Road Characteristics and Skid Testing

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This paper reports the results of many years of skid tests and macrotexture and microtexture measurements as well as newer sets of data obtained during a mini-test conducted in connection with a Federal Highway Administration (FHWA) study to develop a normalization procedure for seasonal effects. The mini-test was concerned mainly with the variation of skid number as a function of placement on the pavement; both lateral and longitudinal placement were examined. It was found that longitudinal placement was not significant if the entire test section was uniform; however, lateral placement is very important, as it can result in the skid numbers differing by more than 10. All of the data available from this mini-test and previous tests were used to correlate macrotexture (*MTD*), microtexture (*BPN*), speed gradient data (SN_0 and *PNG*), and ribbed- and blank-tire skid numbers (SN^R and SN^B). Linear correlations between texture measurements and skid numbers and between speed gradient data and skid numbers were found to be adequate in the normal range of measured skid numbers. Further work is needed before limiting values can be established.

Early in the project, a test plan was developed to study the variation of skid number in both the lateral and longitudinal placement on a test section. The data showed very little variation in the longitudinal direction as long as the entire test section was of the same construction and had no patching.

In the lateral direction, on the other hand, there was considerable variation. Figure 1 shows the variation in *SN* with lateral placement at four sites. Site 2 showed much wear (such as rutting) compared with the others, which is reflected by the *SN*. Site 4 was a fairly new road, while site 1 was a much older road than the rest of the sites. Site 3 is located in a curved section.

Figure 2 shows the variation of microtexture and macrotexture (*BPN* and *MTD*) with lateral placement. The results are similar to those determined from tests conducted in Switzerland (Figure 3) and presented by S. Huschek at a Permanent International Association of Road Congresses meeting (*1*).

It can be concluded that lateral placement is critical and that care must be taken in an ASTM E 274 test to position the test wheel at the lateral location desired (for example, in the center of the left wheel track).

CORRELATIONS

An initial experiment (called a minitest) was conducted to compare the correlation of the skid number (*SN*) from a blank tire (SN^B) with that from a ribbed tire (SN^R) with texture and SN_V (skid number at speed *V*). SN_V is obtained from the following equation:

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$$SN_V = SN_0 \, e^{-PNG/100 \cdot V}$$

where SN_0 and *PNG* are the regression coefficients given below.

Similarly, texture was also correlated to SN_0 and *PNG* and, thus, indirectly, to SN_V. Five sets of data were collected by the Pennsylvania Transportation Institute (PTI) at the test track and at several sites around State College. Two sets were collected by the Texas Transportation Institute (TTI) at its calibration site. Table 1 lists the sites, their locations, and the testing dates. Figure 4 shows ribbed- and blank-tire *SN*s for the test track. The database included test data taken during a previous project at Penn State in the fall of 1978 and spring of 1979, as reported by J. J. Henry (*2*). Mean texture depth (*MTD*) was measured for macrotexture (in milli-inches), and British pendulum number (*BPN*) was the measure for microtexture. All data given for skid number as a function of speed (SN_V) are for the ribbed (ASTM E 501) tire.

SN^B AND SN^R VERSUS TEXTURE

The first correlation was performed for SN^B and SN^R with *MTD* and *BPN*. Linear and nonlinear regressions were performed; in all, thirteen different forms were tried. The three models with the highest correlations and smallest standard deviations are as follows:

Model	R^2	*S*
$BPN = A1 + B1\,SN^R + C1\,(SN^R)^2$	.90	8.3
$BPN = A2 + B2\,SN^B + C2\,SN^R$	.86	9.6
$BPN = A3 + B3\,SN^R$	.87	9.3
$MTD = D1 + E1\,(SN^B/SN^R) + F1\,(SN^B/SN^R)^2$	.88	10.2
$MTD = D2 + E2\,(SN^B - SN^R) + F2\,(SN^B - SN^R)^2$	.84	11.8
$MTD = D3 + E3\,SN^B + F3\,SN^R$	.83	12.4

There were very few differences among these models for either measurement. The following two equations are plotted in Figure 5.

$$BPN = 11.0 - 0.472\,SN^B + 1.59\,SN^R \tag{2}$$

$$MTD = 40.9 + 1.77\,SN^B - 1.20\,SN^R \tag{3}$$

SN^B, SN^R VERSUS SN_V

SN_0 and *PNG* were also correlated with SN^B and SN^R. The results of these regressions suggest the following models:

Model					R^2	*S*
SN_0	=	5.6	+	$1.8\,SN^R - 0.72\,SN^B$	.96	4.7
PNG	=	1.1	+	$0.02\,SN^R - 0.03\,SN^B$	.79	0.3

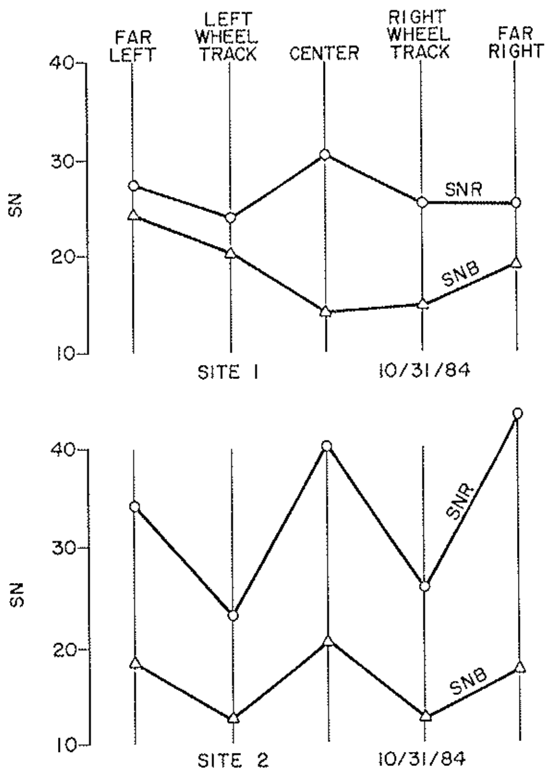

FIGURE 1 Variation in skid number with lateral placement.

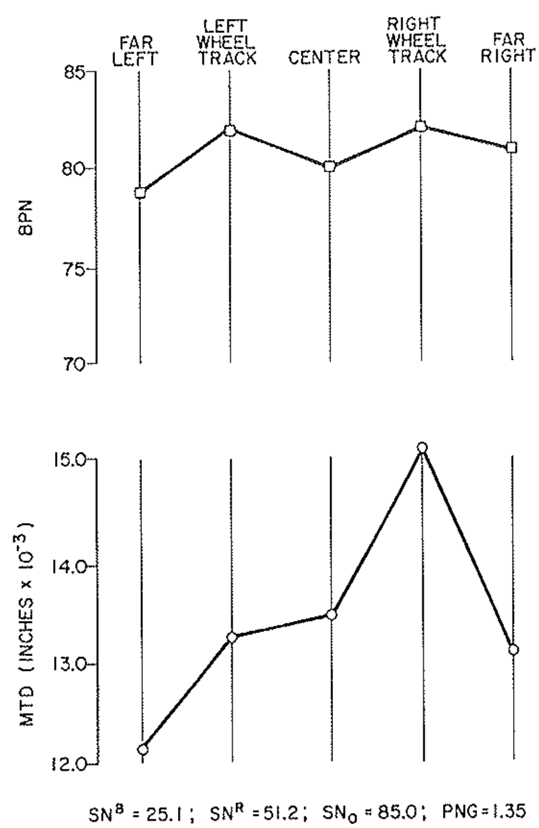

FIGURE 2 Variation in *BPN* and *MTD* with lateral placement.

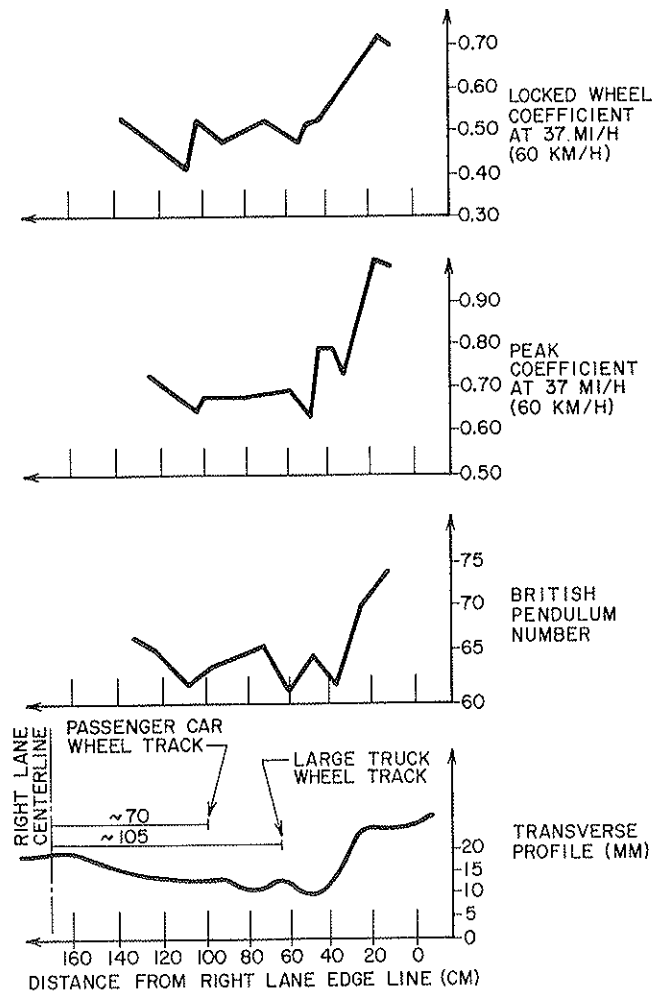

FIGURE 3 Transverse measurements in the right half of the right lane of an 8-yr-old heavily traveled asphalt pavement, PIARC tire, 0.002-in (0.5-mm) water depth (*1*).

These equations are plotted and presented graphically in figure 6. Although the model for *PNG* can be improved to $R^2 = .82$ if $(SN^R)^{1/2}$ and $1/(SN^B)^{1/2}$ are added, there are not enough data points to ensure an improvement. In addition, this change makes the relationship nonlinear.

TEXTURE VERSUS SN_V

A similar set of correlations was performed to establish the relations between SN_0 and *PNG* with *MTD* and *BPN*. The regressions for *PNG* were good, indicating that *MTD* and *PNG* are highly correlated. SN_0 and *BPN* showed high correlations within a given time period and region but not when different times and regions were used. The best regression model for *PNG* follows:

$$PNG = -0.26 = 0.19/\sqrt{MTD}$$

$$R^2 = 0.92, \; S = 0.14 \qquad (4)$$

The regression model for SN_0 gives the following:

$$SN_0 = 9.1 + 0.95\,BPN \qquad R^2 = 0.32, \; S = 17.3 \qquad (5)$$

TABLE 1 SITES FOR MINITEST

Site Number	Date	Location
PS1	8/15/85	Test Track, Section 2
PS2	6/4/86	PA Rt. 45E, between 3/70 and 3/75
PS3	6/4/86	PA Rt. 45W, between 3/75 and 3/70
PS4	5/7/86	Test Track, between 3 and 3.1
PS5	5/12/86	Test Track, between 4.1 and 5.2
TX6	3/27/86	SRS No. 5
TX7	3/31/86	SRS No. 7

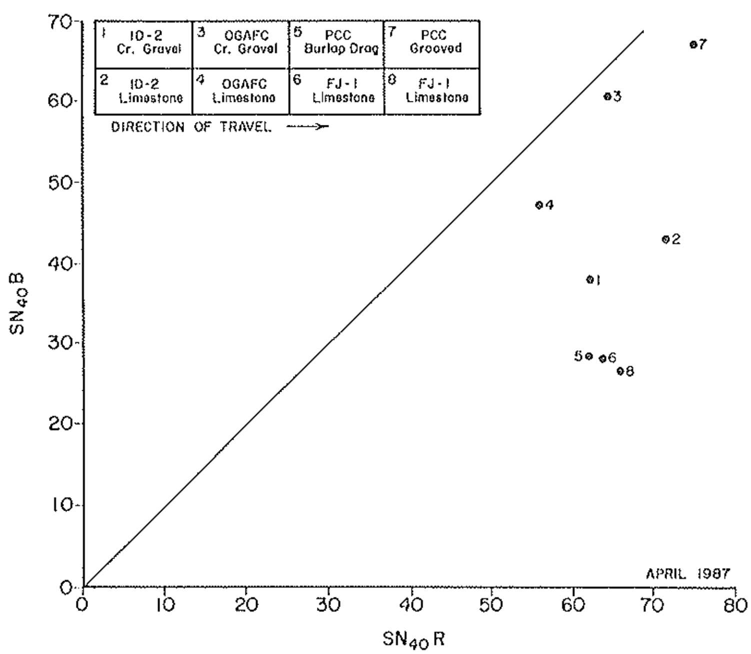

FIGURE 4 PTI skid test facility results.

when all the sites are used. If site PSl (earlier test) and sites TX6 and TX7 (another region) are removed so that all the data are for the same region and time frame, the regression model becomes:

$$SN_0 = -68.4 + 2.41\ BPN \qquad R^2 = 0.98, S = 2.8 \qquad (6)$$

These results lead to the conclusion that, at a given time and place, the two texture parameters (*BPN* and *MTD*) are highly correlated to SN_0 and *PNG*. However, the tire responds to factors other than *BPN* and *MTD*; and, thus, the prediction of *SN* from texture cannot be used for different times and locations. The ribbed- and blank-tire *SN* measurement method does not have this limitation.

SN_0 AND *PNG* MEASUREMENTS

SN_0 and *PNG* are defined by a skid number/speed model referred to as the Penn State Model (*3*). SN_0 is related mainly to microtexture, and *PNG* is related mainly to macrotexture. The model is used to calculate SN_V, the skid number at velocity *V*:

$$SN_V = SN_0\, e^{-PNG/100 \cdot V} \qquad (7)$$

If the logarithm of each side is taken, this relation becomes:

$$\ln SN_V = \ln SN_0 - \frac{PNG}{100} V \qquad (8)$$

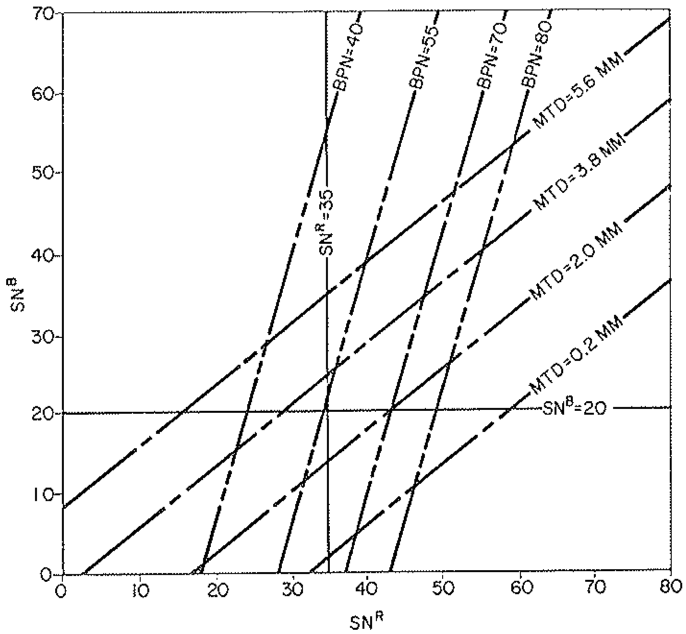

FIGURE 5 Constant SN_0 and PNG versus SN^B and SN^R.

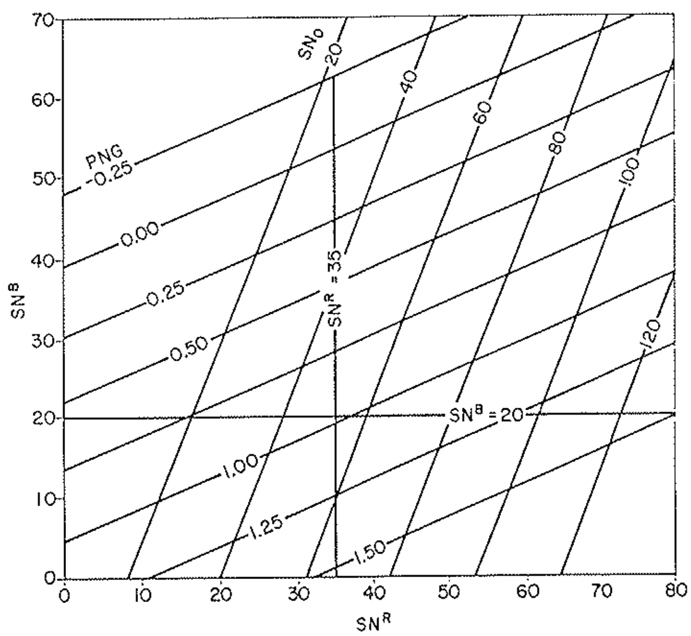

FIGURE 6 Constant SN_0 and PNG versus SN^B and SN^R.

If

$$\ln SN_0 = y,\ \ln SN_0 = A,\ -\frac{PNG}{100} = B,\ \text{and } V = \chi$$

then equation 8 can be written as a linear regression:

$$y = A + B\chi \tag{9}$$

Thus, it is possible to run a skid test at several speeds, perform a linear regression of the ln SN with V, and obtain the constants, A and B, of the regression.

Then

$$SN_0 = \ln^{-1} A \tag{10}$$

$$PNG = -B \times 10^2 \tag{11}$$

Good results can be obtained by performing five skid tests at 30, 40, and 50 mph. If a transient test is run, then the same procedure is used except that SNT20, SNT30, SNT40, and SNT50 for a 50-mph test or SNT20, SNT30, and SNT40 for a 40-mph test are used in place of SN_{20}, SN_{30}, and SN_{40}, where

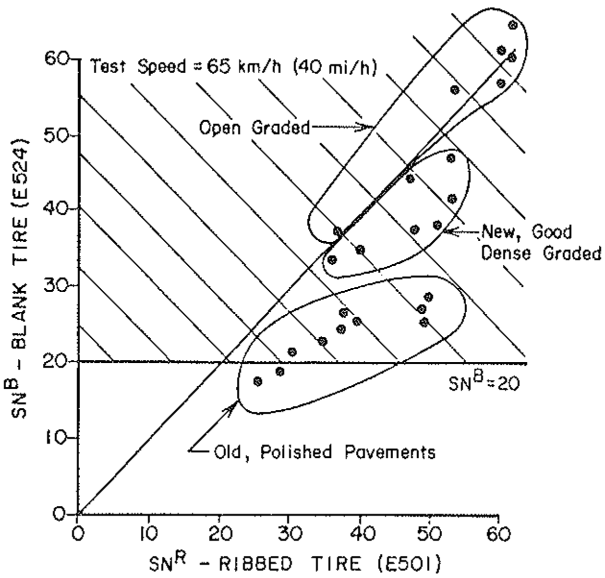

FIGURE 7 Acceptance criteria (shaded area) using blank-tire skid numbers (SN^B_{40}).

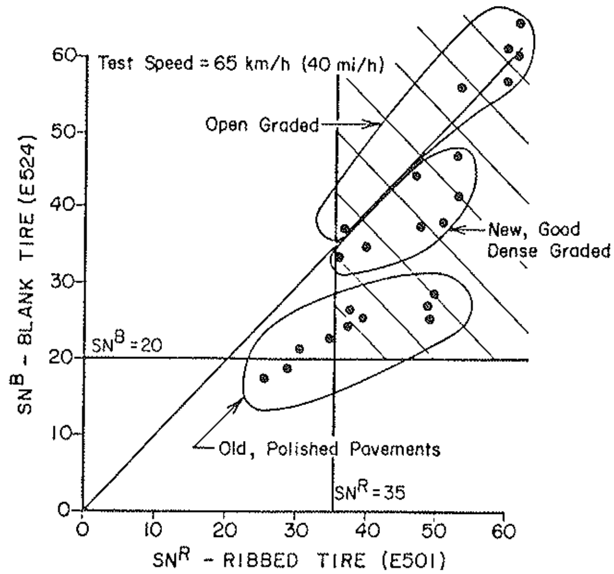

FIGURE 9 Acceptance criteria using both blank- and ribbed-tire skid numbers (SN^B_{40} and SN^R_{40}).

SNTV is the skid number at speed V obtained from a transient test.

SUMMARY

A summary of the relationships developed is given in Figures 7 through 11, which show lines of constant SN_0 and PNG on graphs of SN^B versus SN^R. Also included is a line of constant BPN equal to 55 and a line of constant MTD equal to 0.03 inch. These two values were suggested by Huschek and represent the limits on microtexture and macrotexture (for 55 mph) in Switzerland (*1*). Figures 7 through 11 illustrate various criteria for acceptable pavements. The limits of the acceptable regions, which are superimposed on data from a 1978 study (*2*), are shown only as an example. For instance, if only blank-tire skid numbers (SN^B_{40}) are available and the level of 20 is chosen, the acceptable region will be above the line at $SN^B_{40} = 20$ in figure 7. On the other hand, if only ribbed-tire skid numbers (SN^R_{40}) are available and the limit of 35 is chosen, only the pavements to the right of the line $SN^R_{40} = 35$ in Figure 8 will be acceptable. If data from both tires are available and the same limits are chosen, the upper right quadrant of Figure 9 will contain acceptable pavements. If mean texture depth (MTD) and British pendulum numbers (BPN) are available, the acceptable region will be to the right

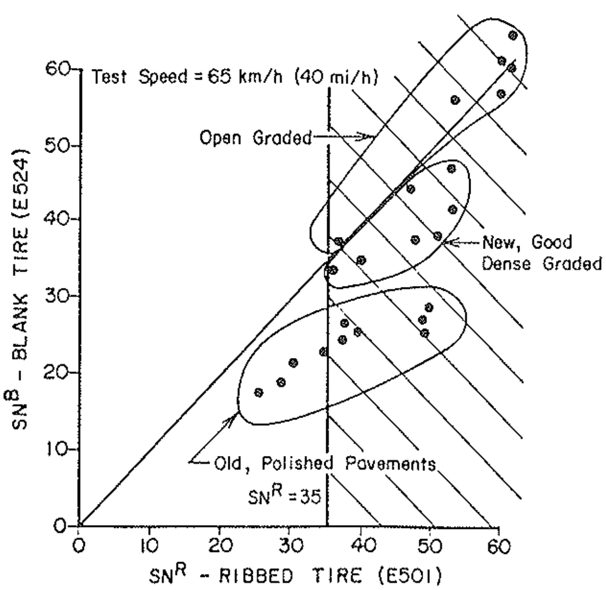

FIGURE 8 Acceptance criteria using ribbed-tire skid numbers (SN^R_{40}).

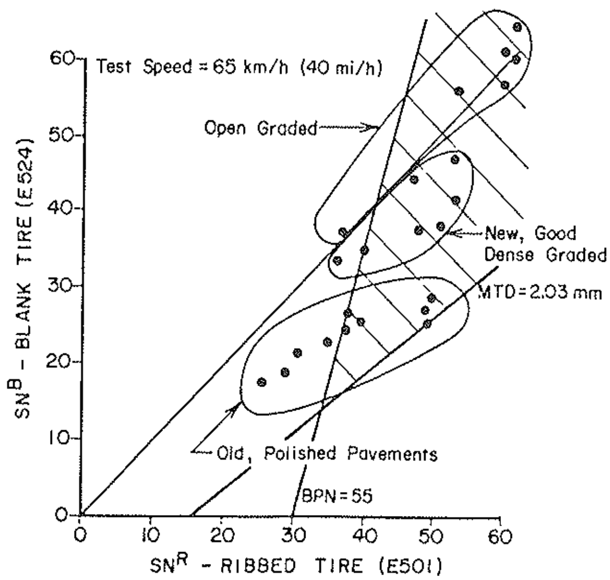

FIGURE 10 Acceptance criteria using sand-patch MTD and BPN.

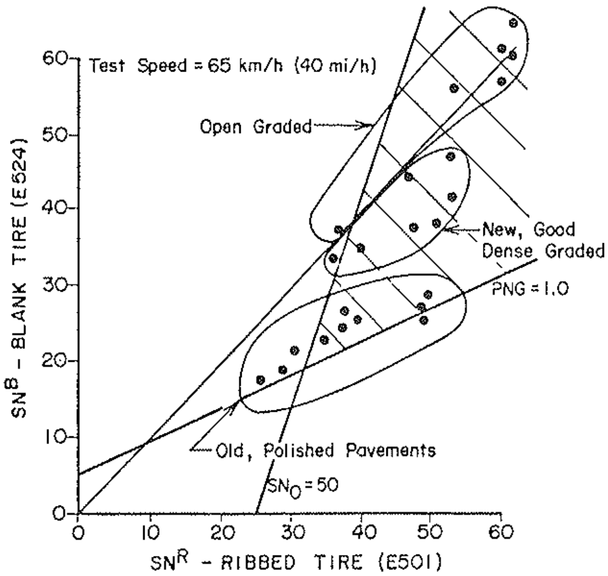

FIGURE 11 Acceptance criteria using skid number/speed intercept (SN_0) and percent normalized gradient (PNG).

of the BPN = 55 line and above the MTD = .030 line in Figure 10. Finally, if SN_0 and PNG data are used, the acceptable region will be to the right of the SN_0 = 50 line and above the PNG = 1.0 line in Figure 11. The levels of acceptability shown in the figures are not intended to be conclusive. Further research should be conducted to determine levels of acceptability from accident data. However, it is clear that the use of any one or two of these parameters would delimit different areas of acceptance, and, thus, some roads that are acceptable on the basis of one criterion are unacceptable on the basis of other criteria.

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