Correlation of Data From Tests With Skid-Resistant Tires

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A standard test tire is generally used for skid resistance testing. The American Society for Testing and Materials (ASTM) Committee on Skid Resistance has recently adopted a new standard tire (ASTM E 501) to replace the first standard tire (ASTM E 249). The new tire is somewhat larger than the first tire and has a bias-belted construction instead of the bias-ply construction of the first tire. The Federal Highway Administration has conducted a test program to establish a correlation between skid resistance measurements of these two tires. A large-scale field test program was held at the Texas Transportation Institute and was supplemented by a small laboratory study at the Tire Research Facility of CALSPAN Corporation. A range of values for the major variables in skid-resistance testing was used. These included four different pavements, three speeds, two water film thicknesses plus some dry tests, maximum and minimum tire groove depths, and, to the degree possible, low and high temperatures during testing. The results show that both tires respond in a similar way to changing test conditions but that tire ASTM E 501 is expected to measure about 4 percent higher than tire ASTM E 249 under standard test conditions at 64 km/h (40 mph). Similar conclusions hold for dry pavements although the difference is somewhat greater. Effect of groove width, which was too narrow in the first production batch but was rectified, has been found to be insignificant under the stated test conditions.

As a result of the First International Skid Prevention Conference in 1958 (1) and the associated program at Tappahannock, Virginia, in 1962 (2), the American Society for Testing and Materials (ASTM) Standard Tire for Pavement Tests (E 249) (3) came into general use for measuring skid resistance. This was probably the most important step in standardizing the measurement of skid resistance. Indeed, subsequent studies (4) have shown that good agreement can be obtained between skid testers of different designs when the standard test tire is used. However, tire and vehicle design did not remain static, and, by 1970, the standard test tire was no longer representative of current tires either in size or in construction. A revised standard for a test tire was prepared by ASTM and was approved in 1974 under the designation E 501 (5). The essential specifications of the two tires are given in Table 1.

During more than 10 years of use, a large amount of test data with the E 249 tire has been accumulated. With the changeover to tire E 501, the skid resistance data of the E 501 tire must be correlated with the accumulated data taken with tire E 249. Past experience has shown that attempts to correlate skid resistance measurements can be frustrating because of the large variability in skid testing. The only way to overcome this problem is by a large-scale test program under controlled conditions.

Exploratory tests were conducted in July 1974, and the full program was executed between September and December of the same year at the Texas Transportation Institute. Some additional field tests were run in May 1975. At the same time as the main test program, laboratory tests were run at the CALSPAN Tire Research Facility. These have been documented in the full report (6) and will not be discussed here. The results of field and laboratory tests were in good agreement.

TEST CONDITIONS

Both tires were tested under equal conditions, some of which were varied according to the test plan. The data given in Table 2 show the various test conditions.

TEST METHOD

Skid tests were conducted according to ASTM E 274 except that the surfaces were continually wet during testing. However, between tests there was sufficient time for the water to drain from the surface; therefore, no puddling occurred. Before the first locked-wheel skid in each test sequence, two watering passes were made, without locking the test wheel, to prewet the surface.

Random sequencing, as far as practical, was used in the design of the test plan. In any one day, tests were made at all three speeds in the morning and afternoon with each of the two types of tires. Each test sequence consisted of eight consecutive skids for a total of 192 skids/test day. Types of tires were switched after one or at most two of such sequences. The same tire was used throughout the test day although provisions had been

Publication of this paper sponsored by Committee on Surface Properties-Vehicle Interaction.

made for replacement in case of failure.

Any test day program was repeated three times with new tires for a total of 384 skids/type of tire under identical conditions, at least as far as conditions could be controlled. During the program, 8448 individual skid measurements were made.

During testing, a number of factors were recorded. Tire, pavement, and ambient air temperatures were measured and recorded. Tire pressure was measured but not readjusted unless a loss of pressure was found. Mean tire groove depth was measured and recorded. Tires were inspected visually for excessive or irregular wear.

The grooves in the first production batch of E 501 tires were narrower than specified. This has now been rectified. To determine whether this difference in groove width of 4.4 instead of 5.1 mm (0.175 instead of 0.200 in) affects the measurement, we added a few days of testing at the end of the first program with tires of narrow and correct groove width. Conditions were the same as those in the full test program although limited in extent. No significant differences could be found.

EXPERIMENTAL DESIGN AND ANALYSIS PLAN

For each type of tire, the experiment is structured as a 2 × 3 × 4 × 8 complete factorial design with 16 replications and two covariates. The factors are water depth (two levels), speeds (three levels), pavements (four levels), and order of run (eight levels). The two covariates are grooved depth x_1 and temperature x_2.

The objective was to establish a correlation between the two test tires and to determine the effect of the design factors and covariates on each tire. The analysis was conducted in three stages.

Within-Mean Analysis

The purpose of the within-mean analysis is twofold. The first is to examine order-of-run effect on each tire under every design combination and overall replications; the second is to compute means and variances for each set of eight skids.

The following linear order-of-run model is assumed for each group of eight runs:

$$y = a + bx \tag{1}$$

where

y = skid number (SN) value for an individual test run;
a and b = regression coefficients to be estimated; and
x = order of run = 1, 2, . . . , 8.

For this model to realistically hold true, all other effects (water depth, speed, pavement, groove depth, and temperature) must be constant while quadratic and higher order-of-run effects are assumed to be zero.

For each group, we calculate the following quantities:

$$\hat{b} = \left[\sum (x - \bar{x})(y - \bar{y})\right] / \left[\sum (x - \bar{x})^2\right] \tag{2}$$

$$E = \left[\sum (y - \bar{y})^2\right] - (\hat{b} \text{ num } \hat{b}) \tag{3}$$

where

$\hat{b}$ = unbiased estimate of b,
E = error sum of squares (constituting the sum of the squares of the deviations of the eight observations about the least squares fit), and
num $\hat{b}$ = numerator of b.

If we assume that each observation is identically and independently normally distributed, a formal consolidated F-test on all data groups can be made. This was done at the 5 percent level of significance to test the null hypothesis that the linear order-of-run effect was nonexistent.

For each tire type, the test statistic is

$$F_{m,n} = \left(6 \sum \hat{b} \text{ num } \hat{b}\right) / \left(\sum E\right) \tag{4}$$

where

m = 384 and
n = 6 × 384 = 2604.

The summations in equation 4 are taken over 384 groups. From this test, the order-of-run effect was concluded to be not significant; therefore, no adjustment was necessary to conduct the between-mean analysis.

Between-Mean Analysis

The results of the within-mean analysis permitted us to disregard the order-of-run effect. Now all analyses involve the group means of eight runs (784 in all). The experiment can now be regarded as a 2 × 3 × 4 factorial design with two covariates and 16 replicates for each of the type of tire means. An analysis of covariance was performed to answer five questions.

1. Is the E 249 or the E 501 standard test tire more variable?
2. Are there significant interactions between variable factor effects?
3. Are the error variances the same at different speeds on different pavements?
4. Does the increase of water depth from the standard of 0.51 to 0.84 mm (0.020 to 0.033 in) have a significant effect on the skid measurement? If such an effect exists, is it the same for both tires?
5. Do groove depth and temperature have significant effects?

Table 3 gives a summary of the analysis of variance conducted on each tire. The mean squares are seen to be comparable between types of tires for all main effects, interactions, and error terms. All effects have been adjusted by the two covariates (groove depth and temperature), which thereby reduces the number of degrees of freedom in the error mean square estimate by two. If a random components model is assumed to exist (7, Chapter 22), a simple statistical test procedure is employed for testing the significance of each error source in Table 3. This procedure develops individual F-tests on the mean squares for the main effects and interactions. Computed F-values are given in the table and are compared to the critical F-test value provided in the last column. Those that exceed the corresponding test values are considered to be significant. It is seen that only the H × P and H × V source effects are not significant.

A regression analysis was performed to determine the effect of increasing water depth. The results show that the skid number decreases by $H_1 - H_2$, which, according to the following, are equal and opposite:

Tire	H	σ	df
E 249	0.735	0.157	364
E 501	0.831	0.149	364

Thus, for tires E 249 and E 501, average respective SN decreases of 1.47 and 1.66 can be expected. This difference between the two tires was determined to be insignificant.

The data given in Table 4 show the effects of groove depth and temperature. The standard deviations (σ's) are obtained by the relation $t = b/(\sigma_b)$. All t-values are significant, which indicates that groove depth and temperature do affect the skid resistance measurement. To test for equality of this effect for both tires, we assumed approximate normality and applied the following test statistic:

$$u = (z_1 - z_2)/[(\text{var } z_1 - \text{var } z_2)^{0.5}] \quad (5)$$

where z's = slopes of regression. At the 5 percent level, the tests show that groove depth and temperature effects are about the same for both tires.

A comparison of the within-mean variances and between-mean variances from Table 3 is given in Table 5. From the data given in Table 5, the following pooled within-mean and between-mean information is determined:

Pooled Data	E 249	E 501	Pooled Data	E 249	E 501
Within mean			Between mean		
Variance	4.46	4.80	Variance	3.38	2.97
σ	2.11	2.19	σ	1.84	1.72

First, there is a reversal in the relative magnitude of the variances. The E 501 tire exhibits a larger within-mean variance but a smaller between-mean variance than the E 249 tire. The variances, however, are of the same order of magnitude. Second, the between-mean variances, although somewhat smaller than the within-mean variances, are not smaller by a factor of eight as might be expected. Our data tell us that the between-mean variance is based on means of eight observations and, if the model is correct, should have a smaller expected value than the within-mean variance based on individual observation. Thus an error source was probably introduced by the transverse and longitudinal variability of the pavements although efforts were made to maintain the same path in each run. Some seasonal variations in the surfaces due to environmental effects also probably occurred because the tests extended over a period of 3.5 months (September to December 1974).

Furthermore, it can be seen in Table 5 that the error variances are highest at the 32-km/h (20-mph) speed condition and much lower at the two higher speeds (except on pavement section 1, which is portland cement concrete). This has been attributed to the usually greater skid resistance and speed gradients at low speeds. Therefore, for the same deviation from the desired test speed, the spread of measured skid resistance will be greatest at the lowest speed.

Tire-Calibration Analysis

In this, the third part of the analysis, various sets of equations are derived relating SN values of E 249 and E 501 tires. Thus, when skid resistance is measured with the new test tire, the equivalent skid resistance for the E 249 tire can be computed by using the given appropriate equation. These equations were tested for their predictability, and the recommendations given in this paper are based on these tests.

The full calibration model is

$$SNY = a_0 + a_1 SNX + a_2 D + a_3 T \quad (6)$$

where

SNY = predicted skid resistance for tire E 249;
SNX = measured skid resistance for tire E 501;
$D = 25.4[(x_1)_{249} - (x_1)_{501}]$ in millimeters;
$T = \{[(x_2)_{249} - (x_2)_{501}] - 32\}/1.8$ in degrees Celsius;
x_1 = mean groove depth of designated tire;
x_2 = pavement temperature of the wet pavements; and
a_i = the i th fitted constant in equation 4 (i = 0, 1, 2, 3).

Prediction of skid resistance presumes the same speed, pavement, and water depth for both tires. Therefore, these factors do not appear in equation 6. Groove depth and temperature, however, are uncontrolled variables, and the equation provides a correction for these.

In the preliminary analysis, variability was found to decrease with increasing speed (Table 5). The analysis of variance showed strong pavement and speed interactions. The failure of between-mean variances to be appreciably less than the within-mean variances was also surmised to be due to pavement variability. All this indicated the need to examine in the calibration various pavement and speed combinations as well as each of the major factors.

Calibrations were made separately for each speed and pavement, each pavement pooled over the three speeds, each speed pooled over the four pavements, and all pooled data. Thus an increasingly larger sample was included in the calibrations. Calibrations were also made without forcing the regression equation to go through zero by the constant term a_0, the intercept. The coefficients in the equations became increasingly consistent as the sample size increased and as the constant term was dropped. Figure 1 shows the coefficients for the composite data, with and without the intercept, while consecutively omitting the terms in T and D. Omission has little effect on the a_1 terms, which indicates that their inclusion is only of secondary importance.

PREDICTABILITY OF CALIBRATIONS

The predictability of a calibration can be thought of as the variance of a predicted response. The calibration models examined so far were of the general form

$$y = \sum_{1}^{k} a_i x_i \quad (7)$$

where

y = response;
a_i = computed coefficient with covariance matrix W (i = 0, 1, . . . , k); and
x_i = independent or controlled variable.

For $x_0 = 1$, this model contains a constant term or intercept; for $x_0 = 0$, the model does not involve the intercept. For every regression equation as given in equation 7, a residual or error variance is also obtained, which we label s_e^2. This model may be used as a predictor at a given set of values $x' = (x_0, x_1, \ldots, x_k)$ or $(x_1, x_2, \ldots, x_k)$. If the prediction is to be used for estimating the mean of the population corresponding to x', then the variance of the predicted response is estimated by

$$s_p^2 = x'Wx \tag{8}$$

where x = transpose of row vector x′. However, if equation 8 is to be used to estimate the response to an individual observation at x′, then the predicted variance is

Table 1. Pavement friction test tire specifications.

Item	E 249 Tire	E 501 Tire
Size designation	7.50-14	678-15
Rim designation	14 × 5J	15 × 6JJ
Tread width, mm	118	149
Number of ribs	5	7
Number of 5.1-mm grooves	4	6
Groove depth, mm	8.89	9.09
Minimum groove depth[a], mm	0.381	0.419
Inflation pressure, kPa	165.5	165.5
Test load, kg	492	492
Construction	Bias ply	Bias belted

Note: 1 mm = 0.0394 in. 1 kPa = 0.145 lbf/in². 1 kg = 2.205 lb.
[a]Wear indicator.

Table 2. Test conditions.

Item	Test Conditions
Tire description	New and shaved to wear indicator
Water film thickness[a], mm	0.51 and 0.84
Speed, km/h	32, 64, and 97
Wheel load, kg	492
Inflation pressure, kPa	165.5
Time[b]	Morning and afternoon
Surface[c]	
Skid number range	20 to 60
Texture range, mm	0.3 to 1.25

Note: 1 mm = 0.0394 in. 1 km/h = 0.621 mph. 1 kg = 2.205 lb. 1 kPa = 0.145 lbf/in².
[a]Some dry tests were also conducted.
[b]Two test series were run—one in the morning and one in the afternoon—to cover as wide a temperature range as possible.
[c]Four surfaces were tested.

Table 3. Summary of analysis of variance between means.

Source	df	Mean Squares E 249 Tire	E 501 Tire[a]	Average[a]	Both Tires
Water depth (H)	1	119.79	146.71	133.25	133.00
Pavement (P)	3	12 682.78	11 796.92	12 239.85	12 237.30
Speed (V)	2	4 349.23	3 859.99	4 104.61	4 101.08
H×P	3	30.18	22.51	26.34	25.10
H×V	2	10.83	1.33	6.08	4.73
P×V	6	128.34	104.28	116.31	113.01
H×P×V	6	13.11	18.38	16.05	15.72
Error variance	358	3.38	2.97	3.17	3.18[b]

Note: df = degrees of freedom.
[a]Two tires.

Table 4. Linear regression coefficients for covariates groove depth and temperature.

Tire	Groove Depth Slope b	σ	t	Wet Pavement Temperature Slope b	σ	t
E 249	8.700	0.909	9.568	-0.025	0.0106	-2.342
E 501	10.402	0.720	14.457	-0.023	0.0099	-2.303
Both	9.694	0.568	17.056	-0.024	0.0073	-3.286

estimated by

$$s_y^2 = x'Wx + s_e^2 \tag{9}$$

In practice, equation 9 is used to compute the prediction variance and will serve here as the criterion of the predictability of an equation. The criterion for selection of the appropriate prediction model has been the subject of considerable research in recent years. Some of the accepted ranking criteria are relatively complex, and the required set of computations has to be done by computer. Also, for any particular experiment, such criteria would not agree on the same ranking order. However,

Table 5. Error variances.

Pavement Type	E 249 Tire 32 km/h	64 km/h	97 km/h	E 501 Tire 32 km/h	64 km/h	97 km/h
2	5.80	1.99	1.54	6.35	2.52	1.54
11	4.21	2.00	1.40	5.09	1.92	1.67
1	5.19	4.35	5.80	5.23	5.07	6.45
6	12.60	5.15	3.54	11.71	5.95	4.12
Mean	6.94	3.37	3.07	7.09	3.87	3.45

Figure 1. Calibrations for composite data (384 observations).

MODEL SNY =	COEFFICIENTS			
$a_0 + a_1SNX + a_2D + a_3T$	-1.49	1.018	13.32	-0.087
$b_0 + b_1SNX + b_2D$	-1.41	1.015	13.66	
$c_0 + c_1SNX$	-1.59	1.011		
$a'_1 SNX + a'_2 D + a'_3 T$		0.977	18.52	-0.067
$b'_1 SNX + b'_2 D$		0.976	18.55	
$c'_1 SNX$		0.963		

Figure 2. Skid resistance and speed gradients versus texture depth by putty method.

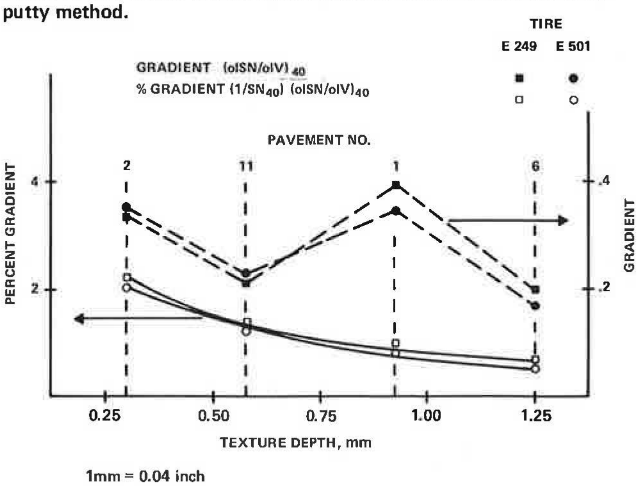


Table 6. Predictions for composite data models.

Nominal SNX	Prediction Model a SNŶ	Variance	σ	Prediction Model a′ SNŶ	Variance	σ	Prediction Model c SNŶ	Variance	σ	Prediction Model c′ SNŶ	Variance	σ
10	8.69	2.9412	1.72	9.77	3.2047	1.79	8.52	3.0928	1.76	9.63	3.4171	1.85
30	29.05	2.9255	1.71	29.30	3.2183	1.79	28.74	3.0722	1.75	28.89	3.4243	1.85
50	49.41	2.9570	1.72	48.83	3.2455	1.80	48.96	3.0988	1.76	48.16	3.4387	1.85
70	69.78	3.0447	1.75	68.37	3.2863	1.81	69.18	3.1726	1.78	67.42	3.4603	1.86

a useful and simple criterion that gives similar results to those for equation 9 is the average estimated variance (AEV) (8). In effect, the AEV criterion tends to give higher preferred ranking to simpler models. Four values of SNX were selected for predictability testing. Table 6 gives predictions for the full and truncated intercept and nonintercept models together with the standard deviations of the predictions. The intercept models give somewhat closer predictions in the high SN range; the nonintercept models give better predictability in the low SN range, which is more critical. The standard deviations are of the same order of magnitude for all composite prediction equations. Similar analyses were made for each pavement, each speed, and each pavement and speed combination.

ADDITIONAL ANALYSES

To determine the dependence of skid resistance on speed, we fitted to the data quadratic regression equations of the form

$$SN = a + bV + cV^2 \qquad (10)$$

All linear coefficients were negative, and all quadratic coefficients were positive. The resulting equations represent decreasing slopes with higher speeds, which is in agreement with experience.

Skid resistance and speed gradients were computed and plotted against the texture depth (Figure 2). Smooth curves were obtained for percentage gradients, that is, the gradient divided by the skid resistance at the same speed.

Regression equations of skid resistance versus temperature were also computed but were inconclusive despite the large amount of data and the wide temperature spread of 5 to 45° C (41 to 113° F). The effects of the other conditions were probably dominant. All that can be concluded from this analysis is that a 5° C (9° F) temperature increase may cause a drop of at most 2 SN.

ORDER-OF-RUN EFFECT PROGRAM

The analysis procedure was performed in three steps: determination of order-of-run effect within each group of eight runs, covariance analysis on the resulting tire means, and evaluation of calibration equations from regression lines. Because the latter two steps employed standard statistical packages (9, 10), this discussion concentrates on the order-of-run effect program.

As previously noted, the test procedure included a pavement prewetting run before each of the eight skid runs. This step introduces a possible cumulative error within the eight runs. The error appears as a trend in the SN that is positively correlated with the run order. The magnitude and statistical significance of this trend can be measured by means of techniques of linear regression, and a special program was developed for this purpose.

The program actually served three functions in the initial analysis scheme: data summary, order-of-run effect determination, and significance testing of overall order-of-run effect for each test series. By measuring and compensating for this trend, one can compress the data by a factor of eight to one without loss of significance in later analyses.

The program is written in FORTRAN IV for an IBM 360 model 65 and executes in 76 000 bytes of core. One execution of the program processes the data from one test series (3072 points). Data are numerically coded to identify test series, type of tire, water depth, surface, and so forth. Each pass of the main program loop reads two sets of eight runs (one set per card). The loop accumulates statistics for each eight-run series and computes the slope coefficient and the associated F-statistic for the eight skid numbers. The sample output from this loop is shown in Figure 3. Punched output consisting of the mean SN, groove depth, and pavement temperature was generated for later input to the covariance analysis programs. Following the eight-run trend analysis, table summaries of the mean SNs were printed as shown in Figure 4. Similar tables were constructed for variances and covariates for groove depth and pavement temperature. The final step in the program is the calculation of the overall F-statistic to test the slope coefficient for each type of tire over all 3072 data points.

SUMMARY

After more than 4000 field skid tests with each of the two types of tires and additional laboratory tests, we believe that findings presented here provide as reliable a set of correlations as possible when one considers the large variability in skid testing.

Table 7 gives a summary of the recommended correlation equations that give the expected skid resistance of the E 249 tire (SNY) as a function of the skid resistance measured with the E 501 tire (SNX); two additional terms account for any difference in groove depth and difference in pavement temperature. (Calculations for D are based on use of inches and calculations for T are based on use of degrees Fahrenheit. SI units are not given inasmuch as operation of this model requires U.S. customary units.) All other test conditions, such as speed, wheel load, and water depth, are the same for both tires. In most cases, differences between groove depths and temperatures either will not be known or will be neglected. In this case, the terms involving D and T drop out and there remains a simple relation between the skid numbers of the two tires, namely, SNY = kSNX where k represents the appropriate coefficient in Table 7.

Equations A to D in Table 7 have been obtained by averaging over the four pavements used in this program and should therefore be valid for any type of pavement normally found on public highways. Equation A may be used at any speed between 16 and 112 km/h (10 and 70 mph), and equations B to D apply only at the indicated speeds. Equations E to H are valid only for pavements that are similar in every respect to the corresponding pavement in this program. These equations may also be used over the speed range 16 to 112 km/h (10 to 70 mph).

The coefficients for D and T in Table 7 vary over a wide range. These differences have no physical meaning but are caused by the uncertainty in the measurements. This is especially true for temperature measurements, where the coefficients vary by a factor of 20 or greater. Whenever the terms involving D and T are to be included, equation A should be used because the coefficients are based on a larger sample (384 data pairs of mean SNs) and therefore have more validity. However, for skid resistance data at the standard test speed of 64 km/h (40 mph), equation C is recommended, provided that the terms in D and T are neglected. The prediction variance at this speed has been found to be smaller than at the other test speeds and also smaller than with the composite model (equation A).

Table 7 also gives the prediction variances for each of the eight equations. The given values have been computed for the simple case of equal groove depth and equal temperature (D = O and T = O) and are based on the sample size used in this correlation, namely eight skids. For a different sample of size n, the first term in the variance equations should be multiplied by 8/n. Thus

Figure 3. Order-of-run analysis output.

REGRESSION ANALYSIS OF TEST TIRE CALIBRATION DATA
(RUN DATA VS RUN ORDER)

TIRE	:	E501
TEST SERIES	:	40-2
TIME	:	PM
REPLICATION	:	4
CONDITION	:	NEW
SPEED	:	40
SURFACE	:	6
WATER DEPTH	:	.033
ROAD TEMP	:	60 F
GROOVE DEPTH	:	0.364 IN.

STATISTICAL ANALYSIS :

MEAN SKID RESISTANCE	=	30.80
VARIANCE	=	1.43
STD. DEV.	=	1.19
NUMBIJ SS(X,Y)	=	-12.00
DENBIJ SS(X,X)	=	42.00
BIJ	=	-0.29
BIJ X NUMBIJ	=	3.43
ERROR S.S.	=	6.57
WITHIN VARIANCE	=	1.09
F (H:B=0)	=	3.13

REGRESSION ANALYSIS OF TEST TIRE CALIBRATION DATA
(RUN DATA VS RUN ORDER)

TIRE	:	E501
TEST SERIES	:	40-2
TIME	:	PM
REPLICATION	:	4
CONDITION	:	NEW
SPEED	:	60
SURFACE	:	6
WATER DEPTH	:	.033
ROAD TEMP	:	61 F
GROOVE DEPTH	:	0.364 IN.

STATISTICAL ANALYSIS :

MEAN SKID RESISTANCE	=	29.80
VARIANCE	=	5.71
STD. DEV.	=	2.39
NUMBIJ SS(X,Y)	=	23.00
DENBIJ SS(X,X)	=	42.00
BIJ	=	0.55
BIJ X NUMBIJ	=	12.60
ERROR S.S.	=	27.40
WITHIN VARIANCE	=	4.57
F (H:B=0)	=	2.76

Note: SI units are not given for the variables of this model inasmuch as its operation requires that they be in U.S. customary units.

Figure 4. Typical summary printout by mean skid number.

UPPER ROW -MORNING, LOWER ROW - AFTERNOON

		TIRE E249					TIRE E501				
SITE	REPS SPEED	1	2	3	4	MEAN	1	2	3	4	MEAN
	20	24.300	23.562	21.800	22.587	23.062	24.300	24.800	23.175	23.950	24.056
		25.925	22.587	22.950	22.275	23.434	25.437	20.850	25.200	24.450	23.984
2	40	12.687	15.700	14.275	13.950	14.153	15.800	17.100	15.525	13.950	15.594
		14.250	15.425	14.600	14.362	14.659	15.787	15.900	16.150	15.300	15.784
	60	10.987	11.262	9.862	10.600	10.728	11.500	10.925	11.225	12.012	11.416
		11.500	11.950	10.637	10.800	11.222	11.712	12.575	11.725	11.262	11.819
	20	23.350	19.412	21.175	21.662	21.400	26.312	20.887	21.800	22.125	22.781
		21.487	20.737	22.112	20.425	21.191	22.600	22.812	26.800	21.525	23.434
11	40	15.437	15.200	15.525	16.050	15.553	17.000	16.400	17.237	16.500	16.784
		15.787	15.787	16.262	15.500	15.834	16.275	16.400	18.937	17.550	17.291
	60	12.562	11.750	11.962	11.400	11.919	12.212	11.862	12.800	13.200	12.519
		11.837	12.550	11.350	10.875	11.653	12.812	12.575	13.537	11.100	12.506
	20	51.012	49.437	48.650	50.987	50.022	48.012	49.437	48.387	48.062	48.475
		51.612	49.575	49.437	47.900	49.631	52.562	51.937	49.437	48.387	50.581
1	40	38.662	38.500	38.562	37.087	38.203	40.075	39.712	37.512	39.800	39.275
		39.637	38.725	37.575	37.087	38.256	39.025	40.500	37.562	38.300	38.847
	60	32.050	30.250	29.425	27.950	29.919	35.925	31.487	27.550	30.875	31.459
		33.525	32.550	30.675	30.300	31.762	32.687	35.337	28.800	31.887	32.178
	20	37.437	43.562	32.675	35.987	37.416	33.437	38.375	33.425	35.512	35.187
		33.112	36.962	33.550	33.550	34.294	33.500	36.825	34.425	37.525	35.569
6	40	28.675	32.462	30.050	30.000	30.297	29.775	31.800	30.987	30.612	30.794
		29.512	32.175	28.925	28.600	29.803	30.425	32.300	29.175	29.862	30.441
	60	30.175	27.062	27.925	26.412	27.894	29.550	28.150	27.300	27.000	28.000
		25.425	27.800	27.925	28.300	27.362	27.612	30.300	27.800	26.462	28.044

BY SPEED	20	40	60
	32.782	25.098	20.650

BY SITE	2	11	1	6
E249	16.210	16.258	39.632	31.178
E501	17.109	17.553	40.136	31.339

BY TIRE	
E249	25.819
E501	26.534

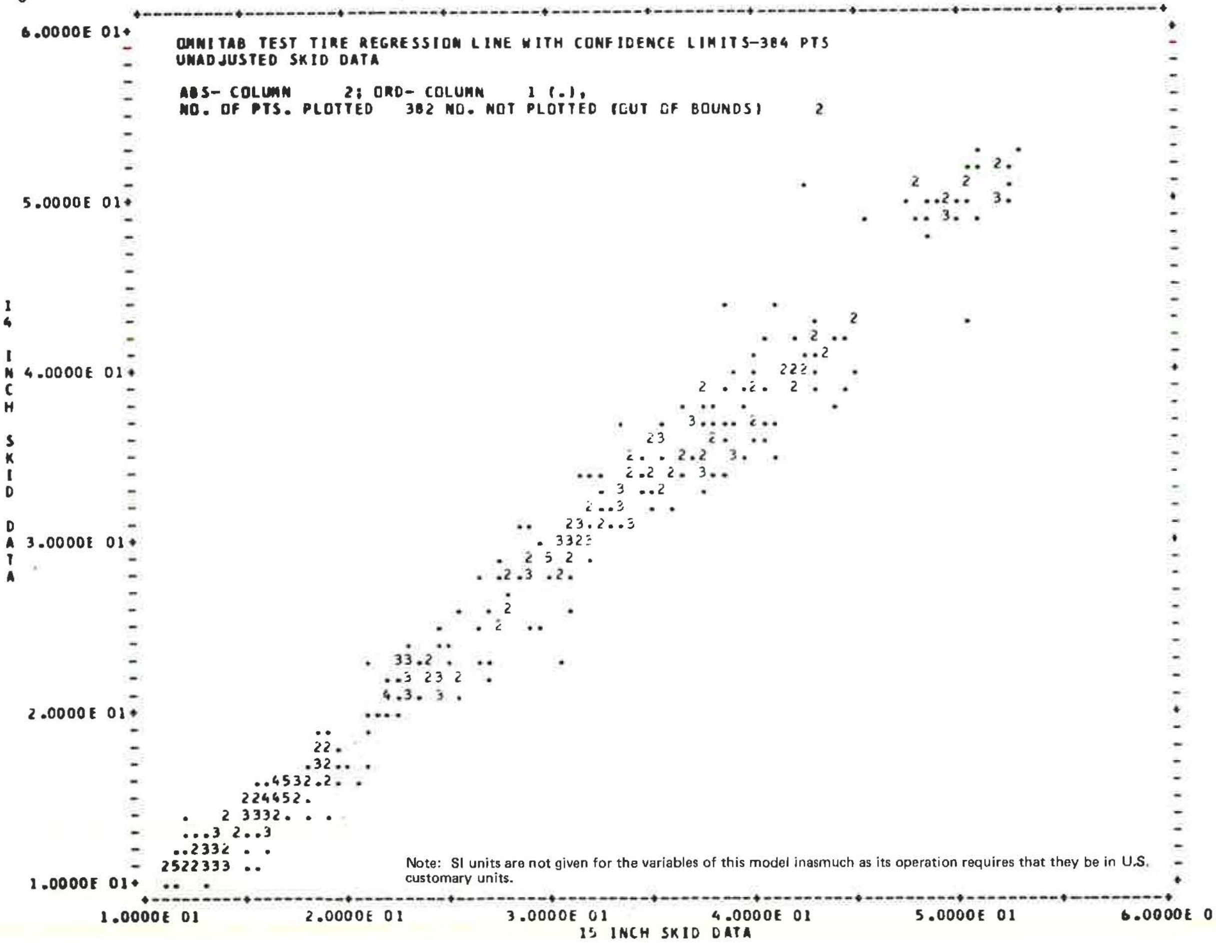
Note: SI units are not given for the variables of this model inasmuch as its operation requires that they be in U.S. customary units.

Table 7. Summary of correlation equation and associated variances.

Equation	Prediction: SNY =	Variance for D = T = O	Application
A	0.977 SNX + 18.52 D - 0.067 T	3.2030 + $(0.0041\ SNX)^2$	General
B	0.991 SNX + 15.07 D - 0.177 T	4.9700 + $(0.0075\ SNX)^2$	32 km/h
C	0.957 SNX + 12.31 D - 0.006 T	1.6434 + $(0.0053\ SNX)^2$	64 km/h
D	0.964 SNX + 22.71 D - 0.002 T	2.2213 + $(0.0072\ SNX)^2$	97 km/h
E	0.986 SNX + 29.62 D - 0.125 T	3.6735 + $(0.0067\ SNX)^2$	Pavement type 1
F	0.924 SNX + 12.82 D - 0.073 T	2.0914 + $(0.0097\ SNX)^2$	Pavement type 2
G	0.997 SNX + 14.29 D - 0.106 T	3.6853 + $(0.0091\ SNX)^2$	Pavement type 6
H	0.918 SNX - 3.84 D - 0.054 T	1.2766 + $(0.0084\ SNX)^2$	Pavement type 11

Note: 1 km/h = 0.621 mph.

Figure 5. Mean skid number of ASTM E 249 (14-in) tire versus mean skid number of ASTM E 501 (15-in) tire.



the prediction variance (or standard deviation, which is the square root of the variance) increases as the number of skids per test site decreases.

The correlation between the two tires over all conditions is shown in Figure 5. The computer prints a number whenever two or more points fall on the same coordinates (at the given resolution). The best fit line (from Figure 1) is

$$SNY = -1.49 + 1.018\ SNX \quad (11)$$

which is different from the recommended nonintercept prediction equation in Table 7 (equation A)

$$SNY = 0.977\ SNX \quad (12)$$

Dropping the constant term is justified because it simplifies the conversion and may improve the prediction. In any case, the difference between the two equations is about 1 to 2 percent in the critical skid resistance range of 30 to 40 SN. This is much less than the percentage standard deviation caused by pavement nonuniformity.

Some tests were conducted on dry surfaces, both in the field and in the laboratory. These were limited tests, and the data are insufficient for computing a correlation equation. The results show, however, that skid resistance measurements with the E 501 tire may be expected to be 5 to 10 percent higher than with the E 249 tire. There are six other important findings.

1. The within-mean variances (variance among the eight repeat skids within each sample) as well as the between-mean variances (variance among the mean skid numbers) are about the same for both types of tires. The variance at 32 km/h (20 mph) is, however, more than twice that at the two higher speeds; therefore, low-speed skid testing is not recommended unless prevailing conditions make this necessary.

2. The effect of increased water depth is the same for both tires and may drop about 2 SN when the standard water film thickness of 0.5 mm (0.02 in) is doubled.

3. Tire wear has a somewhat stronger effect on the

E 501 tire than on the E 249 tire. The drop in measured skid resistance is most pronounced during the initial wear. The difference in wear effects between the two tires may vanish when the groove width of the E 501 tire is corrected to meet the specifications. This groove width was, in the first production run, 4.4 instead of 5 mm (0.175 instead of 0.200 in). This has now been corrected. A brief test program was conducted to determine the effect of this change. Under the prevailing test conditions, no systematic difference that came about as a result of the different groove widths could be found.

4. The effect of temperature on skid resistance is confirmed. For a temperature increase of 5° C (9° F), a decrease in SN of at most 2 percent may be expected. However, temperature effects are frequently submerged in other effects, and, at present, no reliable correction method is known.

5. Based on an analysis of four replications with different tires in which all other conditions held constant, tires of the same type and same production run do not differ significantly with respect to skid resistance measurement.

6. The decrease of skid resistance with speed depends on pavement macrotexture. Good correlation can be obtained between macrotexture and percentage gradients (the skid resistance and speed gradient divided by the skid resistance at the same speed).

In general, both tires respond similarly to changing test conditions; therefore, skid testing with the E 501 tire is not expected to present more problems than were experienced with the E 249 tire. This statement does not, however, apply to tire wear, which will have to be judged from experience.

In summary, the equations given in the stub of Table 7 may be used to relate skid resistance measurements taken with one type of tire to those of the other type of tire. The corresponding variances are given for SNX (when skid resistance is measured with the new test tire). If, however, SNX is to be computed from a measured SNY, the latter can be used in the variance equation, without introducing significant errors.

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