Obtaining Skid Number at Any Speed from Test at Single Speed

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This paper reports the results of a set of tests from New York, Pennsylvania, Texas, and Florida that were used to correlate skid number measurements made with ASTM ribbed and blank tires with skid number (*SN*) data recorded at any speed [in other words, the calculation of *SN* at any speed from the determination of the skid number/zero speed intercept (SN_0) and percent normalized gradient (*PNG*)]. Correlations were made with actual data at three or four speeds. Similarly, SN_0 and *PNG* were determined from transient tests of a ribbed-tire run at a single speed, and these results were correlated with the actual speed data. It was found that a transient skid test made with a ribbed tire at 40 or 50 mph, or a locked-wheel test with both the ribbed and blank tire at 40 mph, produced excellent results. *SN* could be calculated over a range of 20 to 60 mph with a correlation (R^2) better than 0.96 and as high as 0.99.

Two methods stand out as lending themselves to a new skid tester design: the method employing a ribbed and a blank tire in combination, and the spinup method. A series of tests was undertaken to determine the feasibility of these methods. With one minor exception no special equipment or instrumentation was constructed or obtained. The available friction testers were used, and a large number of the tests were conducted as part of the overall testing program of this project.

The objective of the experiments was to determine if the results of ribbed/blank tire tests and of spinup/spindown tests can be used to compute SN_0 and *PNG*, hence the *SN*/speed relationship. The reference was the SN_0 and *PNG* obtained from lockup tests with the ribbed ASTM E 501 tire at several speeds. Tests the results of which were to be compared were made at the same locations and wheel tracks of public highways, or of the Pennsylvania Transportation Institute Skid Resistance Research Facility, and as close together in time as practical in order to eliminate as many extraneous variables as possible from the comparisons.

The ribbed/blank tire comparisons were made in only one (left) wheel track, thus eliminating the effect of the possible differences between wheel tracks. This required changing the tires, or rather the wheels to which either a ribbed E 501 or a blank E 524 tire had been mounted. This procedure eliminated errors that could be caused by differences in water application and instrumentation of the two wheels of the two-wheel tester. Thus the results of the tests were kept free of influences that might obscure the validity of the comparisons.

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For the spinup/spindown investigations, the standard locked-wheel tests were used except that oscillograph chart speed was set at the maximum to get optimum resolution. The test wheel speed trace was quite free of noise, and the force trace was smoothed visually. This permitted wheel speed and force to be related, thereby obtaining the transient skid numbers TSN_VSD (spindown) and TSN_VSU (spinup). Examples of such charts are reproduced as Figure 1.

The following data sets were used:

SN_{30}, SN_{40}, SN_{50}, and SN_{40}^B, or SN_{20}, SN_{30}, SN_{40}, and SN_{40}^B, and TSN_VSU, TSN_VSD

to calculate from either one of the first two sets of *PNG* and SN_0 by performing a least squares fit of the three points to

$$SN_V = SN_0\, e^{-PNG/100 \cdot V} \tag{1}$$

This equation is referred to as the Penn State Model (*1*).

Taking the log of each side:

$$\ln SN_V = \ln SN_0 - \frac{PNG}{100} V$$

If $\ln SN_v = y$, $\ln SN_0 = A$, and $PNG/100 = B$ then

$$y = A - BV \tag{2}$$

A linear least-squares fit can then be used to calculate A and B, from which SN_0 and *PNG* result. These are considered the actual or standard SN_0 and *PNG* to which everything else is to be correlated.

In a similar manner, *PNGSU*, *PNGSD*, SN_0SU, and SN_0SD (*SU* and *SD*, referring to spinup and spindown, respectively) can be calculated from the transient skid numbers TSN_VSU and TSN_VSD. In addition, the following regressions were performed:

$$\begin{aligned} PNG &= A_1 + B_1\, SN_{40}^R + C_1\, SN_{40}^B \\ &= A^2 + B_2\, SN_{40}^R + C_2\, SN_{40}^B \\ &\quad + D_2\sqrt{SN_{40}^R} + E_2\, 1\sqrt{SN_{40}^B} \\ SN_0 &= A_5 + B_5\, SN_{40}^R + C_5\, SN_{40}^B \\ &= A_6 + B_6\, SN_{40}^R + C_6\, SN_{40}^B \\ &\quad + D_6\sqrt{SN_{40}^R} + E_6\, 1\sqrt{SN_{40}^B} \end{aligned}$$

For each pair of SN_0 and *PNG* calculated (test at three speeds, spinup, spindown, and SN^B and SN^R), CSN_{30}, CSN_{40}, and CSN_{50} could then be calculated (*C* indicating the calculated skid numbers).

Next, the correlations were obtained. The following com-

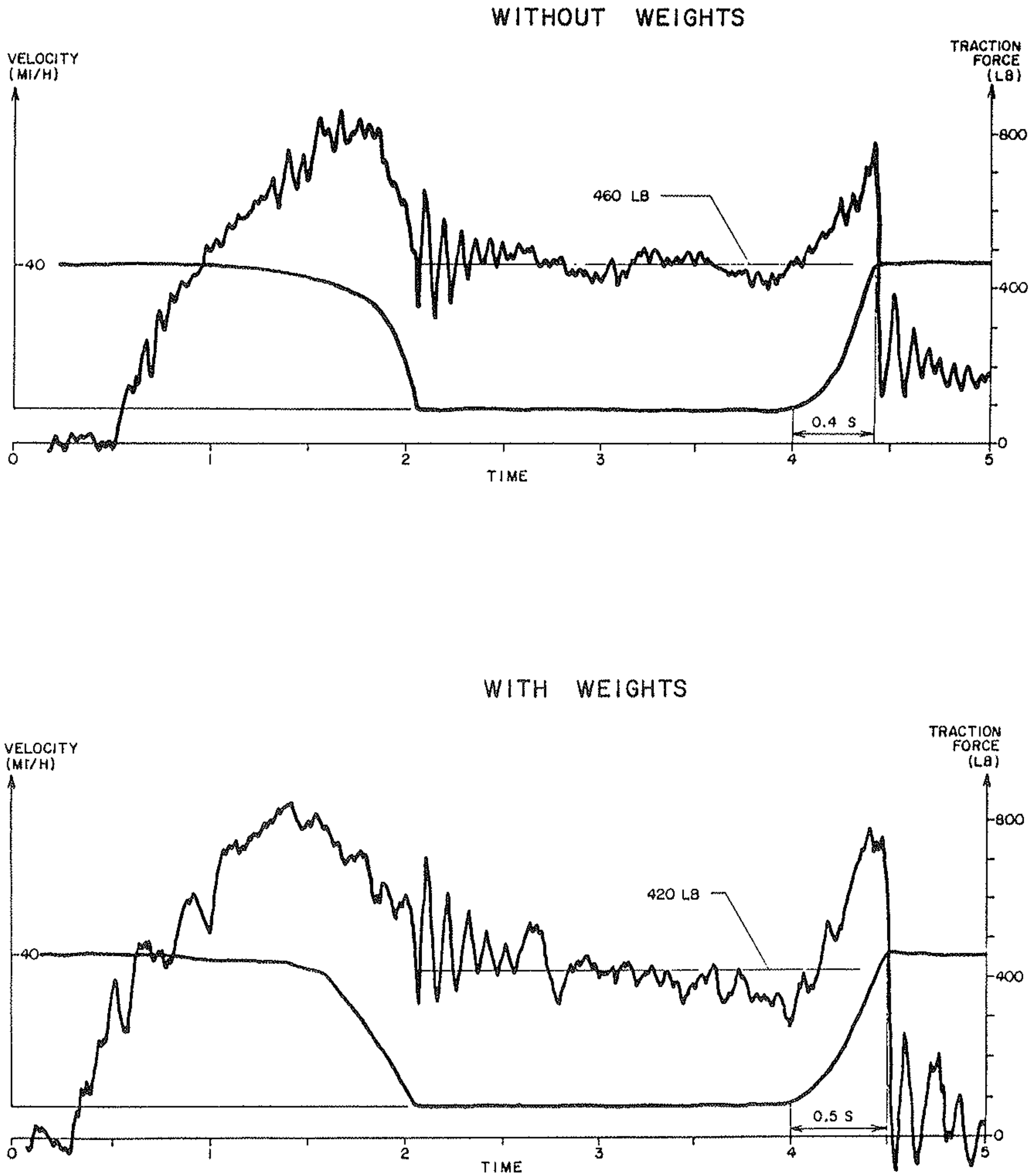

FIGURE 1 Oscillograph charts illustrating spindown and spinup tests.

TABLE 1 CORRELATIONS OF SN_0 AND *PNG* FROM RIBBED/BLANK TIRE TEST

COEFFICIENTS

Equation		NY (ALL)	NY (S)	NY(C)	FL	TX	NY(S) + FL	NY(S) + FL + TX
	A	-0.582	-0.704	-0.495	-0.851	-0.365	-0.8172	-0.801
1	B	1.59	1.77	1.48	2.03	1.32	1.9292	1.784
	C	9.97	6.19	11.9	0.3	12.8	2.901	8.571
	α	-0.0272	-0.0303	-0.0254	-0.0419	-0.0173	-0.0336	-0.0317
2	β	0.0102	0.0158	0.00626	0.0159	0.0032	0.0188	0.0175
	γ	1.23	1.10	1.33	1.44	1.057	1.06	1.0372
	A	-0.858	-1.53	-0.801	-0.73		-0.876	-0.682
	B	-7.66	17.2	-8.7	24.6		2.778	2.894
3	C	124.0	188.0	137.0	-293	*	-11.29	-12.75
	D	-79	-315	-52	-227		-19.0	24.7
	E	-382	-537	-424	981		45.5	35.4
	a	-0.0204	-0.0417	-0.0202	-0.102		-0.0198	-0.01996
	β	-0.286	-0.46	-0.307	0.43		0.069	0.0106
4	γ	3.99	6.41	4.21	-5.33	*	-0.680	0.113
	δ	2.75	-4.86	3.12	-24.2		4.708	3.844
	ε	-12.8	-19.1	-13.14	24.8		2.504	-0.49

R^2

Equation	NY (ALL)	NY (S)	NY(C)	FL	TX	NY(S) + FL	NY(S) + FL + TX
1	0.92	0.90	0.96	0.95	0.99	0.99	0.94
2	0.77	0.70	0.90	0.89	0.99	0.85	0.78
3	0.96	0.96	0.99	0.99	*	0.95	0.96
4	0.90	0.87	0.99	0.90	*	0.85	0.79

*Too few data points to give five coefficients

Equations:

1. $SN_O = A \cdot SN^B + B \cdot SN^R + C$
2. $PNG = \alpha \cdot SN^B + \beta \cdot SN^R + \gamma$
3. $SN_O = A \cdot SN^B + B \cdot SN^R + C \sqrt{SN^R} + D/\sqrt{SN^B} + E$
4. $PNG = \alpha \cdot SN^B + \beta \cdot SN^R + \gamma \sqrt{SN^R} + \delta/\sqrt{SN^B} + \varepsilon$

TABLE 2 R^2 VALUES OF SN_0 AND *PNG* WITH SN_{40}^B AND SN_{40}^R

	SN_{40}^B	SN_{40}^R
SN_0	.059	.869
PNG	-.832	-.151

parisons were made to determine the correlation factor R^2 (or R, if so noted):

SN_0 with SN_0SU

SN_0SD

SN_0 from SN^R and SN^B

SN_0 from SN^R, SN^B, SN^R, and $1/(SN^B)^{1/2}$

PNG with *PNGSU*

PNGSD

PNG from SN^R & SN^B

PNG from SN^R, SN^B, SN^R, and $1/(SN^B)^{1/2}$

What follows are the comparisons of CSN_V with the measured SN_V for each of the four methods.

RESULTS OF RIBBED/BLANK TIRE METHOD

The results of the correlation of SN_0 and *PNG* are given in Table 1. In the case of the New York sites, straight and curved sections were first combined [NY (all)] and then separated [NY(S) and NY(C)]. When the New York sites were combined with the Texas and Florida sites, only the straight, or tangent, sites were used since the non-tangent sites produce a poor correlation in calculating *PNG*.

The correlation coefficients (R^2) of SN_0 and *PNG* for the four equations are given in Table 1. The R^2 values N(S), FL, TX, and combined are excellent for SN_0 (R^2 = 0.94 for all sites combined to R^2 = .99 for the Texas sites). The correlations of *PNG* are also very good but less than for SN_0. The R^2 values range from .778 for all sites combined to .99 for the Texas sites, and can be improved slightly by using $(SN^R)^{1/2}$ and $1/(SN^B)^{1/2}$. However, the improvement is not worth the added complexity of the calculation.

Table 2 shows the correlation, using all of the New York sites, between SN_0 and *PNG*, with SN_{40}^B and SN_{40}^R. This correlation shows that the ribbed tire is mostly sensitive to SN_0 and only mildly sensitive to *PNG*. The blank tire is sensitive mainly to *PNG* and has very little sensitivity to SN_0.

TABLE 3 SN_0 AND *PNG* CORRELATIONS (R^2 VALUES) USING SPINUP AND SPINDOWN METHOD, NEW YORK SITES

	SN_0	SN_0T40SD	SN_0T40SU	SN_0T50SD	SN_0T50SU
SN_0	1	.902	.890	.898	.901
SN_0T40SD		1	.932	.919	.959
SN_0T40SU			1	.933	.955
SN_0T50SD				1	.959
SN_0T50SU					1

	PNG	PNGT40SD	PNGT40SU	PNGT50SD	PNGT50SU
PNG	1	*.208/.810	*.200/.611	*.814/.90	*.683/.810
PNGT40SD		1	.616	.538	.730
PNGT40SU			1	.495	.531
PNGT50SD				1	.909
PNGT50SU					1

Note: *All sites/tangent only sites
Numbers without an asterisk represent results for all sites.

TABLE 4 CORRELATIONS (R^2 VALUES) OF CALCULATED CSN_V FOR SPINDOWN AND SPINUP TESTS WITH MEASURED SN_V

SN (Measured)	Calculated					
	*SN_0 & PNG	T50SD	T40SD	T50SU	T40SU	Site
SN_{30}	.992	.974	.987	.978	.980	NY
SN_{40}	.994	.971	.987	.981	.985	NY
SN_{50}	.987	.964	.984	.979	.986	NY
SN_{30}	.995	--	.989	--	.989	TX
SN_{40}	.996	--	.991	--	.989	TX
SN_{50}	.994	--	.993	--	.985	TX

*Values calculated from actual speed data.

$$CSN_V = SN_0 \, e^{-\frac{PNG}{100} V}$$

RESULTS OF SPINUP/SPINDOWN METHOD

Two separate sets of spinup and spindown tests were performed. One set included all of the New York sites, the calibration site at the Texas Transportation Institute, and the Bryan, Texas, sites. Table 3 shows the correlations of SN_0 and *PNG* with the spinup and spindown tests run at both 40 mph and 50 mph on the New York sites. SN_0 correlates with all the tests with an R^2 of about .9, showing very good correlation.

Table 3 also shows the values of R^2 when *PNG* is compared with the values of *PNG* computed from spinup and spindown tests. These tests showed lower correlations than those for SN_0. However, the results at 50 mph were considerably better than those at 40 mph. When the curved sections are removed, all the R^2 values improve—the 40 mph tests more than the 50 mph tests. Once the curved sections were removed, the correlations were very good: R^2 values ranged from .611 to .90.

In summary, it may be said that good *PNG* correlations are fairly easy to obtain, but very good SN_0 correlations can also be obtained easily. This indicates that macrotexture is less homogeneous than microtexture.

The next set of correlations was performed by using the SN_0 and *PNG* values calculated from the various tests to calculate CSN_{30}, CSN_{40}, and CNS_{50}. These were then correlated with the SN_{30}, SN_{40}, SN_{50} values actually measured. Table 4 gives the correlation values (R^2) for each speed for all the New York sites and for the Bryan and TTI sites. While the SN_0 and *PNG* correlations were good, these results show that when the SN_0 and *PNG* values were used to calculate CSN_V the calculated values were excellent. For all the speeds and methods, the lowest R^2 value was .964. In fact, the spindown and spinup tests produced results almost as good as the values calculated directly for the curve fit to the actual speed data.

Because these results were so good, calculated CSN_{20} and CSN_{60} were also compared with those values calculated from the original speed data. Again, the same correlations were found. The tests were then run at the PTI Skid Resistance Research Facility at speeds up to 60 mph, and again no significant degradation of results was found.

SUMMARY

The results of these tests show that the spinup or spindown transient tests can be used to obtain skid number versus speed data from 20 mph up to at least 60 mph from a single test at one speed. Similarly, a ribbed and blank tire can be used and similar results obtained.

It is recommended that where a standard *SN* cannot be obtained at 40 mph a transient test be made. From those data an *SN* can be calculated for 40 mph so that all test data would be reported at the same speed. If this method were always used, then on the basis of the reported SN_0 and *PNG* one would know whether the microtexture, or the macrotexture, or both, needed corrective action.

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