REFERENCES

1. K. H. Schulze and L. Beckman. Friction Properties of Pavements at Different Speeds. ASTM, Special Technical Publ. 326, 1962, pp. 42-49.
2. K. H. Schulze. Einfluss der geometrischen Feingestalt der Strassenoberflache auf den Kraftschluss. Strasse und Autobahn, Vol. 10, No. 10, 1959, pp. 379-385.
3. T. D. Gillespie. Pavement Surface Characteristics and Their Correlation With Skid Resistance. Joint Road Friction Program, Pennsylvania State Univ., and Pennsylvania Department of Highways, Rept. 12, 1965.
4. H. A. Goodman. Pavement Texture Measurement From a Moving Vehicle. Joint Road Friction Program, Pennsylvania State Univ., and Pennsylvania Department of Highways, Rept. 19, 1970.
5. E. D. Howerter and T. J. Rudd. Automation of the Schonfeld Method for Highway Surface Texture Classification. TRB, Transportation Research Record 602, pp. 57-61, 1976.
6. H. W. Kummer and W. E. Meyer. Tentative Skid-Resistance Requirements for Main Rural Highways. NCHRP, Rept. 37, 1967.

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

**Mr. McDonald and Mr. Kobett were with the Midwest Research Institute when this research was performed.*

Relation of Accidents and Pavement Friction on Rural, Two-Lane Roads

Rolands L. Rizenbergs, James L. Burchett, and Larry A. Warren, Division of Research, Kentucky Department of Transportation

Friction measurements were made with a skid trailer at 50 km/h (40 mph) on 2350 km (1460 miles) of rural, two-lane roads (U.S. routes) in Kentucky. Maintenance sections or subsections were treated as test sections. Accident experience, friction measurements, traffic volumes, and other available data were obtained for each section. Various expressions of wet-pavement accidents and pavement friction were related and analyzed. Averaging methods were used in developing trends and minimizing scatter. A moving average for progressively ordered sets of 10 test sections and test sections grouped by skid numbers and peak slip numbers yielded more definite results. The expression of accident occurrence that correlated best with skid resistance and peak slip resistance was ratio of wet- to dry-pavement accidents. Wet- to dry-pavement accident ratios increased greatly as skid number decreased from approximately 40 and as peak slip number decreased from approximately 71.

To ensure safe highway travel in wet weather, pavements must have sufficient and enduring skid resistance to enable drivers to perform driving tasks without risk of skidding and loss of vehicle control. Investigations to establish minimum friction requirements in Kentucky have focused on analysis of accident experience as related to pavement friction (1). The primary objective of this study was to discern a relationship between accident experience and pavement friction for principal, two-lane roads (U.S. routes) in rural areas of Kentucky. Evaluation of such a relationship in conjunction with economical and technical considerations will guide the establishment of minimum friction requirements for pavements.

To define a relationship between accidents and pavement friction, we must know or hold constant the effect of all pertinent parameters to the extent possible. By limiting this study to the principal, two-lane roads in rural areas, we were able to assume that parameters such as highway geometrics, access, and traffic speed would remain within reasonable bounds. Traffic characteristics (volume and density) and pavement-surface condition (wet or dry and pavement friction when wet) are respectively the regenerative and causative factors.

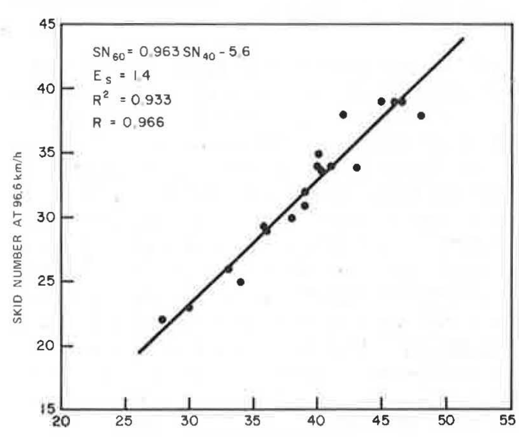
Annual average daily traffic volumes were obtained for 1969 and 1971. Accident data were those reported during 1969, 1970, and 1971. Pavement friction measurements were made between June and December 1970 on 2350 km (1460 miles) of the principal, two-lane roads. Both locked-wheel and peak slip resistances were measured. The measurements that best correlate with wet-pavement accidents remain to be established.

DATA ACQUISITION AND COLLATION

Measurements of annual average daily traffic (AADT) are generally available biennially. AADT data for 1969 and 1971 were averaged and used in these analyses.

Friction measurements were obtained by using a surface dynamics pavement friction tester. The two-

Figure 1. Relationship between skid numbers measured at 63.4 and 96.6 km/h.



wheeled, skid-test trailer was acquired in 1969. This skid trailer complies with ASTM designation E 274 (2). The measurements represent friction developed between a standard test tire (ASTM designation E 249) and a wetted pavement. The locked-wheel measurement is expressed as a skid number (SN); incipient or peak friction is expressed as a peak slip number (PSN). Measurements were obtained during the summer and fall of 1970 on most of the roads having a posted speed limit of 96.6 km/h (60 mph). Tests were made in the left wheel path only and at 1.6-km (1-mile) intervals in each lane; no less than five tests per lane were made on each test section. The test speed was 63.4 km/h (40 mph). Additional tests were made on selected class 1 bituminous pavements at 96.6 km/h (60 mph). Comparison between the SNs obtained at the two speeds is presented in Figure 1.

Accident data were obtained from state police records, which are computerized and maintained by the Kentucky Department of Justice. All accidents reported during 1969, 1970, and 1971 were analyzed. Accidents for the 3-year period totaled 8481; of these, 1844 occurred during wet-pavement conditions. From these accident records, many expressions of accident occurrence may be calculated. However, based on the findings of an earlier study on the Interstate and parkway routes (1), rates of wet-pavement accidents and ratios of wet-to dry-pavement accidents were used primarily.

The ASTM definition of a test section was used: a section of pavement of uniform age and uniform composition which has been subjected to essentially uniform wear along its length. Almost all construction and resurfacing projects (maintenance sections) involved fit this definition. Because the direction of travel of vehicles involved in accidents was not given in the accident reports, test sections included both directions of travel. There were 230 test sections; 217 of these were bituminous pavements and the remaining 13 were portland cement concrete (PCC) pavements. The average length of the test section was 10.1 km (6.3 miles). Sections less than 3.2 km (2.0 miles) in length were not included.

The left wheel-path SNs and PSNs for both directions of travel were averaged to characterize the frictional properties of the test sections. Distribution of the SNs for the 230 test sections is shown in Figure 2. The relationship between SN and PSN is shown in Figure 3. Rates of wet-pavement accidents for 100 million vehicle·km (62 million vehicle-miles), the total distance traveled under all pavement conditions, and ratios of wet- to dry-pavement accidents were calculated for each test section. The rates were based on the lengths of sections and AADT (1969 and 1971). Both rates and ratios pertain to accidents for a 3-year period.

SKID NUMBERS AND ACCIDENTS

The ratio of wet- to dry-pavement accidents versus SN for the 230 test sections is shown in Figure 4. The data points are extremely scattered. The relationship between accident occurrence and skid resistance is obviously obscured by other causative factors. Multiple-regression analyses were performed with the ratio of wet- to dry-pavement accidents as the dependent variable and SN, AADT, pavement width, and access points per kilometer as the independent variables. The data were further stratified by AADT and SN. Similar analyses were performed with the wet-pavement accident rate as the dependent variable. The coefficients of correlation (R) indicated a substantially better correlation between SN and the ratio of wet- to dry-pavement accidents than with the wet-pavement accident rate. The correlation coefficients, however, were low (less than 0.430). For the ratio of wet- to dry-pavement accidents, some correlation with AADT was evident; but with pavement width or access points per kilometer, correlation was not evident in the range of SNs between 17 and 44. For the wet-pavement accident rate, there were stronger correlations with volume (above 2700 vehicles/d) and pavement width than with SN and to a lesser extent with access. These findings, however, must be viewed with caution because the data base was not sufficiently large to yield definitive results.

Two averaging methods were used to reduce variability and thus to more clearly discern general relationships in the data sets with and without volume stratification. In the first method of calculating averages, test sections were grouped by SN. The average ratio of wet- to dry-pavement accidents was calculated for each group of two SNs. These averages are plotted in Figures 5, 6, and 7. Lines were drawn to approximate trends. Reasonably distinct break points were evident. When all test sections were included (Figure 5), the trend line indicated the ratio of wet- to dry-pavement accidents decreased as SN increased to approximately 41; further increases in SN resulted in nominal reduction in the accident ratio. Stratification of data by AADT indicated that on the low-volume roads (650 to 2700 vehicles/d) the critical SN was about 43. On high-volume roads (above 2700 vehicles/d) the critical SN was about 38.

The second method involved calculation of an average ratio of wet- to dry-pavement accidents and average SN for progressively ordered sets of 10 test sections. The first average was of the 10 test sections with the lowest SNs. The test section with the lowest SN was then dropped, and a test section with the next highest SN was added. This procedure was repeated until all test sections had been averaged in a group of 10. In cases in which more than one test section had the next highest SN, one of these test sections was randomly added each time. Test sections were dropped in the same sequence as they were added. The resulting averages are plotted in Figures 8, 9, and 10. The trend lines were similar to those developed by the previous method. The break points in the trend lines, however, occurred at slightly different SNs. The following table gives the critical SN derived by using the two averaging methods.

AADT Stratification	Grouped by SN	Moving Average
650 to 8400	41	40
2700 or less	43	45
Above 2700	38	39

Plots of the 10-point moving average and test sections grouped by SN but involving wet-pavement accident rate were also prepared. The plots also indicated a relationship between accident occurrence and skid resistance, but the data points were more scattered; and, as stated above, other variables correlated with accident occurrence as well. The break points in the trend lines were at higher SNs than for the accident expression of ratio of wet- to dry-pavement accidents.

The above analysis showed that the critical SN was higher for the low-volume (650 to 2700 vehicles/d) roads than for the high-volume (2701 to 8400 vehicles/d) roads. Therefore, we had to ascertain whether traffic volume or other factors accounted for the differences in critical SNs. Information was available on pavement width, access, and pavement friction, but an inventory of highway geometrics was not available. Accident records did indicate whether the accidents occurred on grade or level and on curve or tangent sections. Various expressions of accident occurrence, such as ratio of wet-pavement accidents on curves to wet-pavement accidents on tangent sections and dry-pavement accidents on curves to dry-pavement accidents on tangent sections, were calculated for test sections grouped by AADT. The results are given in Table 1 in addition to average SN and other data.

The high AADT roads exhibited slightly lower SNs and had wider pavements. There were no appreciable differences in access points per kilometer. The ratios of wet- to dry-pavement accidents, however, did not indicate trends consistent with the level of skid resistance. Obviously, other influences were present. The ratios of accidents grouped by other identifying conditions in dry weather and also in times of wetness showed marked differences between AADT groups—the ratios were substantially lower for test sections with high AADT. Also, the ratios within sorted wet-pavement accidents were much higher than the ratios of dry- to dry-pavement accidents within the same AADT group and, therefore, reflect increased hazards associated with wet-weather driving on curves and grades compared to driving on tangent sections. The ratios in the wet-pavement categories, of course, would also be affected by differences in skid resistance between level, tangent sections, and sections with other geometrical alignments.

The accident ratios given in Table 1 do suggest a difference between test sections with low and high AADT in regard to geometrics of the highway. The average adequacy rating (3) for each set of test sections was 60. However, when adjusted to the same traffic volume, the adequacy rating was substantially higher for the high

Figure 2. Distribution of SNs for 230 test sections.

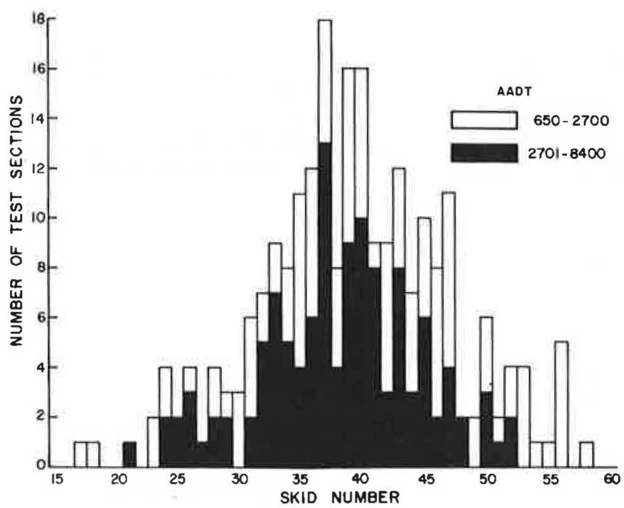


Figure 3. Relationship between SN and PSN at 63.4 km/h.

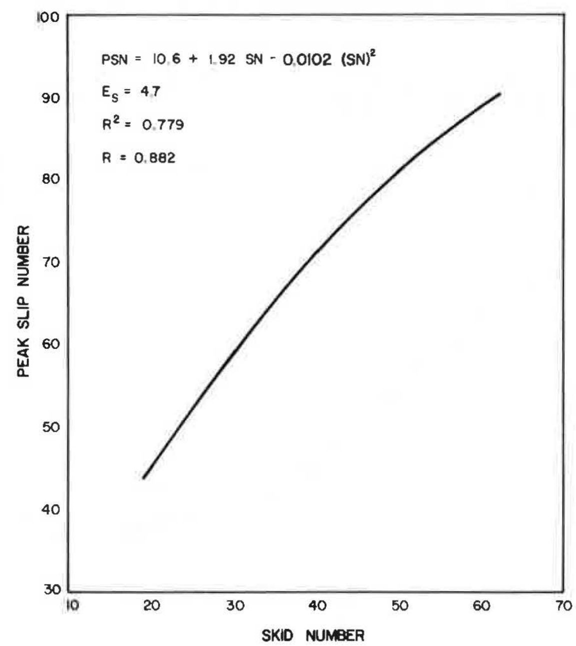
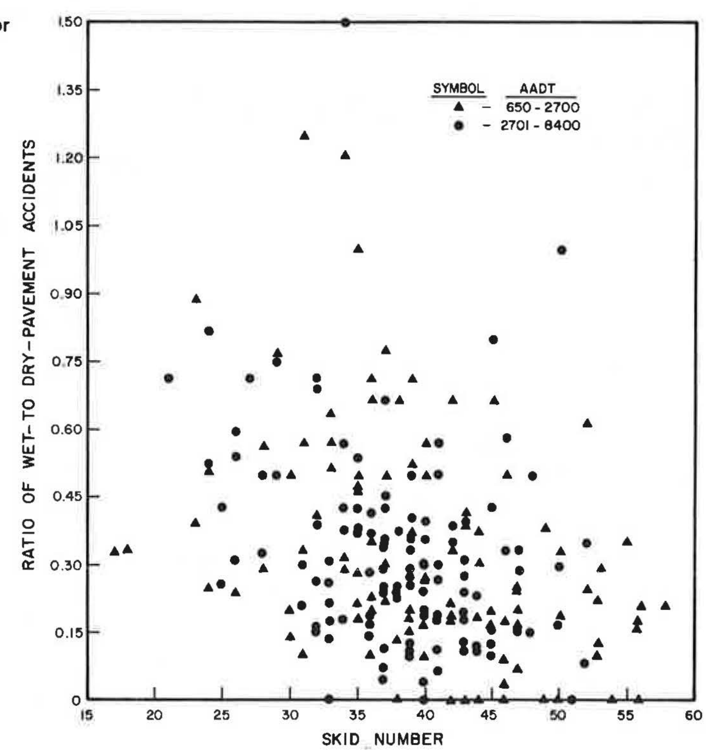


Figure 4. Ratio of wet- to dry-pavement accidents versus SNs for 230 test sections.



AADT roads than for the low AADT roads. This finding implied that the previous conclusion may be correct. The higher critical SNs derived from Figures 6 and 9, therefore, may be partially attributable to the poorer geometrics associated with the low AADT roads.

The accident data used in the analysis here pertained to the entire 3 years although skid resistance was measured in the summer and fall of 1970. Pavements, of course, exhibit lower friction during the summer and fall, but the measured values may not necessarily represent the lowest friction during the year for a particular test section nor for the road system as a whole. The rapid change in the slope of the curve in Figure 8, for example, may occur at some higher or lower SN depending on when the measurements were made. Measurements are normally conducted in the summer and fall,

Figure 5. Average ratio of wet- to dry-pavement accidents of 230 test sections (grouped by skid number) versus SN, without volume stratification.

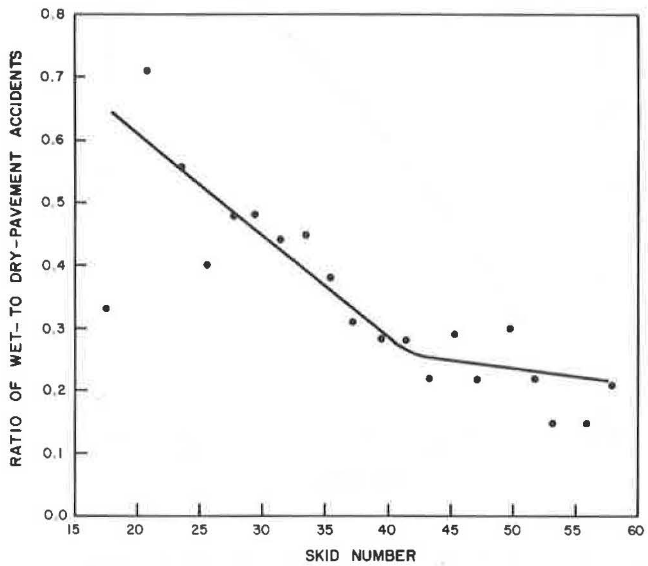


Figure 6. Average ratio of wet- to dry-pavement accidents of 230 test sections (grouped by skid number) versus SN, with volume stratification at AADT below 2701.

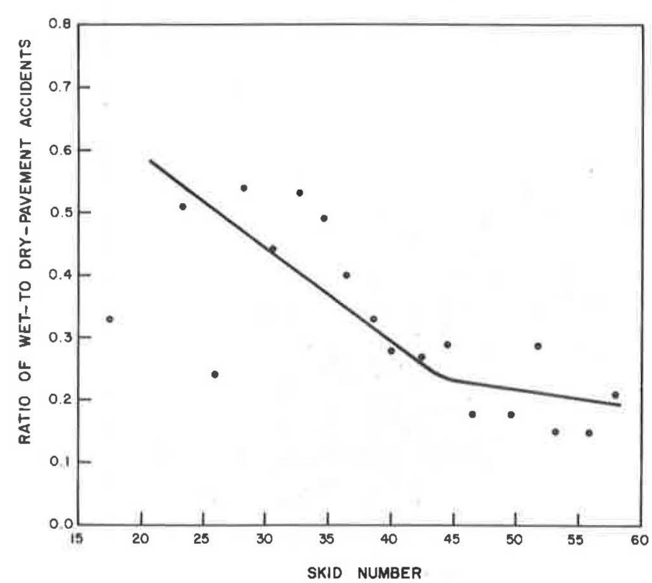


Figure 7. Average ratio of wet- to dry-pavement accidents of 120 test sections (grouped by skid number) versus SN, with volume stratification at AADT above 2700.

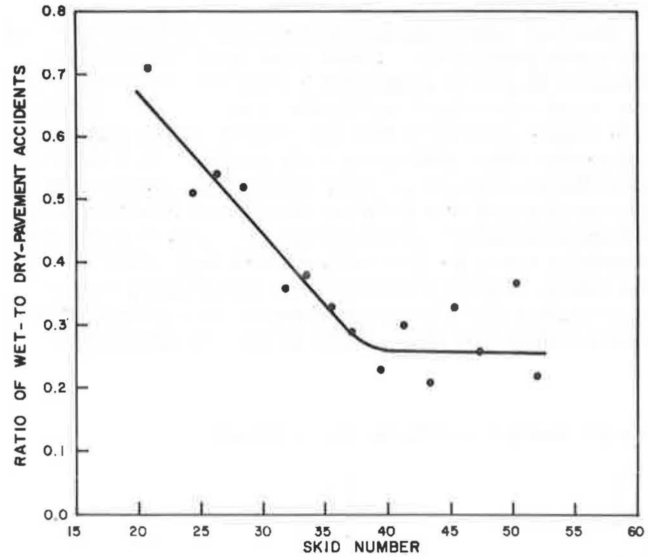


Figure 8. Ten-point moving averages: ratio of wet- to dry-pavement accidents for 230 test sections versus SN, without volume stratification.

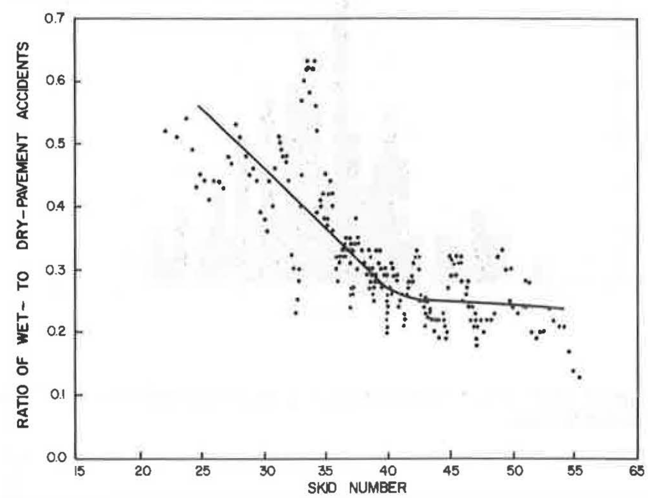
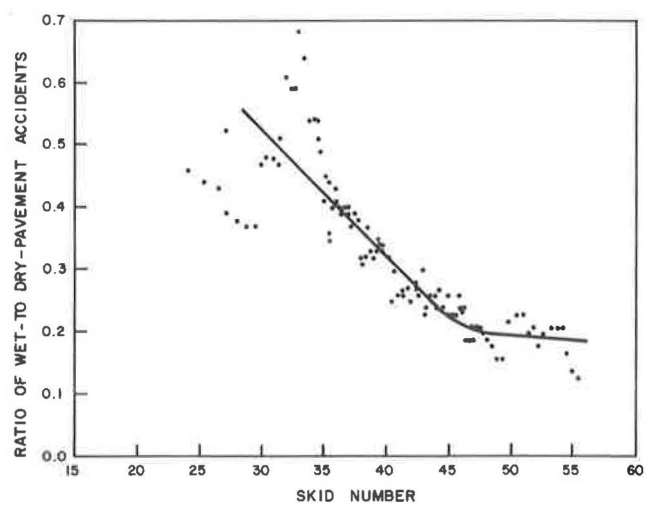


Figure 9. Ten-point moving averages: ratio of wet- to dry-pavement accidents for 110 test sections versus SN, with volume stratification at AADT below 2701.



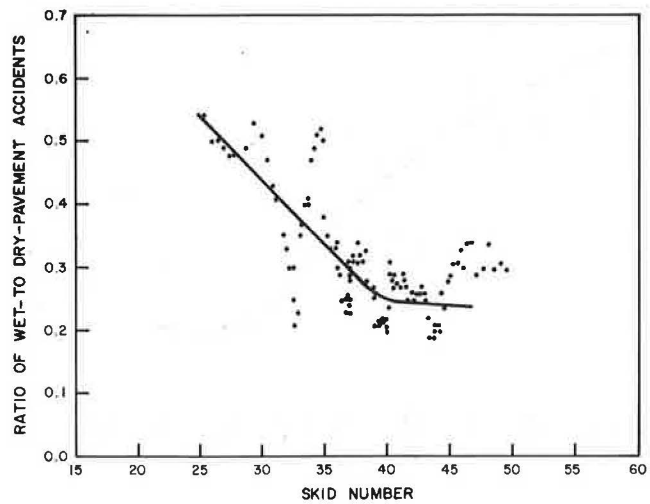


Figure 10. Ten-point moving averages: ratio of wet- to dry-pavement accidents for 120 test sections versus SN, with volume stratification at AADT above 2700.

and the critical SN derived here will apply. If the measurements are conducted during other seasons of the year, the seasonal variation peculiar to a given pavement type must be taken into consideration.

Wet-pavement accident rates were calculated for 100 million vehicle·km (62 million vehicle-miles) for total travel under all pavement conditions rather than wet-pavement travel. The true accident rate for wet-pavement conditions would be nine times higher since pavements were wet only 11 percent of the time. Wet-weather accidents accounted for 22 percent of all accidents. Only 11 percent of all accidents, therefore, can be attributed to the time associated with wet-weather driving. This percentage, and the wet-pavement accident rate and the ratio of wet- to dry-pavement accidents vary from year to year according to the precipitation experience.

The influence of skid resistance on accidents for test sections with SNs above 41 was nominal. The ratio of wet- to dry-pavement accidents was approximately 0.23 (Figure 5). The lowest accident ratio would not be less than 0.13 since pavements were wet 11 percent of the time. Other factors related to wet-weather driving

Table 1. Data for test sections grouped by traffic volume.

Item	Annual Average Daily Traffic Volume							
	650 to 1700	1701 to 2700	2701 to 3700	3701 to 4700	4701 to 8400	650 to 2700	2701 to 8400	650 to 8400
Number of test sections	53	57	57	35	28	110	120	230
Skid number	42.8	38.2	39.2	37.0	37.6	40.4	38.2	39.3
Peak slip number	73.2	68.6	70.0	67.3	68.5	70.9	68.9	69.8
AADT	1263	2219	3159	4135	6036	1758	4115	2988
Access points per kilometer	5.2	5.3	5.2	6.1	5.5	5.2	5.5	5.3
Section length	6.9	7.2	6.2	5.6	4.8	7.0	5.7	6.3
Pavement width	19.7	20.4	20.4	21.7	22.0	20.1	21.2	20.6
Wet-pavement accident rate[a]	23.9	31.7	27.8	26.0	17.5	28.0	24.9	26.3
Ratio of wet- to dry-pavement accidents								
All sections	0.27	0.37	0.35	0.36	0.22	0.32	0.32	0.32
Tangent sections	0.25	0.28	0.27	0.32	0.20	0.26	0.27	0.27
Tangent sections on grade	0.28	0.40	0.33	0.37	0.35	0.34	0.35	0.34
All tangent sections	0.23	0.31	0.28	0.35	0.21	0.27	0.28	0.28
Level curved sections	0.30	0.52	0.39	0.49	0.24	0.41	0.38	0.40
Curved sections on grade	0.44	0.62	0.74	0.40	0.27	0.53	0.53	0.53
All curved sections	0.46	0.59	0.74	0.44	0.33	0.53	0.56	0.55
Ratio of dry- to dry-pavement accidents								
Level curved and level tangent sections	0.48	0.33	0.23	0.25	0.09	0.41	0.20	0.30
Curved and tangent sections on grade	0.99	1.58	0.77	0.58	0.25	1.30	0.59	0.93
All curved and all tangent sections	0.60	0.63	0.41	0.28	0.12	0.61	0.30	0.45
Ratio of wet- to wet-pavement accidents								
Level curved and level tangent sections	0.45	0.50	0.43	0.72	0.15	0.48	0.45	0.46
Curved and tangent sections on grade	0.72	1.24	1.45	0.62	0.21	0.99	0.92	0.95
All curved and all tangent sections	0.87	1.05	0.89	0.68	0.20	0.96	0.67	0.81

[a] Accidents/100 million vehicle·km.

Note: 1 km = 0.62 mile.

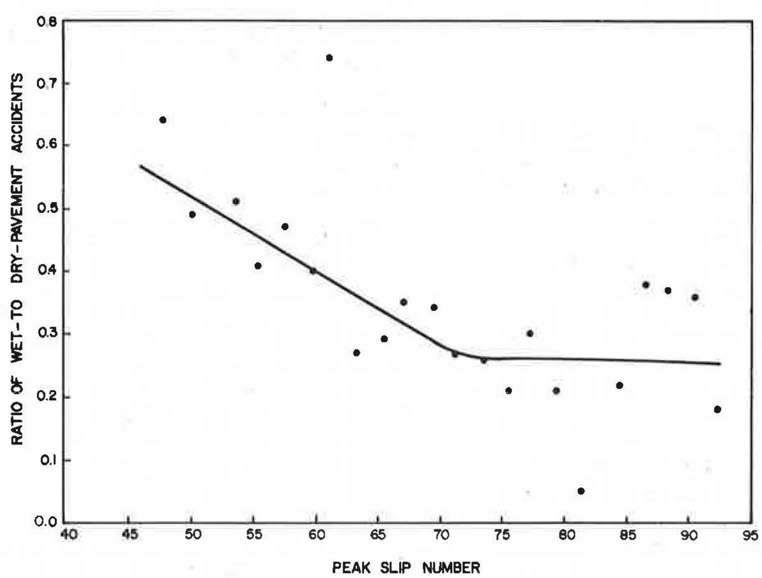


Figure 11. Average ratio of wet- to dry-pavement accidents of 230 test sections (grouped by peak slip numbers) versus PSN, without volume stratification.

Figure 12. Average ratio of wet- to dry-pavement accidents of 110 test sections (grouped by peak slip numbers) versus PSN, with volume stratification at AADT below 2701.

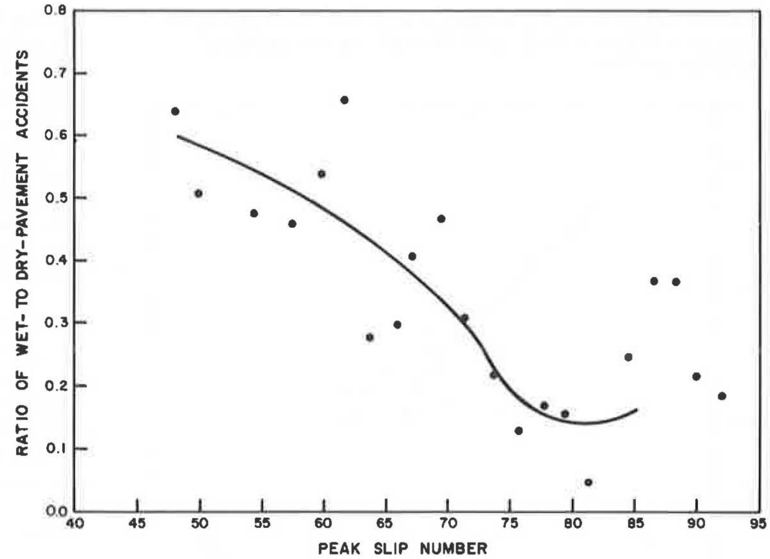
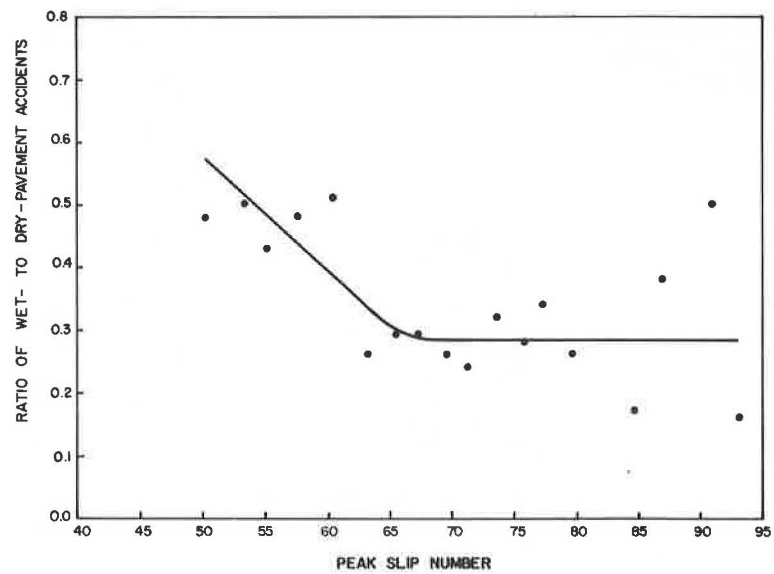


Figure 13. Average ratio of wet- to dry-pavement accidents of 120 test sections (grouped by peak slip numbers) versus PSN, with volume stratification at AADT above 2700.



contributed to the elevated accident ratio.

PEAK SLIP NUMBERS AND ACCIDENTS

As stated above, the measurement that best correlates with accident experience remains to be established. The peak friction force was measured routinely during all tests; thus PSNs were available for analysis.

Multiple-regression analysis again indicated substantially better correlation between PSN and the ratio of wet- to dry-pavement accidents than with wet-pavement accident rate. The correlation coefficients were low (less than 0.350). Correlation with AADT was also evident.

Test sections were grouped by PSNs, and the average ratio of wet- to dry-pavement accidents was calculated for each group of two PSNs, as shown in Figures 11, 12, and 13. When all test sections were included (Figure 11), the greatest change in slope occurred at a PSN of 71. Stratification of data by AADTs indicated a change at a higher PSN for the low-volume roads and a lower PSN for the high-volume roads. Similar results were obtained by using the 10-point moving average; and the change in the slopes remained at the same PSNs. The critical PSNs are given in the following table.

AADT Stratification	Moving Average	Grouped by PSN
650 to 8400	71	71
2700 or less	74	74
Above 2700	65	65

The point of greatest change in slope of the curve in Figure 11 was at a PSN of 71 and in Figure 5 at SN of 41. According to Figure 3, a PSN of 71 is equivalent to SN of 40. The data were not so scattered in Figures 5, 6, and 7 as in Figures 11, 12, and 13; and, as cited above, there was a stronger correlation between accident occurrence and SNs than with PSNs. These findings, therefore, suggest that the SNs relate better to accident occurrence. This conclusion was not necessarily surprising because of the inherent measurement and chart analysis errors associated with peak slip resistance (PSN) determination. Peak slip resistance occurs for a very brief period of time during wheel lockup, and the measurement represents a much shorter length of pavement than the locked-wheel test (SN). For that reason, the poor agreement between SN and PSN in Figure 3 was attributed largely to inaccuracies in PSN.

SUMMARY AND CONCLUSIONS

On rural, two-lane roads, ratio of wet- to dry-pavement accidents correlated best with pavement friction. Even using the best expression of accidents, we found that scatter and spurious variability in data seem inevitable. Averaging methods as a means of developing trends and minimizing scatter between variables were used in the study. Of the averaging methods investigated, the moving average and test sections grouped by SNs yielded more definite results. Definite trends were established in regard to the relationship between ratio of wet- to dry-pavement accidents and SN (Figures 5 and 10). When all test sections were included, the ratio of wet- to dry-pavement accidents decreased rapidly as SN increased to approximately 40; further increases in SN beyond this point resulted in only slight reduction in the ratio of wet- to dry-pavement accidents. Stratification of the data into two AADT groups showed that the critical SNs were higher for the low-volume roads than for the high-volume roads. Ratios of dry- to dry-pavement and wet- to wet-pavement accidents (Table 1) and sufficiency ratings suggested that the low-volume roads may have poorer geometric characteristics. The effect of traffic volume on the frictional demand of traffic, therefore, could not be separated from the other contributing influences.

Definite trends were also evident between ratio of wet- to dry-pavement accidents and PSN. The greatest change in slope of the trend line (Figure 11) occurred at a PSN of approximately 71. Scatter of data was somewhat worse than for SNs. This scatter was to be expected because of the inherent measurement and chart analysis inaccuracies associated with peak slip resistance determinations. A PSN of 71 is equivalent to an SN of approximately 40 (Figure 3); and, as shown in Figure 8, an SN of 40 also corresponds to the greatest change in slope of the trend line. Multiple-regression analysis, however, showed a stronger relationship between accident occurrence and SNs.

The curves shown in Figures 5 through 10 not only suggest critical SNs but may also be useful in ascertaining the level of accident experience peculiar to the roads involved in this study. No meaningful reduction in wet-pavement accidents may be realized by improving the skid resistance of those pavements that exhibit SNs above the critical value. Also, a low SN does not necessarily imply an accident problem. Some sections with low SNs obviously exhibited accident histories similar to sections with substantially higher SNs. Highway geometrics, pavement rutting and roughness, and so forth, of course, need to be considered in the selection of pavements for deslicking. However, the following general guide is suggested for assessing pavement skid resistance in Kentucky.

Skid Number	Skid-Resistance Assessment
Above 39	Skid resistant
33 to 39	Marginal
26 to 32	Slippery
Below 26	Very slippery

The ratio of wet- to dry-pavement accidents is particularly adaptable for screening sections because the ratio can be readily calculated. On the other hand, calculation of accident rates requires data on traffic volumes that are not always available or may be inaccurate. Also, a high wet-pavement accident rate may be misleading if the highway also has a high dry-pavement accident rate.

The findings cited in this study pertain to principal, two-lane rural roads (U.S. routes). These roads had posted speeds of 96.6 km/h (60 mph) for daytime and 80.5 km/h (50 mph) for nighttime. In response to the energy crisis, the posted speeds on these highways were changed on March 1, 1974, to 88.5 km/h (55 mph) for both daytime and nighttime. Fatalities, injuries, and accidents, as well as fatality rates, injury rates, and accident rates, have substantially decreased since the beginning of the energy crisis (4). Wet-weather accident experience has also been affected. The relationship between accident experience and pavement friction may have been altered as well.

ACKNOWLEDGMENTS

The work reported in this paper was done by the Bureau of Highways, Kentucky Department of Transportation, in cooperation with the Federal Highway Administration. Contents of the paper reflect our views and not necessarily the views or policies of the Kentucky Department of Transportation or the Federal Highway Administration.

REFERENCES

1. R. L. Rizenbergs, J. L. Burchett, J. A. Deacon, and C. T. Napier. Accidents on Rural Interstate and Parkway Roads and Their Relation to Pavement Friction. TRB, Transportation Research Record 584, 1976, pp. 22-36.
2. R. L. Rizenbergs, J. L. Burchett, and C. T. Napier. Skid Test Trailer: Description, Evaluation and Adaptation. Division of Research, Kentucky Department of Highways, Sept. 1972.
3. Field Procedure Manual for Sufficiency Ratings on All Systems. Kentucky Department of Highways, 1963.
4. K. R. Agent, D. R. Herd, and R. L. Rizenbergs. First-Year Effects of the Energy Crisis on Rural Highway Traffic in Kentucky. TRB, Transportation Research Record 567, 1976, pp. 70-81.

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