Accidents on Rural, Two-Lane Roads and their Relation to Pavement Friction
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ACCIDENTS ON RURAL, TWO-LANE ROADS
AND THEIR RELATION TO PAVEMENT FRICTION

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R. L. Rizenbergs, J. L. Burchett, and L. A. Warren

ABSTRACT

Friction measurements were made with a skid trailer at 40 mph (18 m/s) on 1460 miles (2350 km) of rural, two-lane roads (US 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. 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 ten test sections and test sections grouped by Skid Numbers and Peak Slip Numbers yielded more definite results. The expression of accident occurrence which correlated best with skid resistance and peak slip resistance was ratio of wet- to dry-pavement accidents. Wet-pavement accidents increased greatly as Skid Number decreased from about 40 and as Peak Slip Number decreased from about 71.
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INTRODUCTION

To assure 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 (or) loss of vehicle control. Ideally, wet pavements should provide as much friction as dry pavements. In a practical and realistic sense, however, the question remains as to what minimum level of friction a pavement should provide to safeguard the public from undue hazards associated with wet-weather driving. The critical value may serve as a criterion for design of surface courses providing a due margin of safety and assist in the selection of pavements for resurfacing.

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 (US routes) located in rural areas of Kentucky. Evaluation of such a relationship in conjunction with economical and technical considerations will guide in the establishment of minimum friction requirements for pavements.

To define a relationship between accidents and pavement friction, the effect of all pertinent parameters must be known or held constant insofar as possible. By limiting this study to the principal, two-lane roads in rural areas, parameters such as highway geometrics, access, and traffic speed may be assumed to 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 1460 miles (2350 km) of the principal, two-lane roads. Both locked-wheel and peak slip resistances were measured. The measurement(s) which best correlate(s) with wet-pavement accidents remains to be established.

DATA ACQUISITION AND COLLATION

Traffic Volumes

The measurement of traffic volume which is generally available biennially is an annual average daily traffic (AADT). The AADT data for 1969 and 1971 were averaged and used in these analyses.

Friction Measurements

Friction measurements were obtained using a Surface Dynamics Pavement Friction Tester (Model
965A) developed by the General Motors Proving Ground and manufactured by K. J. Law Engineers, Inc., Detroit, Michigan. The two-wheeled skid-test trailer was acquired in 1969. This skid trailer complies with ASTM E 274 (2, 3). The measurements represent friction developed between a standard test tire (ASTM E 249) (4) and a wetted pavement. The locked-wheel measurements are expressed as Skid Numbers (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 principal two-lane roads (US routes) in rural areas having a posted speed limit of 60 mph (26.8 m/s). Tests were made in the left wheel path only and at 1-mile (1.6-km) intervals in each lane; no less than five tests per lane were made on each test section. The test speed was 40 mph (18 m/s). Additional tests were made on selected Class I, bituminous pavements at 60 mph (26.8 m/s). Comparison between the Skid Numbers obtained at the two speeds are presented in Figure 1.

Accident Information

Accident data were obtained from State Police Records, which are computerized and maintained by the Kentucky Department of Justice. All accidents reported during the calendar years 1969, 1970, and 1971 were analyzed. Accidents for the 3-year period totaled 8481 -- of which 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.

Test Sections

A test section is defined as "a section of pavement of uniform age and uniform composition which has been subjected to essentially uniform wear along its length" (2). Almost all construction projects and resurfacing projects (maintenance sections) involved fit this definition. Inasmuch as the direction of travel for a vehicle involved in an accident was not given in the accident reports, sections included both directions of travel. There were 230 test sections -- of which 217 were bituminous pavements and the remaining 13 were portland cement concrete pavements. The average length of the test section was 6.3 miles (10.1 km). Sections less than 2.0 miles (3.2 km) in length were not included.

The left wheel-path Skid Numbers and Peak Slip Numbers for both directions of travel were averaged to characterize the frictional properties of the test sections. Distribution of the skid numbers for the 230 test sections are exhibited in Figure 2. The relationship between SN and PSN is shown in Figure 3.

Rates of wet-pavement accidents, in terms of 100 million vehicle miles (161 million vehicle kilometers) (total miles (kilometers) traveled under all pavement conditions), and ratios of wet- to
Dry-pavement accidents were calculated for each test section. The rates were based upon the lengths of sections and the AADT’s (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 Skid Number for the 230 test sections are shown in Figure 4. The data points, there, 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 Skid Number, AADT, pavement width, and access points per mile (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 mile (kilometer), correlation was not evident in the range of SN’s between 17 and 44. For the wet-pavement accident rate, there were stronger correlations with volume (above 2700 vehicles per day) 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, thereby, 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 SN’s. These averages are plotted in Figures 5 through 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 the Skid Number 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 per day), the critical SN was about 43. On high volume roads (above 2700 vehicles per day), the critical SN was about 38.

The second method involved calculation of an average ratio of wet- to dry-pavement accidents and average Skid Number for progressively-ordered sets of ten test sections. The first average was of the ten test sections with the lowest SN’s. The test section with the lowest SN was then dropped, and a test section with the next highest SN was added. This was repeated until all test sections had been
averaged in a group of ten. In cases where more than one test section had the next highest SN, one of these 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 through 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 SN's. Table 1 cites the critical Skid Numbers derived by the two averaging methods.

Plots of the ten-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 before, other variables correlated with accident occurrence as well. The break points in the trend lines were at higher SN's than for the accident expression of ratio of wet- to dry-pavement accidents.

The foregoing analysis showed that the critical Skid Number was higher for the low volume (650 to 2700 vehicles per day) roads than for the high volume (2701 to 8400 vehicles per day) roads. It was necessary, therefore, to ascertain if traffic volume or other factors accounted for the differences in critical SN's. 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's. The results are presented in Table 2 along with average SN and other data.

The high AADT roads exhibited slightly lower Skid Numbers and had wider pavements. There were no appreciable differences in access points per mile (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 the high AADT's. 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 presented in Table 2 do suggest a difference between test sections with low and high AADT's in regard to geometrics of the highway. The average adequacy rating (5) 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 AADT roads than for the low AADT roads. This finding implied that the previous conclusion may be correct. The higher critical Skid Numbers 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 while 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 instance, may occur at some higher or lower SN depending on when the measurements were made. Measurements are normally conducted in the summer and fall 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 miles (161 million kilometers) for total travel under all pavement conditions rather than wet-pavement travel mileage. 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, may 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, of course, varies from year to year according to the precipitation experience.

The influence of skid resistance on accidents for test sections with Skid Numbers 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 the wet-weather driving contributed to the elevated accident ratio.

**PEAK SLIP NUMBERS AND ACCIDENTS**

As stated previously, the measurement(s) which best correlates with accident experience remains to be established. The peak friction force was measured routinely during all tests; thus Peak Slip Numbers 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 PSN's, and the average ratio of wet- to dry-pavement accidents was calculated for each group of two PSN's, as shown in Figures 11 through 13. When all test sections
were included (Figure 11), the greatest change in slope occurred at a PSN of 71. Stratification of data by AADT's 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 utilizing the ten-point moving average; and the change in the slopes remained at the same Peak Slip Numbers. The critical PSN's are presented in Table 3.

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 as scattered in Figures 5 through 7 as in Figures 11 through 13; and, as cited earlier, there was a stronger correlation between accident occurrence and SN's than with PSN's. These findings, therefore, suggest that the Skid Numbers relate better to accident occurrence. This 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 lock-up, 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, 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 Skid Numbers yielded more definite results. Definite trends were established in regard to the relationship between ratio of wet- to dry-pavement accidents and Skid Number (Figures 5 and 10). When all test sections were included, the ratio of wet- to dry-pavement accidents decreased rapidly as the Skid Number increased to about 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 SN's 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 2) 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 Peak Slip Number. The greatest change in slope of the trend line (Figure 11) occurred at a PSN of about 71. Scatter of data was somewhat worse than for Skid Numbers. This was to be expected because of the inherent measurement and chart analysis inaccuracies associated with peak slip resistance determinations.
Peak Slip Number of 71 is equivalent to SN of about 40 (Figure 3); and, as shown in Figure 8, 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 Skid Numbers.

The curves shown in Figures 5 through 10 not only suggest critical SN's but may 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 which exhibit SN's above the critical value. Also, a low Skid Number does not necessarily imply an accident problem. Some sections with low SN's obviously exhibited accident histories similar to sections with substantially higher SN's. Highway geometries, pavement rutting and roughness, etc., 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:

<table>
<thead>
<tr>
<th>SKID NUMBER</th>
<th>SKID RESISTANCE ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 39</td>
<td>Skid Resistant</td>
</tr>
<tr>
<td>33 to 39</td>
<td>Marginal</td>
</tr>
<tr>
<td>26 to 32</td>
<td>Slippery</td>
</tr>
<tr>
<td>Below 26</td>
<td>Very Slippery</td>
</tr>
</tbody>
</table>

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 which 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.

It should be emphasized that the findings cited here pertain to principal, two-lane roads (US routes) located in rural areas. These roads had posted speeds of 60 mph (26.8 m/s) for daytime and 50 mph (22.4 m/s) for nighttime. In response to the energy crisis, the posted speeds on these highways was changed on March 1, 1974, to 55 mph (24.6 m/s) 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 (6). Wet-weather accident experience has also been affected. The relationship between accident experience and pavement friction may have been altered as well.

ACKNOWLEDGEMENTS

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not necessarily the official views or policies of the Kentucky Bureau of Highways or the Federal Highway Administration.

REFERENCES


FIGURES

Figure 1. Relationship between Skid Numbers Measured at 40 and 60 mph (18 and 26.8 m/s) on Class I, Bituminous Pavements.

Figure 2. Skid Number Distribution for 230 Test Sections of Rural, Two-Lane Roads.

Figure 3. Relationship between Skid Number and Peak Slip Number at 40 mph (18 m/s) on Rural, Two-Lane Roads.

Figure 4. Test Section Averages: Ratio of Wet- to Dry-Pavement Accidents versus Skid Numbers, with AADT Stratification.

Figure 5. Average Ratio of Wet- to Dry-Pavement Accidents of 230 Test Sections -- Grouped by Skid Number -- versus Skid Number, without Volume Stratification.

Figure 6. Average Ratio of Wet- to Dry-Pavement Accidents of 230 Test Sections -- Grouped by Skid Number -- versus Skid Number, 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 Skid Number, 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 Skid Number, without Volume Stratification.

Figure 9. Ten-Point Moving Averages: Ratio of Wet- to Dry-Pavement Accidents for 110 Test Sections versus Skid Number, 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 Skid Number, with Volume Stratification at AADT above 2700.

Figure 11. Average Ratio of Wet- to Dry-Pavement Accidents of 230 Test Sections -- Grouped by Peak Slip Numbers -- versus Peak Slip Number, without Volume Stratification.

Figure 12. Average Ratio of Wet- to Dry-Pavement Accidents of 110 Test Sections -- Grouped by Peak Slip Numbers -- versus Peak Slip Number, 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 Number -- versus Peak Slip Number, with Volume Stratification at AADT above 2700.
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Figure 6. Average Ratio of Wet- to Dry-Pavement Accidents of 230 Test Sections - Grouped by Skid Number - versus Skid Number, 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 Skid Number, with Volume Stratification at AADT above 2700.
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Figure 10. Ten-Point Moving Averages: Ratio of Wet- to Dry-Pavement Accidents for 120 Test Sections versus Skid Number, with Volume Stratification at AADT above 2700.
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- Grouped by Peak Slip Numbers - versus Peak Slip Number, without Volume Stratification.
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Average Ratio of Wet- to Dry-Pavement Accidents of 120 Test Sections – Grouped by Peak Slip Number – versus Peak Slip Number, with Volume Stratification at AADT above 2700.
### TABLE 1. CRITICAL SKID NUMBERS

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<td>40</td>
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<td>2700 or Less</td>
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<td>Above 2700</td>
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TABLE 2. ACCIDENT RATES AND RATIOS AND OTHER DATA FOR TEST SECTIONS GROUPED BY TRAFFIC VOLUME

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<td>Ratio of Dry- to Dry-Pavement Accidents</td>
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<tr>
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<td>0.63</td>
<td>0.41</td>
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<tr>
<td>Ratio of Wet- to Wet-Pavement Accidents</td>
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<td>0.50</td>
<td>0.41</td>
<td>0.72</td>
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<td>1.45</td>
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*Accidents per 100 million vehicle miles (1.61 million vehicle kilometers)
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<td>Above 2700</td>
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