ACCIDENTS ON RURAL INTERSTATE AND PARKWAY ROADS AND THEIR RELATION TO PAVEMENT FRICTION

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Friction measurements were made with a skid trailer at 70 mph (31 m/s) on 770 miles (1240 km) of rural, four-lane, controlled-access routes on Interstate and parkway systems in Kentucky. Each construction project was treated as a test section. Accident experience, friction measurements, and traffic volumes were obtained for each. Various relationships between wet-weather accidents and skid resistance were analyzed. Averaging methods were used to develop trends and minimize scatter. A moving average for progressively ordered sets of five test sections yielded more definite results. The expression of accident occurrence that correlated best with skid and slip resistance was wet-weather accidents per 100 million vehicle miles (161 million vehicle km). Accidents [at 70 mph (31 m/s)] increased greatly as skid numbers decreased from 27. Analysis of peak slip numbers and accident occurrences indicated similar trends.

•PAVEMENTS must be designed to have sufficient and enduring skid resistance to ensure safe highway travel in wet weather and to enable drivers to perform normal driving tasks without the risk of skidding or loss of vehicle control. In emergencies, a driver may be compelled to brake hard and, with conventional braking systems, may experience skidding regardless of how skid resistant the pavement may be. Antilocking brake systems minimize the risks of skidding and permit the driver to retain directional control of the vehicle. Without such a system, a vehicle will skid, and the driver potentially could loose control of the vehicle when the demand for braking force exceeds the tractive force. As friction (traction) increases, greater deceleration is available and a driver's chances of avoiding collision and remaining on the road are increased. Ideally, wet pavements should provide as much traction as dry pavements. In a practical and realistic sense, however, the question remains: What minimum level of friction should a pavement provide to safeguard the public from undue hazards associated with wet-weather driving? Little satisfaction is derived from merely maintaining a friction level at or near a critical value. The critical value, however, may serve as a criterion for posting wet-weather speed restrictions and for design of surface courses providing a due margin of safety.

Investigations elsewhere (1, 2, 3, 4, 5, 6) to establish minimum friction requirements fall into two categories: (a) studies of driver behavior and, therefore, frictional demands attending driving tasks and (b) analysis of accident data and accident experience as related to pavement friction. Studies in the first category represent a logical approach but involve extensive monitoring of representative driver populations under realistic roadway conditions and situations. Interpretations of what constitutes normal as opposed to emergency reactions or situations present a problem. Friction factors thus derived cannot easily be related to skid resistance measured with conventional testers (such as trailers) operated under prescribed procedures and test conditions.

Accident rates are higher on wet than on dry surfaces; many statistics are available to support this intuitive conclusion. Furthermore, research has shown that accident rates tend to increase as wet skid resistance diminishes. This relationship is now considered to be intuitive and a priori. However, the interaction of many contributing factors such as roadway geometrics, traffic characteristics, and driver behavior together with uncertainties about reliability and availability of accident data, type of friction measurements, and type of analysis has heretofore obscured relationships between accidents and pavement friction.

The primary objective of this study was to discern a relationship between accident experience and pavement friction for rural, four-lane, controlled-access roads on Interstate and parkway (expressway) systems in Kentucky. These highways were purposely chosen for this initial analysis because many of the usually confounding variables could be assumed to have minimal influence. Subsequent evaluations of such a relationship in conjunction with economical and technical considerations will surely guide the establishment of minimum levels of friction.

When a relationship between accidents and skid resistance is to be defined, the effect of all other parameters must be known or held constant insofar as possible. If the study is limited to rural, four-lane, Interstate and parkway facilities, some of the parameters, such as road geometrics, access control, and speed, may be assumed to remain reasonably constant. Traffic characteristics (volume and density) and pavement surface conditions (wet or dry and skid resistance when wet) are the regenerative and causative factors, respectively.

Annual average daily traffic (AADT) volumes were obtained for 1971. Accident data were those reported during 1970, 1971, and 1972. Pavement friction measurements were made between June and October 1971 on 770 miles (1240 km) of the Interstate and parkway systems. Both locked-wheel and peak slip resistances were measured. This peak resistance is often referred to as incipient friction and exceeds the resistance measured by the locked-wheel method. In normal driving, the vehicle operates in a preslip and cornering mode. Therefore, both locked-wheel skid resistance and peak slip resistance at various speeds, or some other type of measurement, may be needed to fully characterize pavements. The measurements that best correlate with wet-weather accidents remain to be established.

DATA ACQUISITION AND COLLATION

Traffic Volumes

Since traffic volumes vary with time, any measurement of volume not obtained at the time and location of each accident would not precisely represent the volume associated with the accident. In studies such as this that cover a system throughout a state, that type of volume measurement is highly impractical. The measurement of traffic volume that is generally available is AADT. The AADT data for 1971 were used in these analyses.

Friction Measurements

Friction measurements were obtained by using a surface dynamics pavement friction tester (model 965A) (7). This skid trailer complies with ASTM E 274 (8). The measurements represent friction developed between a standard test tire (ASTM E 249) (9) 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 of 1971 on all rural, four-lane, Interstate and parkway routes in Kentucky having a posted speed limit of 70 mph (31 m/s). Tests were made in the left wheel path only and at 1-mile (1.6-km) intervals in outer lanes; no less than five tests per lane were made on each construction project. The basic test speed was 70 mph (31 m/s). Additional tests were conducted on selected pavements at 40 mph (18 m/s). Comparison between the SN obtained at the two speeds is shown in Figure 1.

Accident Information

Accident data were obtained from state police records, computerized, and maintained by the Kentucky Department of Public Safety. All accidents reported during 1970, 1971, and 1972 were analyzed. A summary of accidents on rural, four-lane, Interstate and parkway routes is given in Table 1. Accidents totaled 5,907, of which 1,314 occurred during wet-surface conditions.

From these accident records, many expressions of accident occurrence may be calculated. Rates of wet-surface accidents, dry-surface accidents, fatal and injury accidents, and total accidents (including property damage accidents) are commonly calculated. Expressions used in other investigations have included the following:

1. Ratio of wet- to dry-surface accidents,
2. Ratio of wet-surface to total accidents,
3. Ratio of wet-surface, skidding accidents to total accidents,
4. Wet-surface accidents per 100 million vehicle miles (161 million vehicle km),
5. Total accidents per 100 million vehicle miles (161 million vehicle km), and
6. Fatal and injury accidents per 100 million vehicle miles (161 million vehicle km).

Test Sections

A test section is defined as a pavement section of uniform age and composition that has been subjected to essentially uniform wear along its length (8). Almost all construction projects 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 110 test sections.

On rural, four-lane roadways, most traffic travels in the outer lanes (approximately 80 to 85 percent), and a large percentage of maneuvers begin or terminate there. The outer lane, left wheel path SNs were averaged to characterize the skid resistance of the test sections. Distributions of these values for the 110 test sections are shown in Figure 2 for SN and in Figure 3 for PSN. The relationship between SN and PSN is shown in Figure 4.

Mile points recorded in accident reports were used to describe the location of accidents to the nearest 0.1 mile (0.16 km). The ratios of wet- to dry-surface accidents and wet-surface to total accidents and rates of wet-surface accidents and total accidents, in terms of 100 million vehicle miles (161 million vehicle km) [total vehicle miles (kilometers) traveled under all pavement conditions], were calculated for each test section. These rates were based on the lengths of sections and the 1971 AADTs and pertain to accidents for a 3-year period. Similar calculations were made for the accident data for 6-month periods (June through November).

SKID NUMBERS AND ACCIDENTS

Analysis of Test Sections by Cross Classification

For aid in determining the relationship between combinations of traffic volume, SNs, and accidents, data for test sections were arrayed as given in Table 2. Elements of the array are average wet-surface accident rates, total accident rates, ratios of wet-surface to total accidents, and ratios of wet- to dry-surface accidents for all test sections within SN and traffic volume categories.

Analysis of the arrays led to the conclusion that the data needed to be stratified with respect to AADT to better define the relationship between accidents and pavement friction. A plot of wet-surface accident rate versus SN (Figure 5) further demonstrated the need for sorting and grouping the data. Stratification of data by AADT showed improved relationship between accidents and SNs for some accident expressions but not necessarily for other expressions. Considerable variability in data remained after

Figure 1. Correlation of 40 and 70-mph (18 and 31-m/s) trailer tests on bituminous and portland cement concrete pavements.

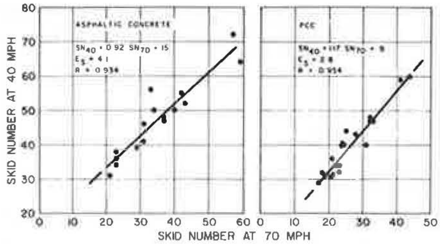


Table 1. Yearly accident occurrence on 110 test sections.

	Accidents				Dry-Surface Accidents				Wet-Surface Accidents				Fatalities			
Route	1970	1971	1972	Total	1970	1971	1972	Total	1970	1971	1972	Total	1970	1971	1972	Total
I-64	190	225	267	682	102	138	164	404	34	46	59	139	16	5	12	33
I-65	287	349	400	1,036	179	225	273	677	72	65	101	238	9	12	12	33
Kentucky Turnpike	233	222	332	787	146	168	242	556	64	29	82	175	6	5	15	14
I-71	229	254	259	742	116	132	145	393	59	68	57	184	2	6	6	70
I-75	643	597	611	1,851	395	361	361	1,117	110	140	167	417	24	29	17	26
Jackson Purchase Parkway	11	16	23	50	9	13	13	35	2	1	7	10	0	0	0	0
Pennyrile Parkway	45	51	63	159	38	38	47	123	4	3	11	18	2	3	0	5
Western Kentucky Parkway	89	76	109	274	59	51	75	185	22	15	20	57	5	3	4	12
Bluegrass Parkway	70	64	62	196	50	41	38	129	10	11	13	34	6	1	5	12
Mountain Parkway	47	32	51	130	27	19	22	68	10	11	21	42	2	2	2	6
Total	1,844	1,886	2,177	5,907	1,121	1,186	1,380	3,687	387	389	538	1,314	72	66	73	211

Figure 2. Skid number distribution for 110 test sections.

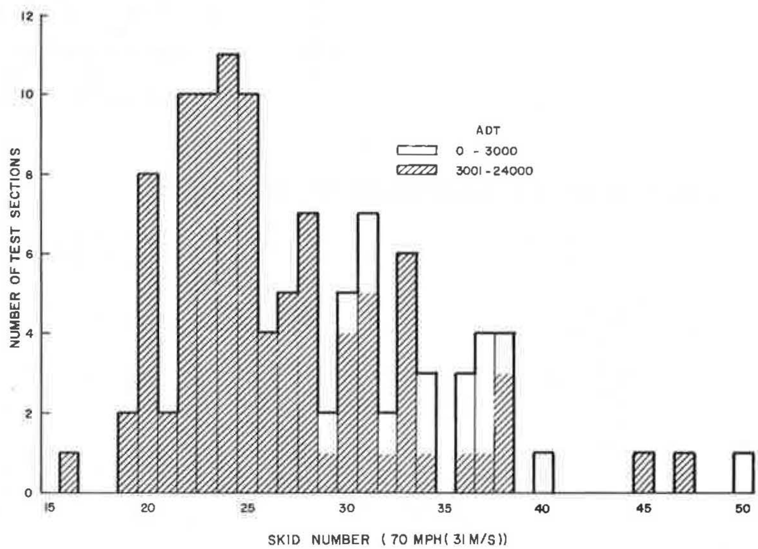


Figure 3. Peak slip number distribution for 110 test sections.

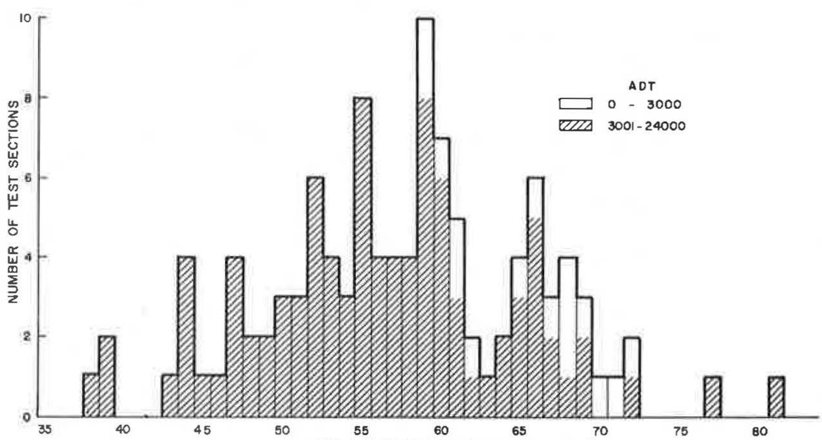


Figure 4. Relationship between skid number and peak slip number at 70 mph (31 m/s).

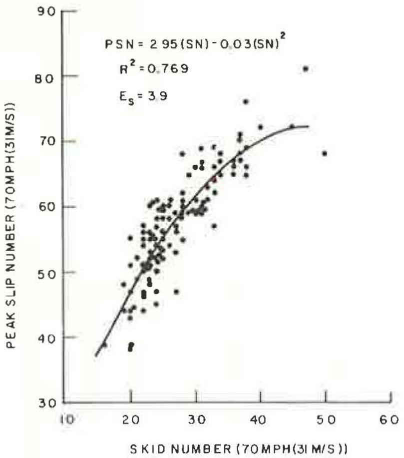


Figure 5. Test section averages for wet-surface accident rate for 1970 through 1972 versus skid number with AADT stratification.

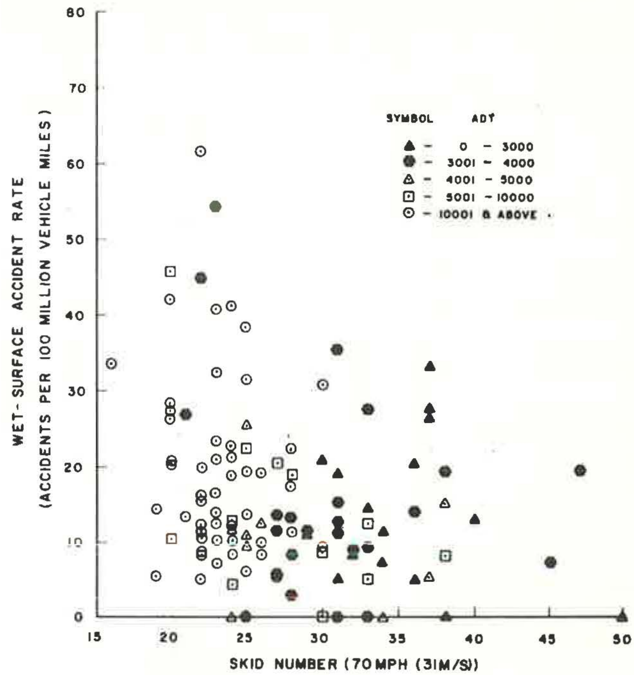


Table 2. Average accident rates at 70 mph (31 m/s) and accident ratios.

Number of Test Sections	AADT	Skid Numbers	Wet-Surface Accident Rates[a] 1970	1971	1972	1970 to 1972	Total Accident Rates[a] 1970	1971	1972	1970 to 1972	Ratio of Wet-Surface to Total Accidents 1970	1971	1972	1970 to 1972	Ratio of Wet- to Dry-Surface Accidents 1970	1971	1972	1970 to 1972
16	0 to 3,000	16 to 20																
		21 to 25																
		26 to 30	14.9	6.3	27.6	16.3	100.1	47.3	74.2	73.8	0.15	0.25	0.41	0.21	0.19	0.50	0.75	0.29
		31 to 35	15.3	8.4	9.2	11.0	51.2	82.3	61.4	65.0	0.45	0.16	0.15	0.19	0.56	0.55	0.21	0.30
		36 to 40	13.0	2.0	38.7	17.9	84.7	49.0	116.0	83.2	0.14	0.03	0.30	0.20	0.23	0.04	0.68	0.31
		41 to 50	0.0	0.0	0.0	0.0	0.0	0.0	474.4	158.1			0.0	0.0			0.0	0.0
24	3,001 to 4,000	16 to 20																
		21 to 25	24.3	27.6	42.8	31.6	113.7	78.8	109.9	100.8	0.14	0.33	0.39	0.29	0.69	0.55	1.47	1.15
		26 to 30	7.2	6.5	15.3	9.7	53.7	70.9	75.9	66.8	0.13	0.13	0.21	0.16	0.23	0.20	0.34	0.22
		31 to 35	16.1	6.2	18.1	13.5	77.0	60.3	88.2	75.2	0.15	0.10	0.18	0.16	0.33	0.24	0.32	0.27
		36 to 40	12.9	25.9	11.8	16.8	48.0	82.1	90.5	73.5	0.58	0.60	0.14	0.31	0.25	0.33	0.50	1.36
		41 to 50	22.9	5.8	11.3	13.3	82.4	76.2	64.9	74.5	0.25	0.07	0.18	0.17	0.49	0.08	0.29	0.26
19	4,001 to 9,000	16 to 20																
		21 to 25	8.0	9.1	19.4	12.2	46.6	41.9	58.1	48.9	0.18	0.24	0.35	0.24	0.40	0.52	0.90	0.45
		26 to 30	6.4	12.5	17.7	12.2	47.4	68.5	75.5	63.8	0.13	0.13	0.21	0.17	0.22	0.35	0.46	0.31
		31 to 35	11.6	0.0	6.3	6.0	58.0	31.4	82.0	57.1	0.17	0.0	0.08	0.11	0.37	0.0	0.50	0.27
		36 to 40	2.8	18.4	7.7	9.6	41.5	35.3	50.9	42.5	0.11	0.55	0.13	0.22	0.17	2.78	0.26	0.38
		41 to 50																
25	9,001 to 14,000	16 to 20	25.4	28.3	24.8	26.2	95.1	95.8	96.1	95.7	0.26	0.25	0.24	0.26	0.54	0.54	0.44	0.50
		21 to 25	16.0	13.9	20.7	16.9	66.6	86.0	91.1	81.3	0.24	0.15	0.22	0.21	0.50	0.27	0.40	0.37
		26 to 30	24.3	24.3	44.5	31.0	76.8	68.7	137.5	94.3	0.32	0.35	0.32	0.33	0.50	0.67	0.52	0.55
		31 to 35																
		36 to 40																
		41 to 50																
26	14,001 to 24,000	16 to 20	21.3	15.9	24.2	20.5	86.3	87.1	97.0	90.1	0.26	0.18	0.24	0.22	0.44	0.32	0.43	0.40
		21 to 25	18.3	20.4	26.1	21.6	87.8	85.8	104.1	92.6	0.19	0.23	0.25	0.22	0.44	0.45	0.43	0.40
		26 to 30	9.7	11.6	17.7	13.0	69.5	76.6	72.1	72.7	0.14	0.16	0.23	0.17	0.25	0.26	0.42	0.27
		31 to 35																
		36 to 40																
		41 to 50																
110	0 to 24,000	16 to 20	24.6	26.0	24.7	25.1	93.5	94.3	96.3	94.7	0.26	0.24	0.24	0.25	0.52	0.50	0.44	0.48
		21 to 25	16.1	26.7	24.5	19.1	75.2	77.0	91.6	81.3	0.20	0.21	0.27	0.23	0.48	0.41	0.61	0.47
		26 to 30	9.3	10.3	19.0	12.9	62.9	70.2	77.0	70.0	0.15	0.16	0.24	0.18	0.24	0.30	0.44	0.28
		31 to 35	15.1	5.9	13.2	11.4	65.3	62.8	78.2	68.8	0.24	0.10	0.15	0.16	0.40	0.31	0.31	0.28
		36 to 40	10.1	10.0	26.5	15.7	67.8	51.1	95.5	71.4	0.21	0.35	0.27	[illegible]	0.21	[illegible]	0.54	0.50
		41 to 50	15.3	3.9	7.5	8.9	54.9	50.0	201.4	102.4	0.25	0.07	0.12	0.11	0.49	0.08	0.19	0.18
94	3,001 to 24,000	16 to 20	24.6	26.0	24.7	25.1	93.5	94.3	96.3	94.7	0.26	0.24	0.24	0.25	0.52	0.50	0.44	0.48
		21 to 25	16.1	16.7	24.5	19.1	75.2	77.0	91.6	81.3	0.20	0.21	0.27	0.23	0.48	0.41	0.61	0.47
		26 to 30	8.8	10.7	18.2	12.6	59.3	72.4	77.3	69.7	0.15	0.15	0.22	0.18	0.25	0.28	0.41	0.27
		31 to 35	14.9	4.6	15.2	11.6	72.3	53.1	86.6	70.7	0.15	0.07	0.16	0.15	0.34	0.18	0.37	0.27
		36 to 40	6.8	21.4	9.4	12.5	44.1	54.0	66.7	54.9	0.30	0.57	0.14	0.26	0.19	2.16	0.35	0.78
		41 to 50	22.9	5.8	11.3	13.3	82.4	76.2	64.9	74.5	0.25	0.07	0.18	0.17	0.49	0.08	0.29	0.26

[a]Per 100 million vehicle miles (161 million vehicle km).

elimination of test sections having AADTs less than 3,000 vehicles per day. However, a trend was unmistakable: Wet-surface accident rates decreased as SNs increased. Resulting relationships between accidents and pavement friction involving the wet-surface accident rate are shown in Figure 6 and for other accident expressions in Figures 7, 8, and 9. (Data in Figures 6 through 18 are stratified at an AADT of 3,000 per day.)

Analysis of data for test sections with AADTs above 3,000 continued so that the expression of accident occurrence relating best to pavement friction could be found. This was accomplished by taking elements in the arrays as predicted values. Actual accident occurrences for each test section were then compared to this predicted value to obtain deviations. This enabled computation of a coefficient of correlation for each accident expression. The correlation coefficients ranked the expressions in the following order:

1. Wet-surface accidents per 100 million vehicle miles (161 million vehicle km),
2. Total accidents per 100 million vehicle miles (161 million vehicle km),
3. Ratio of wet-surface to total accidents, and
4. Ratio of wet- to dry-surface accidents.

The degree of correlation was not sufficiently encouraging to enable a decisive selection of the best expression. Therefore, all four expressions were used in further analyses to determine the relationship between accident occurrence and pavement friction.

Analysis of Test Sections by Averaging Techniques

Three averaging methods were used to reduce variability and, thereby, to more clearly demonstrate general relationships already apparent in the data set for test sections having AADTs above 3,000 vehicles per day. A discussion of these methods and the resulting trends follows.

Cumulative Averages

In the first method, two techniques were used to calculate cumulative averages. The first involved calculating the average of each expression for accident occurrence for all test sections having an SN less than or equal to a given value. The second procedure involved calculating average accident occurrence, for each method of expression, of all test sections having an SN greater than a given value. These average values are plotted as shown in Figures 10, 11, 12, and 13.

In the first procedure of calculating averages, accident occurrences for low SNs had greater influence on the average value obtained. Extreme values of the expressions for accident occurrence for a test section at high SNs were attenuated through division by the large number of test sections with lower SNs. Thus, the second procedure, which yielded opposite weightings, was necessary to verify the trends and to ensure that large deviations at high SNs were not being masked by the averaging process. The resulting trends were reasonably similar for wet-surface and total accident rates. For other expressions, the trend lines were not so similar, and the data points were quite scattered. Wet-surface accident rate decreased as SNs increased to approximately 28; further increase in SNs resulted in only slight reduction in accidents. Since the trends were similar and because of the ranking of accident expressions discussed previously, subsequent analyses were restricted to using wet-surface accidents per 100 million vehicle miles (161 million vehicle km) as the method of expressing accident occurrences.

Average Wet-Surface Accident Rates Grouped by Skid Number

In the second method, test sections were grouped by SNs. The average wet-surface accident rate was calculated for each group; these averages are plotted as shown in

Figure 6. Wet-surface accident rate versus skid number.

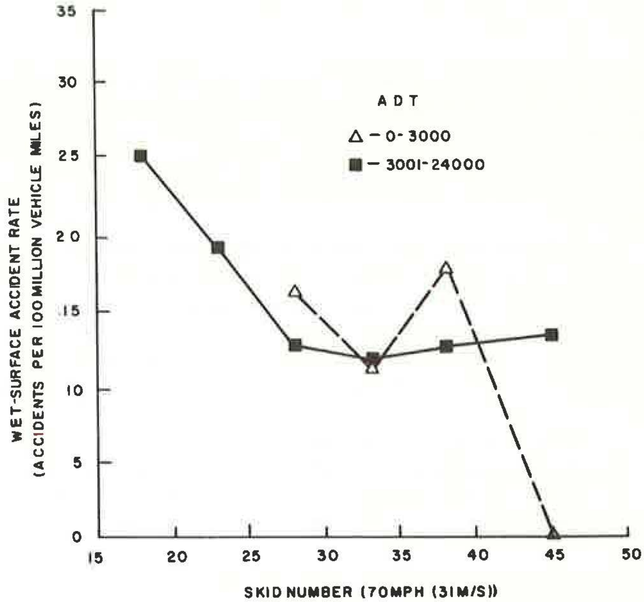


Figure 7. Total accident rate versus skid number.

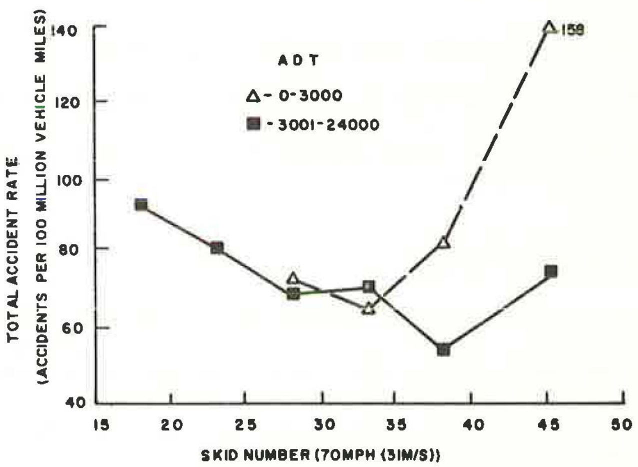


Figure 8. Ratio of wet-surface to total accidents versus skid number.

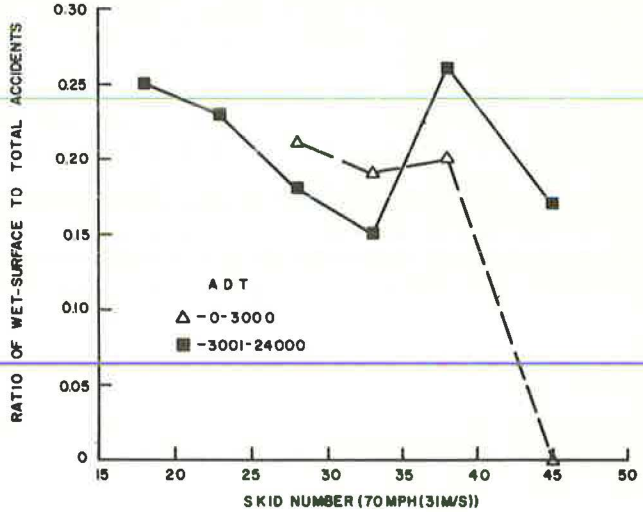


Figure 9. Ratio of wet- to dry-surface accidents versus skid number.

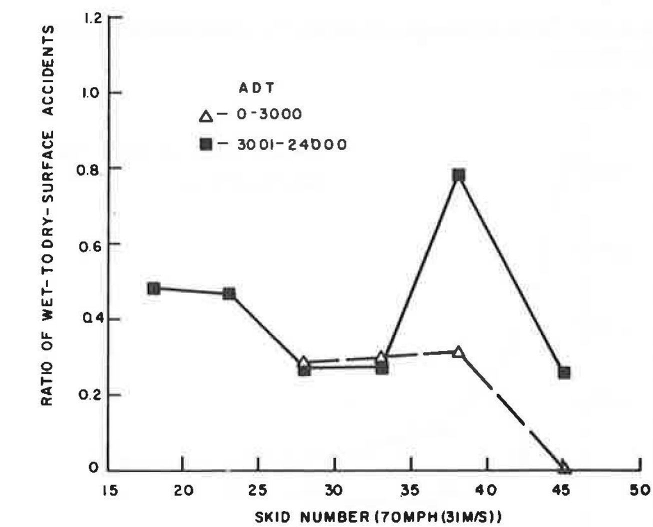


Figure 10. Average wet-surface accident rate versus skid number.

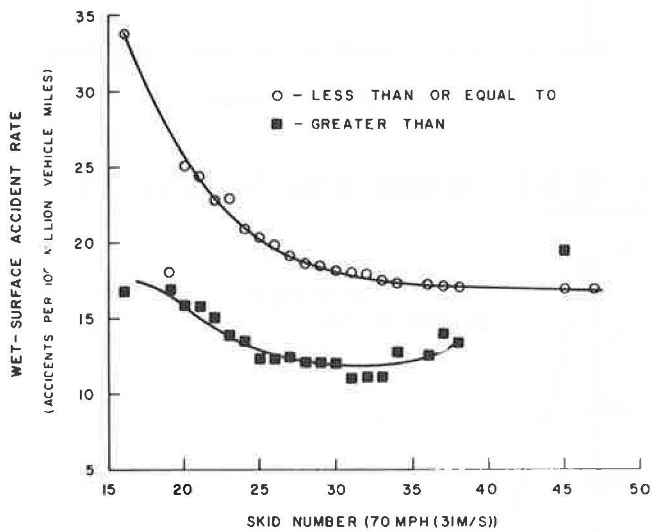


Figure 11. Average total accident rate versus skid number.

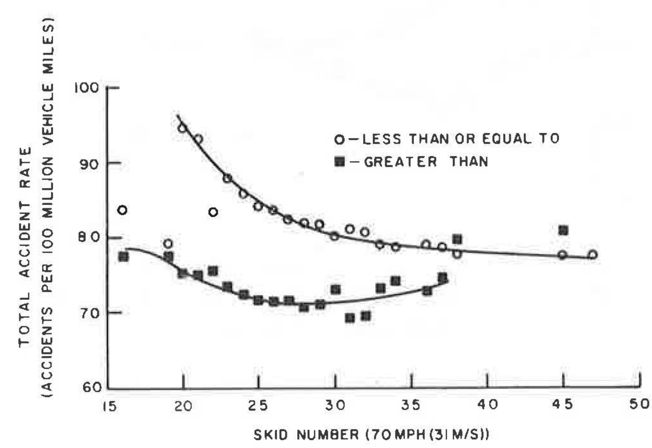


Figure 12. Ratio of average wet-surface to total accidents versus skid number.

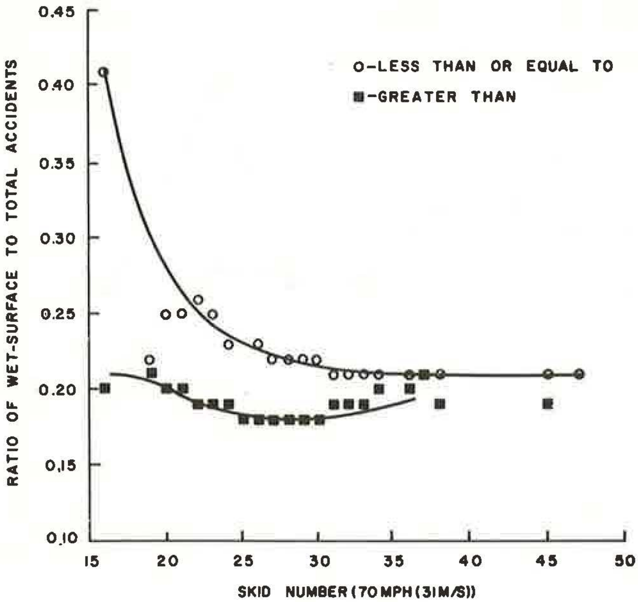


Figure 13. Ratio of average wet- to dry-surface accidents versus skid number.

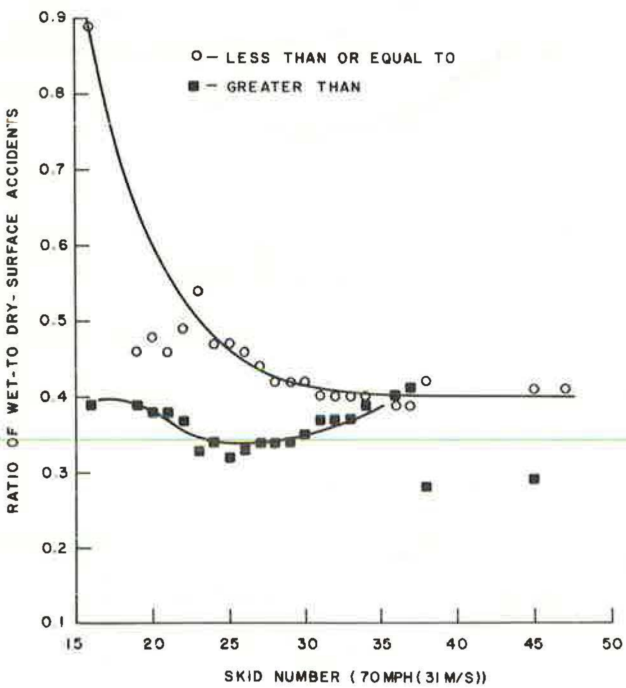


Figure 14. Again the trend indicated that accident rate rapidly decreased as SNs increased SNs up to about 27. The variability was greater than that obtained by the first method because several groups included only one or two test sections, each having equal weighting as groups containing a larger number of test sections. Still, the trends indicated by the two methods were quite similar.

Moving Averages

The third method involved calculation of an average wet-surface accident rate and an average SN for progressively ordered sets of five test sections. The first average was of the five 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 was repeated until all test sections had been averaged in a group of five. 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. Resulting averages are plotted as shown in Figure 15.

The trend was similar to those developed by the previous two methods; however, moving averages indicated a more distinct change in the slopes of the two branches of the curve. At SN < 27, the wet-surface accident rate increased by two to three accidents per 100 million vehicle miles (161 million vehicle km) per SN; at SN > 27, the wet-surface accident rate decreased nominally.

The foregoing analysis involved accident data for the entire 3 years while skid resistance was measured in the summer and fall of 1971. Pavements, of course, exhibit lower friction in the summer and fall, but the measured values may not be assumed to necessarily represent the lowest friction during the year for a particular pavement nor for the road system as a whole. The rapid change in the slope of the curve in Figure 15, for instance, may occur at some higher or lower SN depending on when measurements are made. If accident data were subdivided into subsets for two periods of the year and the measured values reflected the mean SN for each period, the rapid change in the slope would then be expected to occur at the same SN, provided driver behavior remained the same throughout the year. Since skid-resistance values were not available for the winter-spring period, Figure 16 was prepared to show the relationship between wet-surface accident rate and pavement friction for the summer-fall period. In contrast to Figure 15, a slightly higher SN at which the accident rate increased rapidly is evident. The data, however, are more scattered, presumably because of the reduced data base. A shift toward a higher SN would be anticipated because the accident rates associated with the 3-year period were related to friction values that were lower than the mean friction for a full year. Because of greater scatter of data in Figure 16, the trend established in Figure 15 must be accepted as the better indication of the relationship between accidents and pavement friction, even though the accident data in Figure 16 more closely correspond to the measured skid resistance.

Wet-surface accident rates were calculated for 100 million miles (161 million km) of total travel under all pavement conditions rather than for only wet-surface travel. The true accident rate for wet-surface conditions would be several times higher since pavements were wet only 13 percent of the time. In addition, as given in Table 3, precipitation from June to November was substantially less than from December to May. Yet, the wet-surface accident rates for 1970 and 1971 were higher during the period from June to November. Precipitation in 1972, especially during the winter-spring period, was substantially more than that in the two preceding years. If precipitation for the two 6-month periods (during 3 years) were the same, the wet-surface accident rate of 19.5 (June to November) would be 25.2 compared with 19.3 for winter-spring periods. Therefore, lower skid resistance of pavements during summer and fall obviously contributed to an increase in wet-surface accidents.

PEAK SLIP NUMBERS AND ACCIDENTS

As discussed previously, there is a need to analyze different measurements of pavement

Figure 14. Average wet-surface accident rate of 94 test sections grouped by skid number versus skid number.

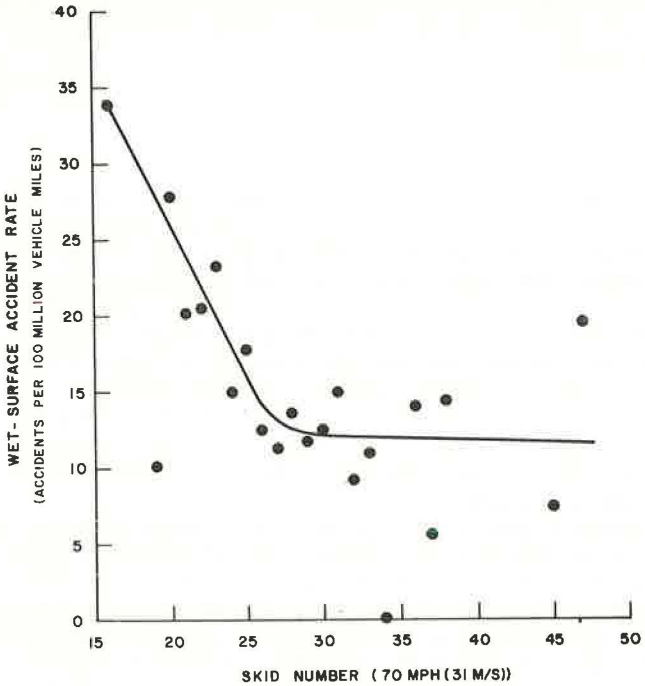


Figure 15. Five-point moving averages for wet-surface accident rate versus skid number.

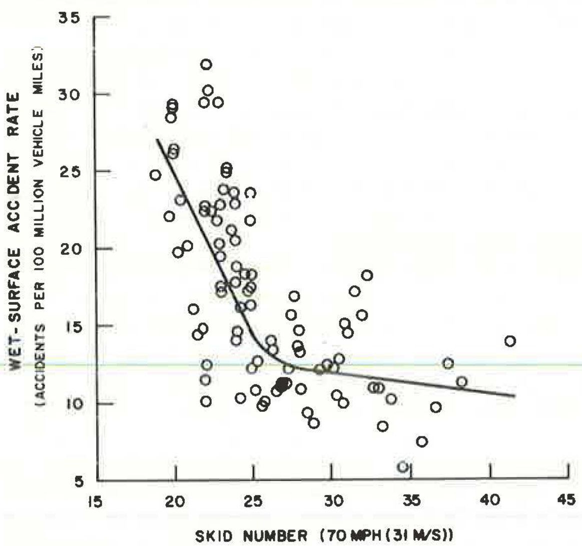


Figure 16. Five-point moving averages for wet-surface accident rate for summer-fall period versus skid number.

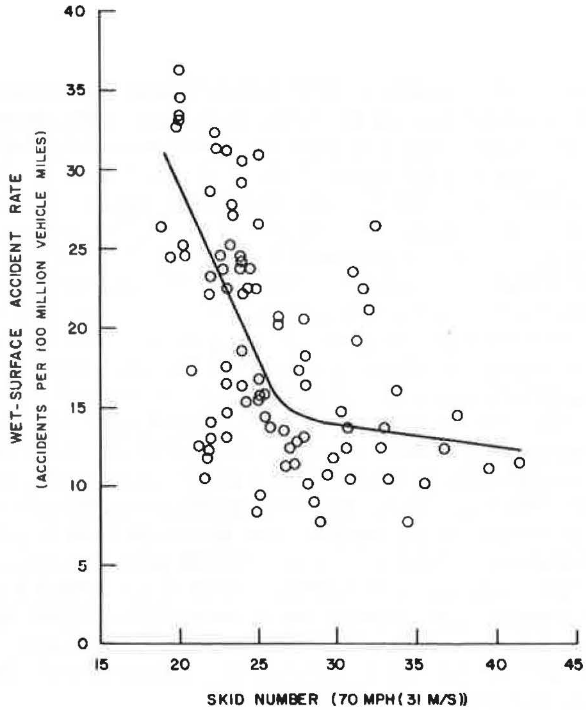
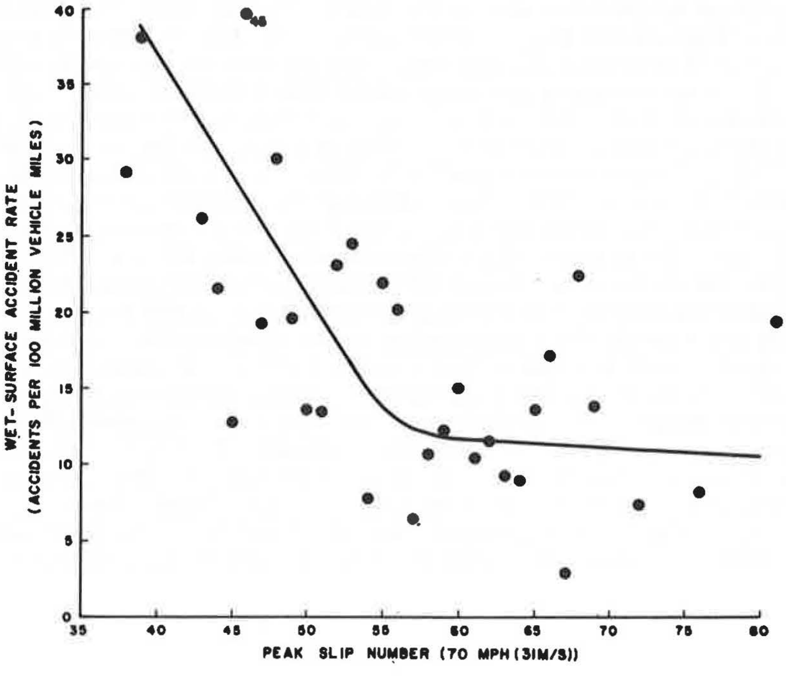


Table 3. Semiannual accident data.

Year	Period	Number of Accidents			Ratio of Accidents		Accident Rates[a]			Precipitation[b] (percent)
		Total	Dry-Surface	Wet-Surface	Wet to Total	Wet to Dry	Total	Dry	Wet	
1970	December to May	965	476	166	0.17	0.35	92.3	45.6	15.9	13
	June to November	879	645	221	0.25	0.34	66.9	49.1	16.8	10
1971	December to May	948	511	160	0.17	0.31	90.7	48.9	15.3	13
	June to November	938	676	229	0.24	0.34	71.4	51.5	17.4	10
1972	December to May	1,029	542	280	0.27	0.52	98.5	51.9	26.8	18
	June to November	1,148	838	278	0.24	0.33	87.4	63.8	21.2	12
1970 to 1972	December to May	2,942	1,529	606	0.21	0.40	93.8	48.8	19.3	15
	June to November	2,965	2,159	728	0.25	0.34	75.3	54.8	18.5	11

[a]Per 100 million vehicle miles (161 million vehicle km) for all pavement conditions.
[b]Trace or more in the Lexington area; periods of snow or ice not included.

Figure 17. Average wet-surface accident rate of 94 test sections grouped by peak slip number versus peak slip number.



friction to determine which correlates best with accident experience. The peak friction force was measured routinely during all tests; thus these data were available for analysis. Test section averages were arrayed as given previously, but PSNs were substituted for SNs. The arrays again indicated the desirability for sorting the data by AADT at 3,000 vehicles per day. Wet-surface accident rates again appeared to be the best expression for accident occurrence. Test sections were grouped by PSN, and average wet-surface accident rates were calculated for each PSN as shown in Figure 17, which indicates more scatter than was obtained with SNs (Figure 14); this may be because each data point represents fewer test sections. The greatest change of slope occurred at PSN $\approx$ 57. Similar results were obtained by using five-point moving average, as shown in Figure 18, and the change in slope remained at the same PSN.

The point of greatest change in slope of the curve in Figure 18 was at PSN = 57 and in Figure 15 at SN = 27. According to Figure 4, a PSN of 57 is equivalent to SN of approximately 27. Scatter of the data in Figure 15 and Figure 18 also appears to be similar and, therefore, suggests that both measurements of friction related equally well to accident occurrence. This was somewhat unexpected because of the inherent measurement and chart analysis errors associated with determination of peak slip resistance (PSN). Peak slip resistance occurs for a very brief period of time during wheel lock-up, and measurement represents a much shorter length of pavement than the locked-wheel test (SN). For that reason, poor agreement between SN and PSN in Figure 4 was credited largely to inaccuracies in PSN. If such a conclusion is valid, some of the scatter of data in Figure 18 may be due to errors in PSN. In that event, PSN may correlate best with accident experience.

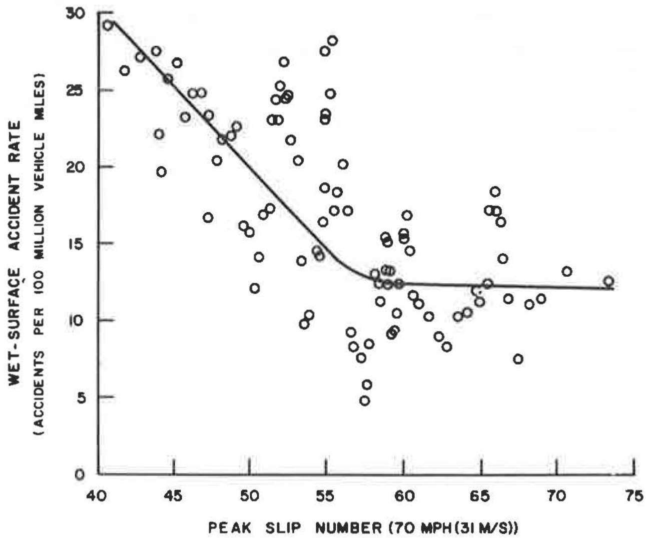
SUMMARY AND CONCLUSIONS

On rural, four-lane, Interstate and parkway (expressway) facilities, wet-surface accidents per 100 million vehicle miles (161 million vehicle km) correlated best with skid resistance. Even when the best statistical expression of accidents is used, scatter and spurious variability in data seem inevitable. Stratification of the data by AADT at 3,000 vehicles per day minimized scatter. 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 yielded more definitive results. Definite trends were established in regard to the relationship between wet-surface accident rates and SNs (Figure 15). Wet-surface accident rate [at 70 mph (31 m/s)] decreased rapidly as the SN increased to 27; further increases in SN beyond this point resulted in only a slight reduction in accident rate. The analysis involved accident data throughout the year (3-year period), and skid resistances were measured in the summer and fall (1971) when pavements normally exhibit lower friction values. As expected, analysis of the accident data for June to November (Figure 16) indicated a slightly higher friction. The data, however, were more scattered because of the reduced data base.

Wet-surface accident rates for 2 of the 3 years considered in this study were higher during the summer-fall periods (Table 3) even though the roads were wet a lesser proportion of time. When adjusted to equal time of precipitation during December to May and June to November, wet-surface accident rates for the summer-fall periods were higher for all 3 years. Lower skid resistance of pavements during summer and fall obviously contributed to an increase in wet-surface accidents.

Definite trends were also evident between wet-surface accident rates and PSNs. The greatest change in slope of the trend lines (Figure 16) occurred at a $PSN_{70} \approx 57$. Scatter of data was no worse than that for SNs. This was somewhat unexpected because of the inherent measurement and chart analysis errors associated with determination of peak slip resistance. PSN = 57 is equivalent to SN $\approx$ 27 (Figure 15); $SN_{70} = 27$ also corresponds to the greatest change in slope of trend lines. This suggests either that the correlation between the two friction measurements overshadowed any subtle differences that may exist between accidents and either measurement of friction or that both skid and slip resistance are equally valid indexes of friction requirements for pavements.

Figure 18. Five-point moving averages for wet-surface accident rate versus peak slip number.



It should be reemphasized that the findings in this paper pertain to rural, four-lane, limited-access, expressway types of highways with posted speeds of 70 mph (31 m/s) and that no consideration was given in the analysis to geometrics of roadways or to points of traffic conflicts. High accident or repeat-accident locations certainly warrant further study to determine what variables or combination of variables may contribute to wet-surface accidents. Nevertheless, it was demonstrated that there is a relationship between accident experience and pavement friction; this relationship should be used as a guide in establishing minimum friction requirements for pavements. The established trends, relating wet-surface accident rates with skid resistance, indicated a definite value of skid resistance below which the accident rate increased rapidly. In addition, the methods described may be used in future analyses to establish skid-resistance requirements for other types of highways.

ACKNOWLEDGMENTS

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