PREDICTION OF PAVEMENT SKID RESISTANCE FROM LABORATORY TESTS

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The objectives of this research were to develop laboratory tests for pre-evaluating aggregates and paving mixtures to predict skid resistance properties in the field and to evaluate field installations for correlation of field and laboratory polishing exposures. A usable correlation was found between British portable tester measurements and field skid-trailer measurements at test speeds of 20, 30, 40, and 50 mph (32.19, 48.28, 64.37, and 80.47 km/h). Different correlations were obtained for open-graded mixes and for dense-surface mixes. Field wear versus laboratory wear correlation was attempted by coring pavements after field testing and then polishing cores to terminal polish in the circular-track machine. The full "as new" polish curve was obtained by remixing and molding unworn portions of the field cores into laboratory specimens for polish in the circular-track machine. New and worn polish curves when compared gave the extent of circular-track wear experienced in the field. Comparisons were valid for that mix only and could not be combined from different mixes to give a traffic exposure versus circular-track equivalency. It was possible, however, to establish an upper limit for field wear equivalent to 3 hours or less of machine wear. The establishment of an upper limit allows prediction from laboratory tests of maximum field polish that may be anticipated for a given pavement mixture design. Examples are given in the report.

•THE laboratory method used for evaluating aggregates and pavement mixes was the North Carolina State University small-wheel circular track, which has been adequately described in other publications (1, 2, 3, 4, 5, 6). The laboratory friction measurement equipment was the British portable tester, and the field friction-measurement equipment was the North Carolina State Highway Commission skid trailer. (NCSHC is now the Department of Transportation and Highway Safety.) Both devices conformed to applicable ASTM standards.

During the research, a field correlation was developed between the NCSHC skid trailer and the British portable tester by concurrent field measurements on a large number of dense-graded and open-graded bituminous pavements. Test speeds for the skid trailer were 20, 30, 40, and 50 mph (32.19, 48.28, 64.37, and 80.47 km/h).

Using cores sampled from the test pavements, age and traffic data, and a remix scheme, we obtained the level of field polish achieved in terms of circular-track exposure and new pavement skid resistance. From this information we were able to develop a method to predict maximum field polish during the service life of a pavement from laboratory tests of the proposed pavement mixture.

FIELD AND LABORATORY FRICTION MEASUREMENTS

The laboratory measurement system used in this research was the British portable tester (ASTM E 303-69). The field measurement method employed by the NCSHC was the skid trailer (ASTM E 274-70).

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We correlated the 2 measurement systems by conducting a series of field tests on I-2 and open-graded mixture pavements with the skid trailer and then the British portable tester in the same skid traces. Skid-trailer test velocities were 20, 30, 40, and 50 mph (32.19, 48.28, 64.37, and 80.47 km/h). Tests were conducted over a period of approximately 8 months beginning in January 1972. At the same time that friction measurements were made, cores 6 in. (152 mm) in diameter were taken from each site, 3 from the inner wheel path and from between wheel paths, to later correlate laboratory circular-track machine wear versus field wear.

Field sites were selected to sample a variety of I-2 mixes in the state, all of the open-graded mixes in service at that time, and as many high-traffic long-service I-2 pavements as could be located. The long-service pavements were selected for terminal or near terminal polish to compare to the circular-track polish results. Eight open-graded mix pavements and 35 I-2 dense-graded mix pavements were tested for the British portable number-skid number (BPN-SN) correlation.

BPN-SN data for each mix at each test velocity were plotted by computer and reduced to a straight-line correlation by using regression analysis. Typical BPN-SN point scatter for the 2 mixes is shown in Figures 1 and 2 for a 40-mph (64.37-km/h) test velocity. Combined BPN-SN-velocity correlations are shown in Figures 3 and 4 without individual points. Statistical data are given in Table 1. BPN and SN values for each site were taken at the same test temperature, but no attempt was made to correct data from different sites to a common temperature. We could not find a temperature correction from published BPN and SN measurement data (1, 7).

CONVERSION NOMOGRAPHS

By using the data from Figures 3 and 4, we developed the BPN-SN-velocity correlation charts shown in Figures 5 and 6. We are not implying that the same correlations would be found for other skid trailers and other British portable testers, but we are fairly confident that these are reasonable relationships for the North Carolina equipment. This is how to use the nomograph in Figure 6 (the same procedure applies to Fig. 5): A circular-track test reveals that the terminal polish value for an I-2 mix is 45. Read from the nomograph in Figure 6 that a field pavement subject to equivalent wear would record SN values of 54, 46, 39, and 36 at 20, 30, 40, and 50 mph (32.19, 48.28, 64.37, and 80.47 km/h) respectively. If the field and laboratory exposures are expected to be the same, then a decision can be made about the suitability of the mix for field use.

FIELD WEAR EQUIVALENCY

Correlation Scheme

The scheme for correlating circular-track machine wear with field exposure involved selecting field pavements in various stages of polish and sampling them by taking sets of 3 cores 6 in. (152 mm) in diameter from the inner wheel path after field skid-trailer and British portable tester measurements had been made. Cores were brought to the laboratory, mounted in the circular-track machine, and polished to determine the additional loss of friction, if any, beyond that already attained under field exposure. Then the cores were removed from the track and softened in the oven; the surface was separated from the lower layers; and the polished surface particles and the cut-edge particles were scraped away leaving an unpolished original pavement mixture. From this material laboratory specimens 6 in. (152 mm) in diameter were molded in sets of 3 to represent the original mix when it was placed in the new pavement. The "new" pavement cores were then polished in the circular-track machine to terminal polish to establish the full polishing curve for the mix. The comparison scheme, in which the 2 curves are plotted together and a circular-track wear-time equivalent to field exposure is read, is shown in Figure 7.

The age, traffic mix, and accumulated wheel passes for each pavement were obtained by calculation from NCSHC records. We did not try to adjust to equivalent wheel passes by assigning weights to various wheel loads. Field exposure was recorded as accumu-

Figure 1. BPN-SN open-graded mix data scatter at 40 mph.

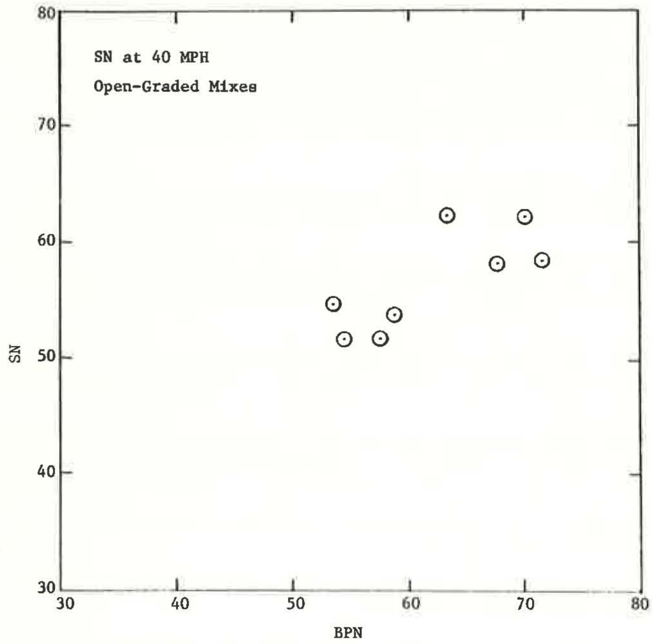


Figure 2. BPN-SN I-2 mix data scatter at 40 mph.

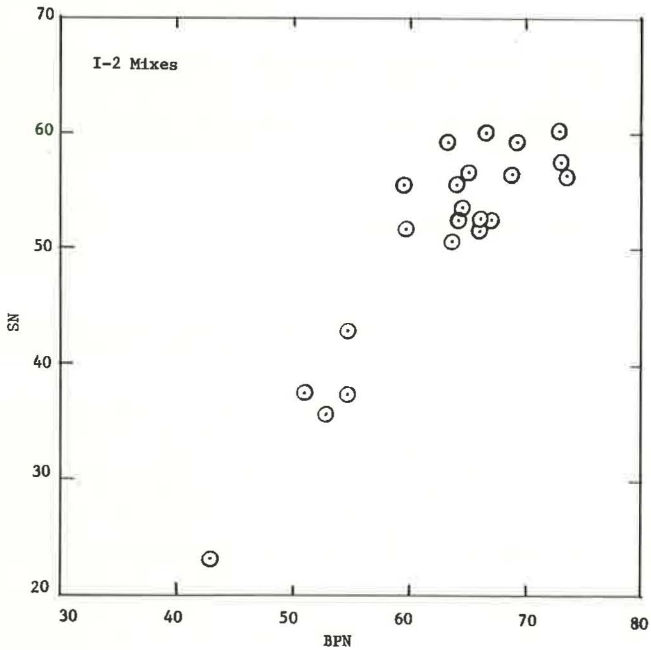


Figure 3. BPN-SN test speed correlations for open-graded mixes.

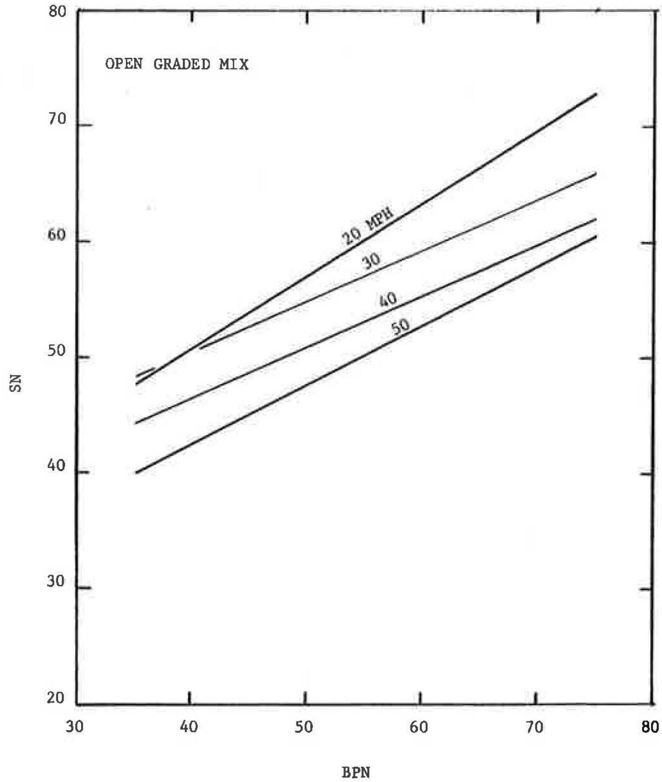


Figure 4. BPN-SN test speed correlations for I-2 mixes.

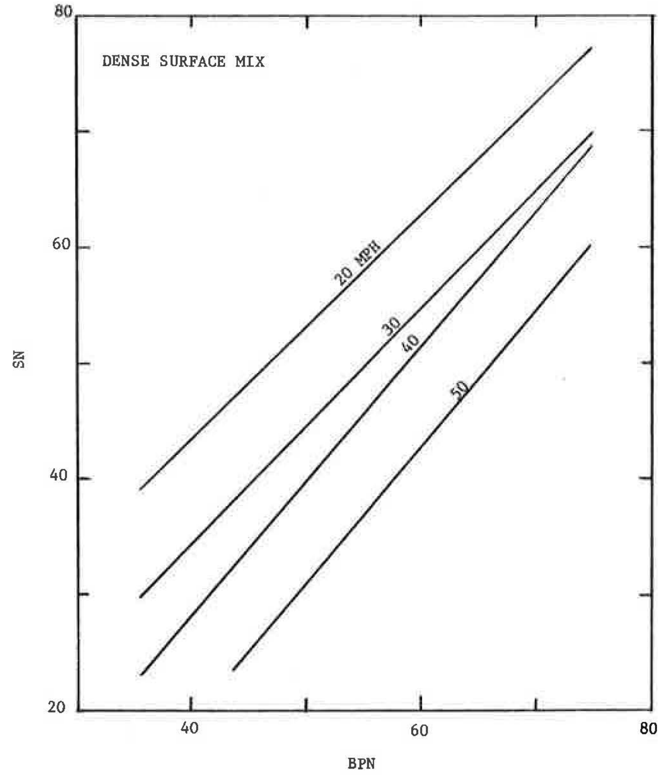


Table 1. BPN-SN speed correlation statistics.

Test Speed (mph)	Mix	Samples	Linear Regression Equation	Correlation Coefficient
20	I-2	22	SN = -4.171 + 0.985 BPN	0.830
30	I-2	22	SN = -6.702 + 1.023 BPN	0.871
40	I-2	22	SN = -19.465 + 1.118 BPN	0.903
50	I-2	22	SN = -28.931 + 1.196 BPN	0.925
20	Open graded	8	SN = 26.232 + 0.621 BPN	0.825
30	Open graded	8	SN = 33.530 + 0.437 BPN	0.629
40	Open graded	8	SN = 28.690 + 0.451 BPN	0.774
50	Open graded	8	SN = 22.254 + 0.512 BPN	0.857

Note: 1 mile = 1.6 km.

Figure 5. BPN-SN-velocity nomograph for open-graded mixes.

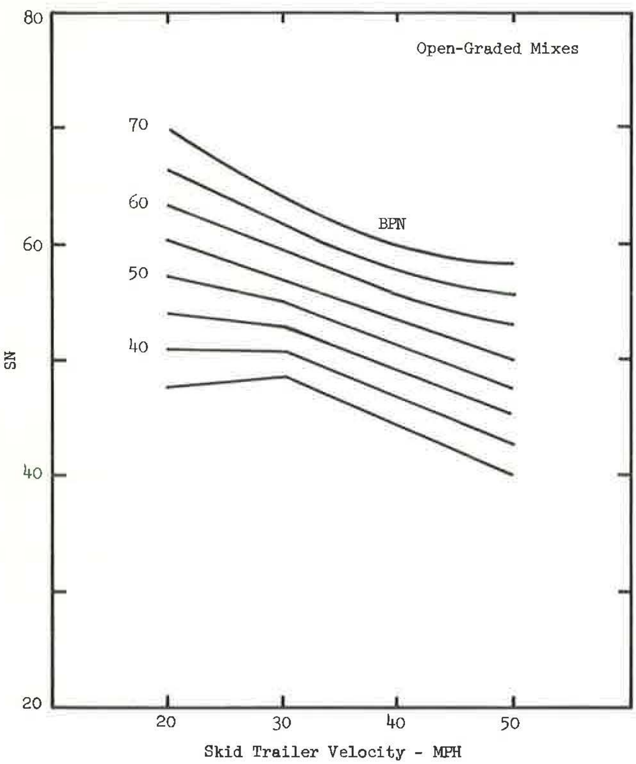


Figure 6. BPN-SN-velocity nomograph for I-2 mixes.

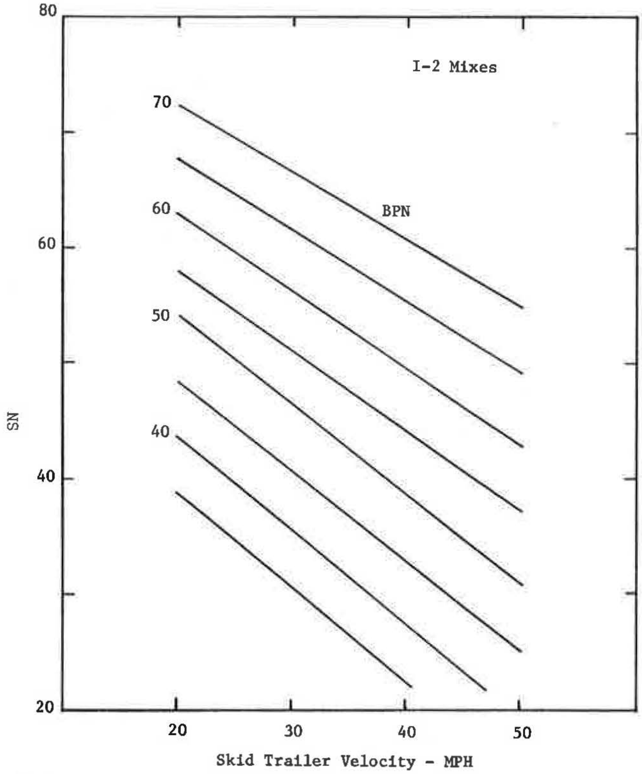
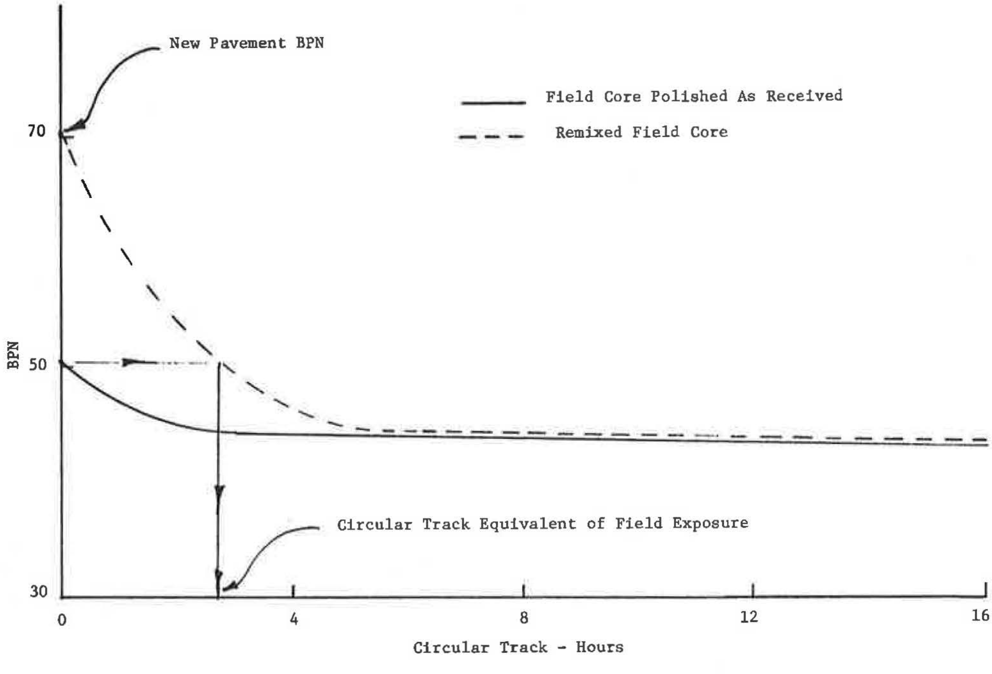


Figure 7. Circular-track versus field exposure equivalency scheme for pavement cores.



lated wheel passes per lane and pavement age in years. Age for I-2 mixes ranged from 0.25 to 11.50 years, and accumulated wheel passes ranged from 300 thousand to 41 million.

In the laboratory wear program, laboratory control specimens were included with each group of pavement cores. For the remix cycle, worn control specimens also were remixed, and a new set of control specimens were included. Original and remix polishing curves for the control specimens were identical for all practical purposes, which indicated that the remix scheme is feasible for approximating original mix properties.

Evaluation of Data

We hoped to be able to state when the work was completed that a direct equivalency between circular-track hours and some function of accumulated wheel passes exists. It is evident from the values for machine hours versus wheel passes obtained by using the scheme in Figure 7 and recorded in Table 2 that no such correlation was obtained for I-2 mixes or for open-graded mixes.

For a given pavement mixture, if a field wear curve could be established, it is expected that a correlation would be obtained for that pavement mixture only. Finding pavements of different ages with identical mix designs and aggregates was unsuccessful mainly because approved aggregates from different sources are substituted in a given production area because of the pressures of supply and demand.

We believe that the most important aspect of the correlation study is that the I-2 mixes had experienced field wear equivalent to less than 2 hours of machine wear in most cases and that the open-graded mixes had experienced in the field less than 3 hours of equivalent machine wear. In other words, mixes in the field that had been exposed to as many as 40 million wheel passes had not polished beyond 3 hours of circular-track machine time. This indicates that the circular-track test is adequate to attain wear at least equivalent to field wear.

Finding an upper limit on field wear with the circular-track method should allow a constructive prediction of field polish limits from laboratory tests. Figure 8, a simple histogram from Table 2 data, shows that 87.5 percent of all I-2 pavements sampled had field polish equivalent to less than 1.5 hours of circular-track exposure and 100 percent had field polish equivalent to less than 2.25 hours of circular-track exposure. For the open-graded mixes, 87.5 percent of the samples showed less then 2.25 hours of equivalent circular-track polish in the field and 100 percent showed less than 3 hours of equivalent circular-track polish in the field.

I-2 mixes sampled went up to 11.5 years in service; the newer open-graded mixes were limited to a maximum 3.67 years in service. It would seem reasonable to estimate that field polish for I-2 mixes would not exceed the 96 percent value of 1.75 hours of circular-track exposure. But, in view of the limited field service of the open-graded mixes, it would seem prudent to estimate that field polish might reach the 100 percent value of 3.00 hours of circular-track exposure.

Prediction of Maximum Field Polish

Examples of maximum field polish prediction from laboratory control mixes plotted in Figure 9 and the nomographs from Figures 5 and 6 replotted for convenience in Figures 10 and 11 respectively are as follows:

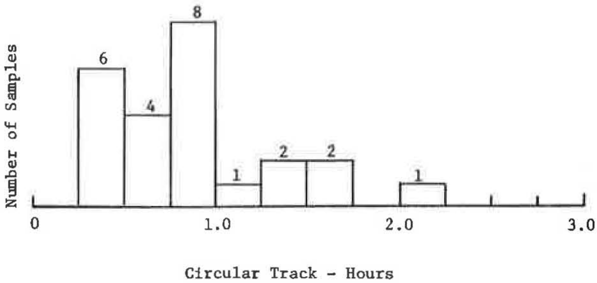
1. For open-graded mixes enter Figure 9 at 3.0 hours on the abscissa, intersect the open-graded mix curve, and pick off BPN of 47 from the ordinate. Enter Figure 10 with BPN of 47, draw the intermediate BPN curve, and pick off predicted SN values for velocity values as follows: (a) 20 mph, 55 SN; (b) 30 mph, 53 SN; (c) 40 mph, 50 SN; and (d) 50 mph, 46 SN. Compare predicted SN values to criteria acceptable for field use.
2. For I-2 mixes enter Figure 9 at 1.75 hours on the abscissa, intersect the I-2 mix curve, and pick off BPN of 52 from the ordinate. Enter Figure 11 with BPN of 52, draw intermediate BPN curve, and pick off predicted SN values for velocity values as follows: (a) 20 mph, 56 SN; (b) 30 mph, 48 SN; (c) 40 mph, 41 SN; and (d) 50 mph, 34 SN.

Predicting field SN values from circular-track results is a practical procedure that can be applied to any laboratory mix before it is chosen for field construction.

Table 2. Field exposure, circular-track data for I-2 and open-graded mix pavements.

Mix	Route	County	Age (years)	Tire Passes (thousands)	Equivalent Circular-Track Hours
I-2	US-64E	Wake	6.42	17,877	0.60
I-2	US-70E1R	Wake	11.50	41,230	0.82
I-2	US-70E1L	Wake	11.50	20,231	1.00
I-2	US-70E2R	Wake	9.75	22,444	1.00
I-2	US-70E2L	Wake	9.75	10,655	0.92
I-2	US-70E3R	Wake	4.92	12,756	0.30
I-2	US-70E3L	Wake	4.92	6,063	0.55
I-2	US-64E	Randolph	0.33	531	0.70
I-2	NC-24	Onslow	6.16	38,376	0.50
I-2	NC-24	Cumberland	8.67	20,155	1.30
I-2	US-17	New Hanover	7.00	10,117	1.00
I-2	US-258-1	Lenoir	7.92	12,922	1.35
I-2	US-258-2	Onslow	10.08	17,971	1.20
I-2	US-258-3	Onslow	10.08	27,138	1.70
I-2	US-74E	Union	5.16	19,565	0.85
I-2	US-74E	Mecklenberg	5.33	20,720	0.35
I-2	I-95 Conn.	Nash	4.58	12,606	0.35
I-2	NC-343	Camden	0.42	316	2.20
I-2	I-85	Alamance	9.67	44,245	0.70
I-2	US-13	Gates	0.25	380	0.45
I-2	US-17	Perquimmons	0.25	519	0.50
I-2	US-301	Nash	2.50	28,758	0.85
I-2	US-220L	Randolph	1.50	1,479	0.70
I-2	US-220R	Randolph	1.50	3,350	1.65
I-2	US-158	Camden	0.25	793	0.90
Open graded	US-70ER	Buncombe	1.67	4,884	0.90
Open graded	US-70EL	Buncombe	1.67	2,233	1.30
Open graded	NC-152	Rowan	2.75	1,967	0.55
Open graded	US-1	Lee	2.58	3,301	0.60
Open graded	US-401	Cumberland	0.67	637	2.90
Open graded	NC-58	Greene	3.67	2,648	2.05
Open graded	US-220	Guilford	2.00	7,380	1.00
Open graded	NC-191	Buncombe	1.83	255	0.25

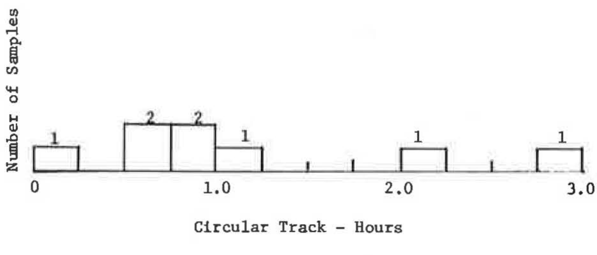
Figure 8. Field polish versus circular-track polish histogram.



I-2 Mixes: 100% < 2.25 Hours

96% < 1.75 Hours

87.5% < 1.50 Hours



Open-Graded Mixes: 100% < 3.00 Hours

87.5% < 2.25 Hours

75% < 1.50 Hours

Figure 9. BPN versus test duration for I-2, open-graded, and No. 4 mixes.

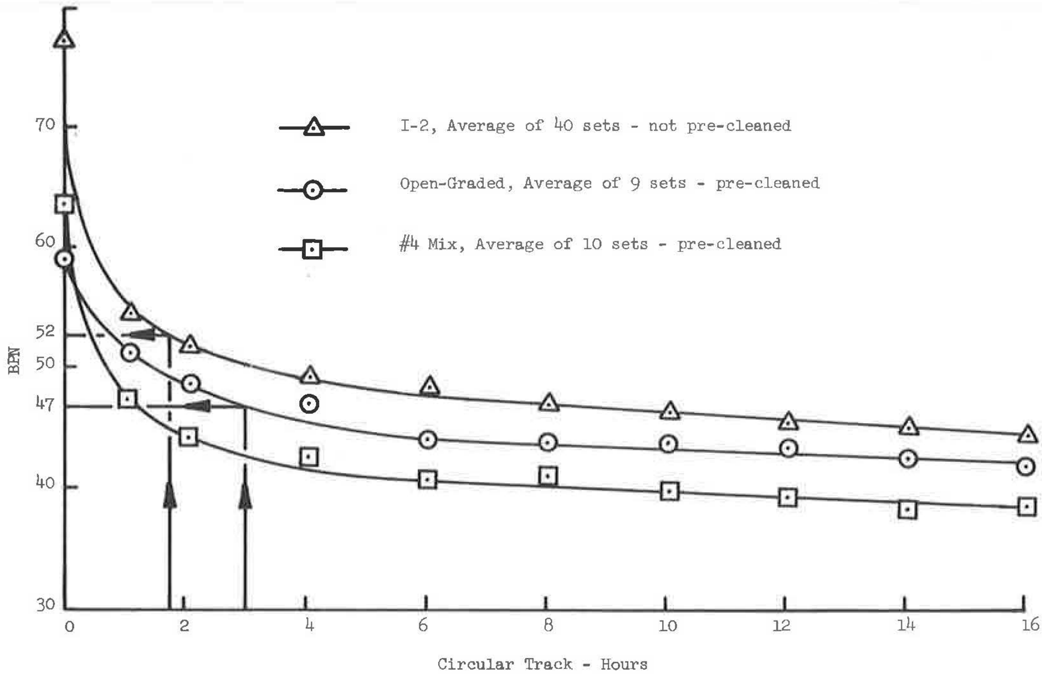


Figure 10. BPN-SN-velocity conversion example for open-graded mix.

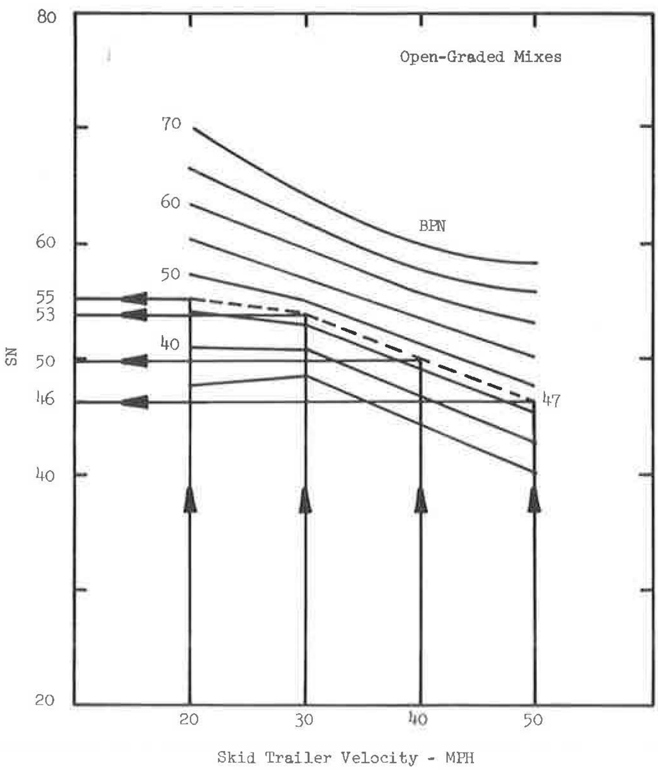
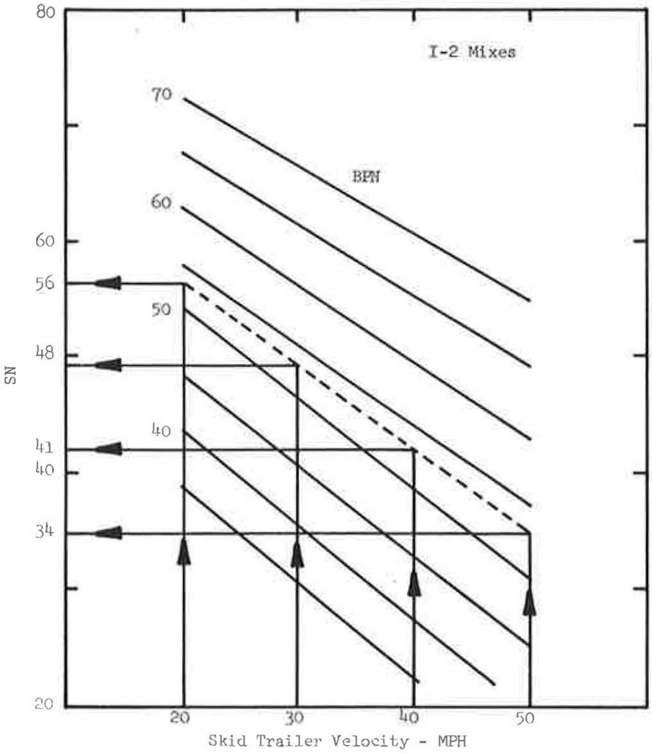


Figure 11. BPN-SN-velocity conversion example for I-2 mix.



Test Time Reduction

The finding from field and laboratory measurements that field polish for the pavements investigated never exceeded 3.0 hours of circular-track exposure implies that the circular-track exposure necessary to establish the polish curve for any bituminous mix can be limited to a maximum of 8 hours and possibly could be reduced to 6 hours. A 6-hour actual exposure time would allow completion of a mixture evaluation in 1 working day after sample preparation and mounting.

SUMMARY

It has been possible during the course of this research to develop methods for determining the wear and polishing properties of aggregates in the laboratory and to predict with reasonable assurance the limits on field polishing of aggregates and mixtures based on laboratory tests.

Field correlation was established between the British portable tester friction measurement method used both in the laboratory and in the field and the NCSHC skid trailer. This correlation allows translation of laboratory friction measurements into skid-trailer SNs at velocities from 20 to 50 mph (32.19 to 80.47 km/h).

From field-laboratory wear correlation studies a method was developed whereby an upper limit on field polish can be predicted for I-2 mixes and open-graded mixes based on circular-track polish results. This prediction method allows the preevaluation of mixes for field polish resistance adequacy before construction is undertaken.

ACKNOWLEDGMENTS

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University. In addition, progress of the research has been aided by many of the personnel of the North Carolina State Highway Commission and the Federal Highway Administration as well as by several members of the North Carolina State University faculty, staff, and student body. The opinions, findings, and conclusions reported in this paper are those of the author and not necessarily those of the sponsors or the Federal Highway Administration.

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DISCUSSION

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The following discusses the relationships between skid-trailer numbers and British portable tester numbers for 4 types of pavement surfaces in Illinois. The data developed in Illinois support the relationships reported by Mullen. Mullen's correlations (as established in North Carolina) are not exactly the same as those developed from the Illinois research project. However, similarities exist, and the differences probably can be attributed to slight differences in state skid trailers and test procedures.

During the summer of 1971, extensive field work was performed by personnel of the University of Illinois in cooperation with research personnel from the Ottawa Physical Research Laboratory of the Illinois Department of Transportation. Approximately 50 sites were selected and studied. Field measurements taken at each site included, in part, state skid-trailer skid resistance values [at 40 mph (64.35 km/h)] and British portable tester skid resistance values. Four types of pavement surfaces, Illinois Class I, Class B, and Class A bituminous surfaces and portland cement concrete (PCC) surfaces, were studied. Skid-trailer tests were followed immediately by tests in the same skid traces with the British portable tester (9).

As a result of the data collection effort expended on Illinois Highway Research Project 406, limited data were obtained that permitted correlation of the BPNs with the Illinois skid-trailer values. To establish the correlation, a reduced major axis technique was employed to construct the line that best approximated or "fit" the observed trend. (This line minimizes the sum of the areas of the triangles formed by lines drawn from each point to the desired line and parallel with the x and y axes.) The 2 skid resistance variables for a specific surface type are plotted in Figures 12, 13, 14, and 15. For each surface type, the best fitting line and the correlation coefficient were established. This line has been drawn on each graph. All pertinent information is given in Table 3.

The information in Table 3 shows that a good correlation resulted for the 2 methods of determining skid resistance coefficients on bituminous surfaces (regression coefficient > 0.90). Greater variability was experienced on PCC pavement surfaces (regression coefficient ≃ 0.80). The relations in Figures 12, 13, 14, and 15 indicate that the British portable tester is responsive to measuring the coefficient of friction of pavement surfaces.

Mullen's approach to correlation of laboratory wear with field exposure appears promising. Further, the finding that the wear exhibited in the laboratory, after only several hours of exposure, was more extensive than that produced in the field after 40 million wheel passes is significant. Preevaluation of material performance can now be made based on sound technical data. This can result in more effective use of materials and in the construction of pavement surfaces that will exhibit desirable skid resistance qualities throughout their design life.

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S. Dahir, Pennsylvania State University

Mullen's paper is of particular interest to us at Pennsylvania State University because it is similar to some of our research findings. The basic objective of our research has been to preevaluate in the laboratory bituminous pavement mixtures and aggregates to predict skid resistance levels for the same mixtures and aggregates in the field. We have attempted to obtain a correlation between skid-trailer skid numbers and BPNs and have both procedures conform to respective ASTM methods. Taking measurements with both instruments on the same pavement at the same time was contemplated but not done because of constraints on time and help.

We attempted some correlations between SN_{40}s taken on Pennsylvania ID-2A dense mixes of 11 Pennsylvania test strips and BPNs taken on cores obtained from the same test sections and polished in the laboratory. The correlation lines, in general, resembled but differed from the BPN-SN_{40} correlation reported by Mullen for the North Carolina I-2 dense mixes.

In our work, we compared BPNs for cores polished with a flat 3.5- by 5.5-in. rubber pad in a reciprocating machine to SN_{40}s taken during 4 years of pavement polishing by traffic and corrected for temperature by PennDOT. Pavement cores terminally polished in the laboratory with a rubber surface were compared to pavements in the field polished with the passage of millions of vehicles over a 4-year period. We wanted to know how valid the results of our prediction curves would be if we used a laboratory polishing method to predict field skid resistance. When we saw Mullen's results obtained by simultaneous SN_{40}-BPN measurement correlations, we gained a greater measure of confidence in our laboratory polishing procedure as a predictor of SN_{40} after the pavement had been exposed to several million vehicle passes. Figures 16 through 19 show some of our results.

One thing that bothers us is the scatter of data around the average best fit curves. This scatter, both in our data and in Mullen's data (Fig. 2), shows a variation of approximately 6 ± 2 SN_{40} for a confidence interval covering 95 percent of the data points. To obtain a safe prediction, then, 1 of 2 approaches may be used. The lower confidence interval value may be used to predict about 6 (or more) skid numbers lower than the expected average, resulting in a satisfactory design for poorly performing aggregates and mixes but in overdesign for the good performers (as many as 12 or more SN_{40}s higher than may be required). Or, curves parallel to the average curve may be drawn

Figure 12. Relationship between BPN and state skid-trailer number for Class I surfaces.

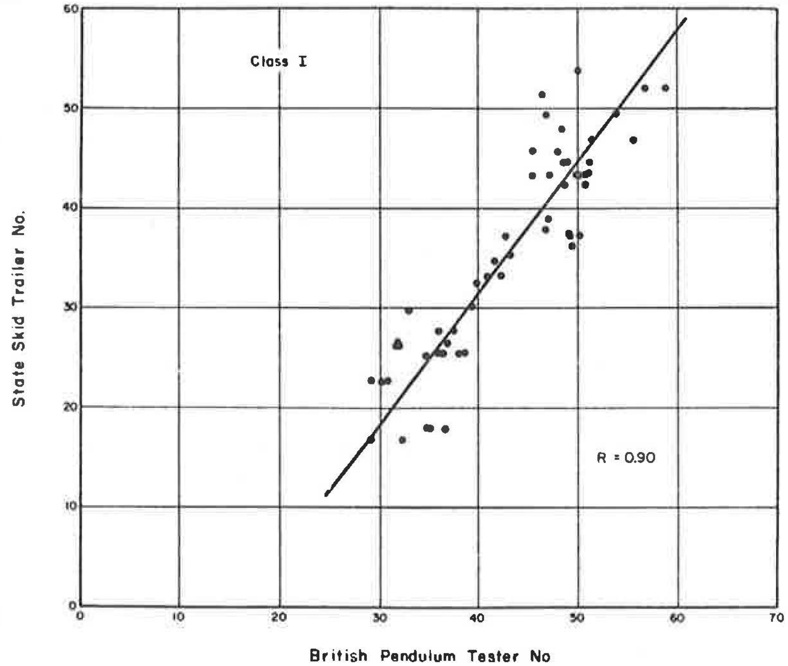


Figure 13. Relationship between BPN and state skid-trailer number for Class B surfaces.

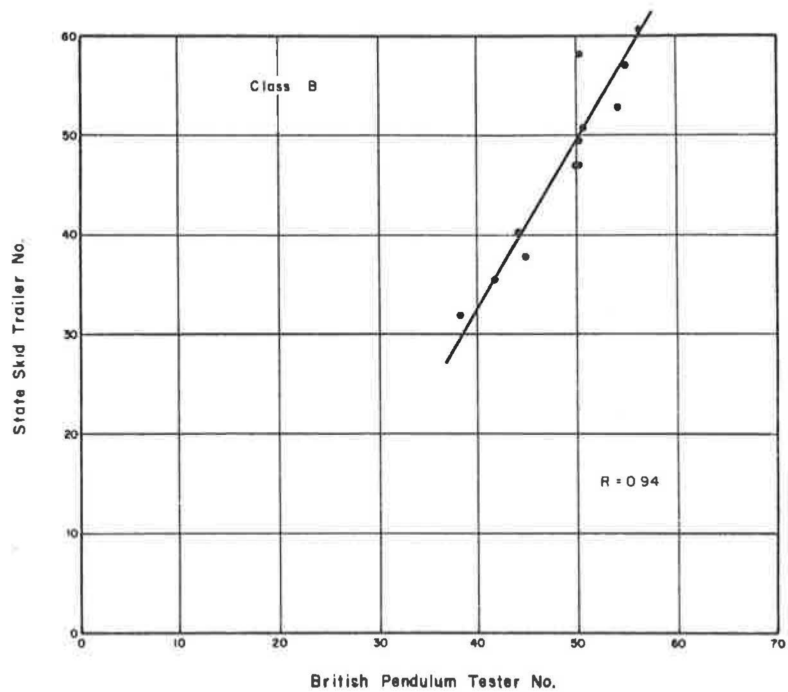


Figure 14. Relationship between BPN and state skid-trailer number for Class A surfaces.

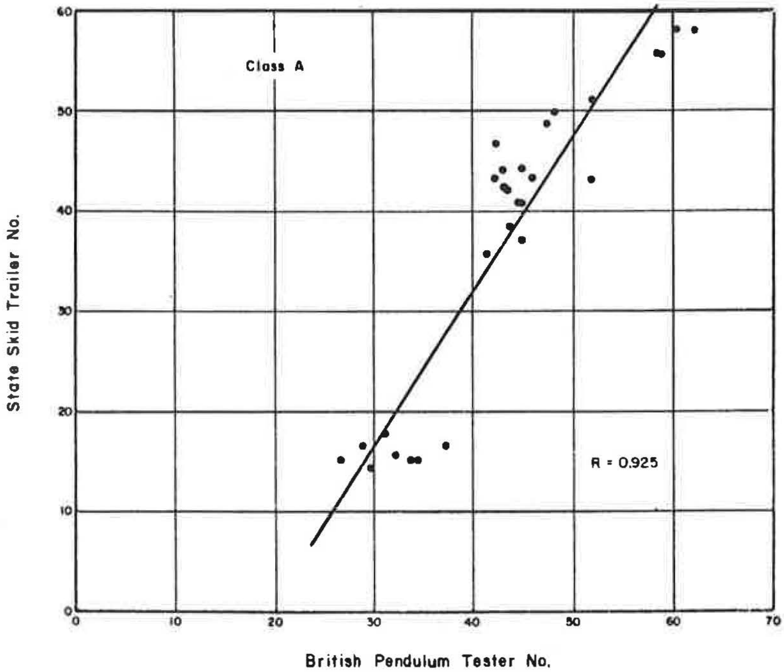


Figure 15. Relationship between BPN and state skid-trailer number for PCC surfaces.

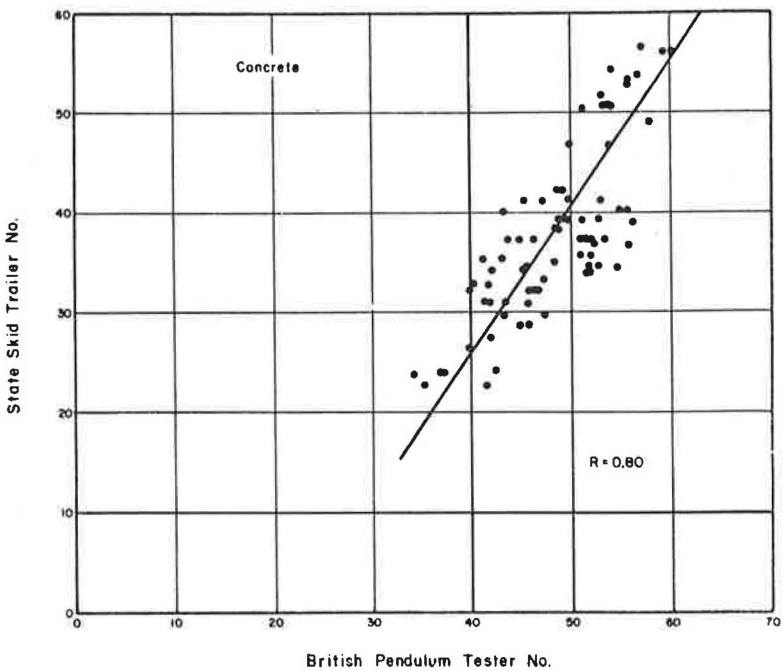


Table 3. Results from statistical analysis.

Type of Surface	N	Slope[a]	Intercept[a]	Correlation Coefficient[a]	Slope x on y[b]	Slope y on x[c]
PCC	76	1.4555	-32.477	0.80	1.8264	1.1599
Class I	56	1.3326	-21.769	0.90	1.4750	1.2040
Class B	12	1.6944	-35.366	0.94	1.7958	1.5986
Class A	28	1.5690	-30.538	0.92	1.6955	1.4520

[a]Reduced major axis. [b]Regression of x on y. [c]Regression of y on x.

Figure 16. Lowest 1972 SN_{40} on 44 sections in Montgomery County, Pennsylvania, 4 years after construction versus BPN of laboratory-polished cores.

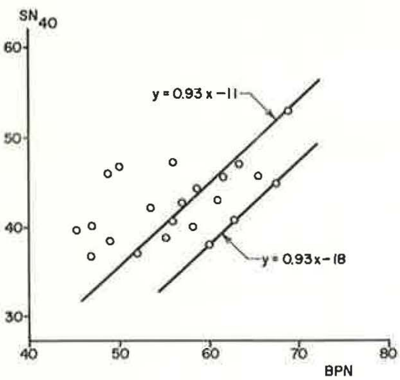


Figure 17. Four-year averages of annual SN_{40} lows for dense mixes containing 9 aggregates versus BPN of laboratory-polished cores from same mixes.

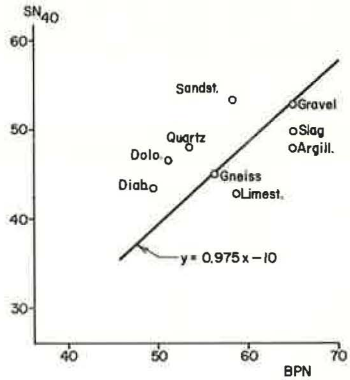


Figure 18. SN_{40} for dense mixes containing 9 aggregates measured 4 years after construction versus BPN of laboratory-polished cores.

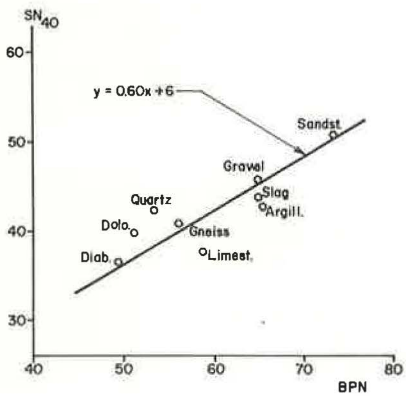


Figure 19. SN_{40} versus BPN for Pennsylvania and North Carolina data of bituminous dense-mix pavements.

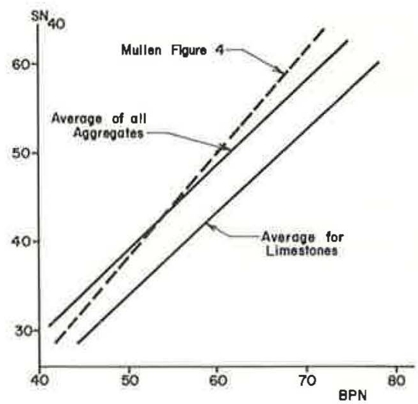
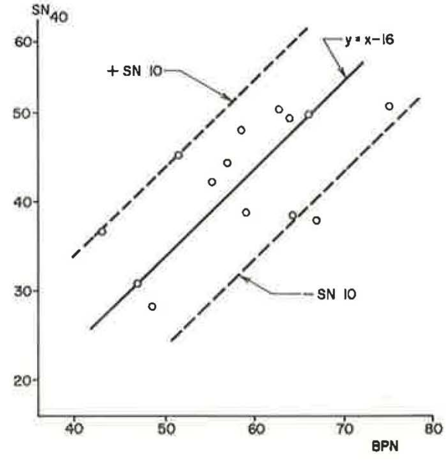


Figure 20. 1972 SN_{40} lows versus BPN of laboratory-polished cores of Pennsylvania limestone test sections.



through data points representing a particular aggregate and mix, and these curves may be used for the types of mixes and aggregates they represent.

The latter may be the more economical of the 2 methods and the more equitable approach when varying quality aggregates of the same type or group are involved, such as in the case of various limestones as may be seen from Figure 20.

AUTHOR'S CLOSURE

The discussions by Dahir and Marek, giving data from Pennsylvania and Illinois, seem to support the findings of the North Carolina BPN-SN correlation work. Differences in the actual correlations obtained are probably attributable to differences in the British portable testers and the skid trailers that were used plus differences in design and construction of the pavement surfaces that were evaluated.

The work presented by the discussants encourages belief in the conclusion that accelerated laboratory test results may be used to predict field performance of mixes and aggregate combinations for wear and polish resistance.