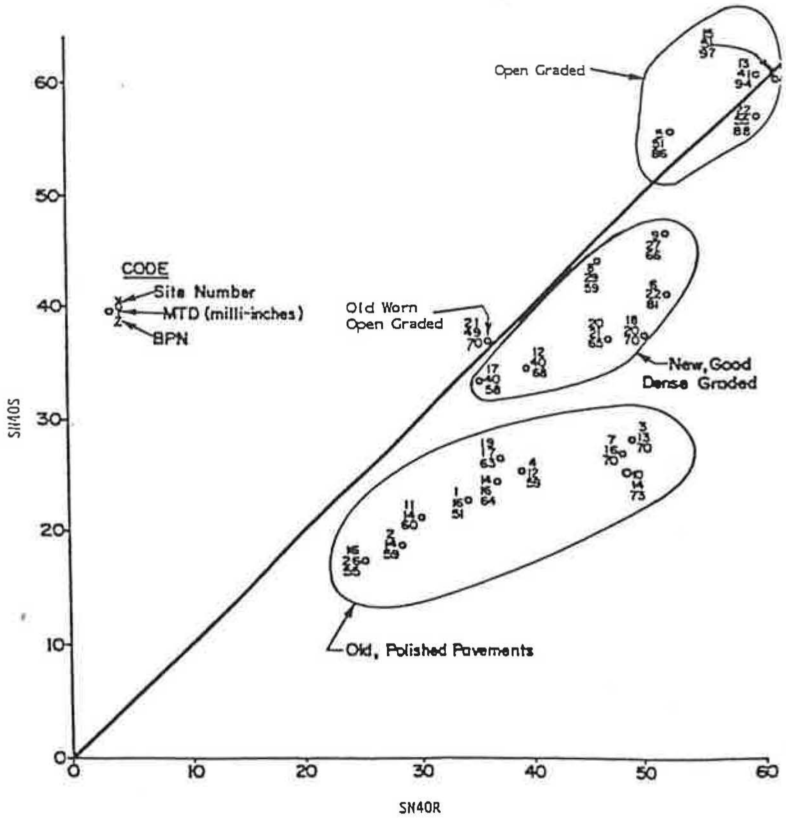

FIGURE 8 Skid numbers and texture for sites in Pennsylvania, fall 1978 [test speed = 65 km/hr (40 mph); 1 milli-inch = .0254 mm].

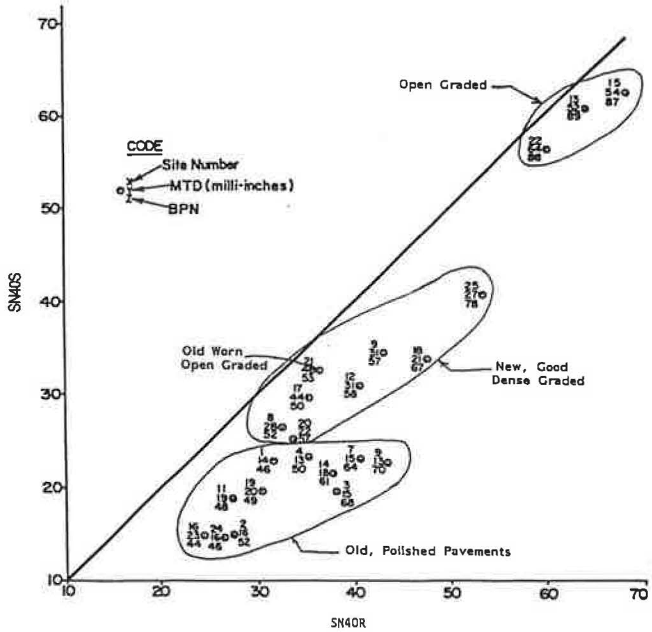

FIGURE 9 Skid numbers and texture for sites in Pennsylvania, spring 1979 [test speed = 65 km/hr (40 mph); 1 milli-inch = .0254 mm].

These results demonstrate that knowledge of skid resistance with both tires enables the investigator of a pavement having low skid resistance to evaluate whether there is a deficiency in macro- or microtexture and can suggest suitable corrective measures.

Using these same data, lines of constant MTD and BPN were mapped onto the SN40R-versus-SN40S plots by Wambold (*11*). From these, he developed acceptance criteria for pavements on the basis of the two skid numbers. Also using these data, Saito and Henry regressed the ratio of the two skid numbers with MTD (*8*). The results produced a high coefficient of correlation:

$$SN40S/SN40R = 0.887(MTD)^{0.36} \qquad R_2 = 0.94 \qquad (9)$$

or

$$MTD = 1.13(SN40S/SN40R)^{2.78} \qquad (10)$$

A similar study in Illinois, based on a new set of data, showed a relationship between MTD and a "macrotexture index" defined as

$$MTI = (SN40R - SN40S)/(SN40R + SN40S) + 1 \qquad (11)$$

This relationship, when converted to MTD in millimeters, is

$$\begin{aligned} MTD &= 1.02(MTI)^{-3.78} \\ &= 0.074(1 + SN40S/SN40R)^{3.78} \end{aligned} \quad (12)$$

These data agree reasonably well with the Pennsylvania data. Equations 10 and 12 produce the same results at an MTD of about 0.84 mm.

That all of these studies have produced significant correlations between texture and skid resistance data with the two tires suggests that the data produced by both tires are useful in assessing pavement condition. However, the consistent lack of response of the ribbed tire to macrotexture suggests that if only one tire can be used in surveys it should be the smooth tire. This suggests that surveys be conducted with the smooth tire and that sections that produce SN40S values less than a selected level be revisited with the two tires. This would allow for a rational strategy for correcting sites with low skid resistance.

CONCLUSIONS AND RECOMMENDATIONS

The original ASTM E274 standard specified that the E249 five-rib tire be used. In 1973 the E249 tire was replaced with the E501 tire, a seven-rib tire. Since then the E274 standard has changed several times, first stating that the ribbed tire is standard, then stating that the ribbed tire is standard and the smooth tire is allowed, and, in the current version, stating that either tire can be used without indicating a preference.

In research studies over the past decade, it has been shown that the use of both tires provides many more data than does the use of either tire by itself. Relationships of macro- and microtexture are given that would be useful to maintenance personnel in determining the cause of loss of skid resistance and thus what maintenance procedures should be used. Thus measurement with both tires is recommended for project-level surveys.

However, if only one tire is used (as would be the case in a network-level survey), the smooth tire is recommended because it is sensitive to macro- and microtexture whereas the ribbed tire responds primarily to the microtexture. As a result, several states now use the smooth tire for routine measurement.

REFERENCES

1. R. A. Moyer. Skid Resistance Measurements with a New Torque Device. *Bulletin 348*, HRB, National Research Council, Washington, D.C., 1962, pp. 44–77.
2. W. E. Meyer, R. R. Hegmon, and T. D. Gillespie. *NCHRP Report 151: Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques*. TRB, National Research Council, Washington, D.C., 1974.
3. R. L. Rizenbergs, J. L. Burchett, and L. A. Warren. Relation of Accidents and Pavement Friction on Rural Two Lane Roads. In *Transportation Research Record 633*, TRB, National Research Council, Washington, D.C., 1977, pp. 21–27.
4. G. A. Ganung and F. J. Kos. *Wet Weather, High-Hazard Accident Locations: Identification and Evaluation*. Report FHWA-CT-RD-403-F-79-4. Connecticut Department of Transportation, Whethersfield, 1979.
5. J. C. Wambold, J. J. Henry, and R. R. Hegmon. Skid Resistance of Wet-Weather Accident Sites. *ASTM Special Technical Publication 929*, Philadelphia, Pa., 1986, pp. 47–60.
6. B. T. Kulakowski, J. C. Wambold, C. E. Antle, C. Lin, and J. M. Mason. *Development of a Methodology to Identify and Correct Slippery Pavements*. Research Report 88-06. Pennsylvania Department of Transportation, Harrisburg, 1990.
7. J. J. Henry. The Use of Blank and Ribbed Test Tires for Evaluating Wet Pavement Friction. In *Transportation Research Record 788*, TRB, National Research Council, Washington, D.C., 1981, pp. 23–28.
8. K. Saito and J. J. Henry. Skid-Resistance Measurements with Ribbed and Blank Test Tires and Their Relationship to Pavement Texture. In *Transportation Research Record 946*, TRB, National Research Council, Washington, D.C., 1983, pp. 38–43.
9. J. J. Henry. Comparison of the Friction Performance of a Passenger Car Tire and the ASTM Standard Test Tires. *ASTM Special Technical Publication 793*, Philadelphia, Pa., 1983, pp. 219–231.
10. D. C. Mahone. *An Evaluation of the Effects of Tread Depth, Pavement Texture, and Water Film Thickness on Skid Number–Speed Gradients*. Virginia Highway and Transportation Research Council, Charlottesville; FHWA, U.S. Department of Transportation, 1979.
11. J. C. Wambold. Road Characteristics and Skid Testing. In *Transportation Research Record 1196*, TRB, National Research Council, Washington, D.C., 1988, pp. 294–305.

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