Skid Resistance Guidelines for Surface Improvements on Texas Highways

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This report pertains to the selection of a minimum skid resistance for use as another guideline for surface improvements by the Texas Highway Department. This problem was approached from an accident standpoint as well as from a design standpoint, since experience on several sections of roadway indicated a sharp reduction of accidents after surface improvements.

Skid resistance and accident data were collected on 517 rural sections that represented a random sample of Texas highways. The skid resistance values were obtained through the use of a towed trailer employing the locked-wheel principle on artifically wetted pavements. An analysis of this data showed that the possibility of a roadway section having a high accident rate increased as the coefficient of friction decreased.

On the basis of this study, composite skid resistances of 0.4 and 0.3 for testing velocities of 20 and 50 mph, respectively, were selected as guidelines for considering surface improvements. In addition, skid resistance values of 0.31 and 0.24 at 20 and 50 mph, respectively, were recommended as minimum values.

•EARLY IN 1963 the Texas Highway Department in cooperation with the Bureau of Public Roads initiated a research project to study skid characteristics of Texas highways. The first prerequisite for this project was to design and construct a device to measure skid resistance (1). After a detailed literature survey and considerable personal contact with other representatives working in this field, a two-wheel trailer was selected which obtained a locked-wheel skid resistance. It was felt that this type of test gave a closer simulation of a braking vehicle. The trailer was designed so that the skid resistance could be obtained with the pavement in a wet condition. The towing vehicle is a two-ton Dodge truck powered by a V-8 engine. The vehicle velocity and frictional force are produced as visual output on a strip chart recorder. Tests may be performed on either wheel individually or both wheels can be braked simultaneously.

After obtaining equipment to measure skid resistance, the question immediately arises—how can accidents be reduced with this device? It is realized that the causes for accidents are much more complex than the influence of the deceleration induced in the vehicle by the pavement surface after the brake application.

Skidding is defined by K. A. Stonex, Assistant Director, General Motors Proving Grounds, as the motion of a vehicle under conditions of partial or complete loss of control caused by the sliding of one or more wheels of a vehicle (2). How the vehicle reacts while skidding is a function of many variables of the vehicle itself, such as brake distributions, load distributions, and braking conditions. It has been found that if the front wheels are locked and the rear wheels roll freely the course of the car is straight. If the rear wheels are locked and the front wheels roll freely the car switches ends by

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TABLE 1

Section	Coefficient		Accidents[a]		Percent Reduction in Accidents
	Before	After	Before (1963)	After[b] (1964)	
1	.275	.462	974	560	42.5
2	.275	.359	1272	814	36.0
3	.275	.467	931	620	33.4
Sawed Concrete	.275		960	770	19.8

[a]Accidents are given per 100 million vehicle miles based on one year of observations.

[b]"After" accidents have been extrapolated to a yearly basis from seven months of information.

sliding sideways to a position approximately 180 deg to the position before brake application, much as a pendulum swings about its pivot (2). Many variations can be expected if variations are experienced in the number and extent to which wheels lock.

Since coefficient of friction is related to skidding, and studies have found that wet pavement coefficients are much lower than dry pavement coefficients, it seems obvious that skidding is related to weather conditions. It is common knowledge that the number as well as the severity of accidents increases on wet roadways. However, investigators both in this country and abroad have made detailed studies of accidents, skidding, and weather conditions. Giles and Sabey of the Road Research Laboratory, United Kingdom, report that 8 percent of the total number of accidents in dry conditions involved skidding, whereas 27 percent of the total number of accidents on wet roads involved skidding (3). Virginia investigators report 0.66 percent of the total number of accidents in dry conditions were skidding accidents and 14.65 percent of the total number of accidents on wet roads were skidding accidents (4). Virginia also reports that skidding of some nature occurred in 35 percent of 37,507 accidents during 1956 in Virginia. Dr. Bruno Werner reports that from 1953 to 1956 in open country one accident out of every 4 or 5 involved slippery road conditions as a cause in Germany (5). The Road Research Laboratory, United Kingdom, reports that urban areas, even though they have the majority of accidents, are by no means the chief areas, since over one-third of all skids on wet roads occur on rural roads (3).

The studies enumerated indicate that skidding accidents occur chiefly in wet weather, and coefficients are lower under wet conditions. Therefore, it follows that accidents are in some way related to skid resistance.

A few years ago a slick section of pavement in Texas was "deslicked" by sawing small, closely spaced longitudinal grooves in the concrete surface (6). This operation increased the coefficient of friction from 0.32 before sawing to 0.42 after sawing as measured by the stopping-distance method at 30 mph with wet pavement conditions. Immediately after the grooving work, the accident rate on the section decreased sharply, but within a year the grooves began to polish and the accident rate started to increase.

Recently sections of the sawed concrete were overlaid with asphaltic concrete containing two different types of aggregate. Coefficient of friction values were obtainted on the overlaid sections and also on the sawed section. Using the sawed section as a "before" coefficient and the coefficients obtained on the overlaid sections as "after" values, Table 1 compares the resultant accident rates. Even though there was a reduction in accidents on the sawed concrete from 1963 to 1964, the reduction of accidents on the overlaid sections was considerably greater.

These studies lead to the question, how can skid resistance measurements be used to decrease accidents? The most obvious answer is to establish a minimum coefficient of friction value. Technically, this minimum coefficient should vary as to location,

such as hills, intersections or curves, and probably between rural and urban areas. The AASHO Guide (7) refers to stopping sight distance and superelevation, both of which are minimum coefficient values described as "stopping distance" of a vehicle. Other agencies have set minimums, among them England (3), Michigan (8), and Virginia (9).

The objective of this report is to establish a guide for a minimum coefficient value to be used on Texas highways. This minimum coefficient value will be selected using minimum design requirements, accident information and economics. Although the value should vary with location, this report will only consider general guidelines for a statewide value. Future studies will encompass more specific applications.

METHOD OF ANALYSIS

During the initial background study and after a review of available information, it was found that considerable research would be necessary for a complete study of the influence of surface friction on accidents. In line with the objective of this study, it was felt that sufficient information could be accumulated to establish a guide for a needed minimum coefficient of friction value. This would be done quickly with the thought of a complete study shortly after.

Selection of Test Sections

The advisory committee for this project recommended that skid resistance tests be performed on 517 sections which were previously selected by the Texas Transportation Institute in connection with pavement structure research study (10). This decision was based on two considerations:

1. It was felt that existing data could be used for both projects and therefore no duplicate data gathering would be required.
2. The sections selected would provide a random sample and thereby assure a representative sample of Texas highways.

Since the 517 test sections are predominantly rural, additional sections were also selected in urban areas to provide a cross-check of any conclusions or observations. The urban sections were also used to develop study guidelines for the rural sections.

Urban.—The urban study was performed on Interstate Highway 35 in two cities, Austin and San Antonio. A preselected number of skids were performed on selected roadway sections in both cities. The roadway sections were selected on the basis of construction project boundaries. In general, when the sections are linked end to end they compose the entire distances between city limits. Information was collected within each section boundary on each of the several accident types. The accident information was obtained directly from the police department files for each of the two cities. In both cities, the skid resistance values were obtained on the outside lanes and these were used for comparison purposes.

Rural.—The rural tests were made on the 517 preselected sections. These sections are also being used as a part of an overall skid study of Texas materials which will be reported at a later date. Tests in rural sections consisted of respective averages of five skids made for each of the following conditions: at 20 mph in the inside wheelpath, 50 mph in the inside wheelpath, and at 20 mph with the left wheel or test wheel between the wheelpaths. Rural accident information was obtained from an annual report by the Texas Highway Department which compiles all accidents reported by the Texas Department of Public Safety (11).

Figures 1 and 2 show the inside wheelpath coefficient of friction frequency distributions for the 517 test sections for testing velocities of 20 mph and 50 mph, respectively. Note that the statewide average based on this sample is 0.506 at 20 mph and 0.391 at 50 mph.

Selection of Accident Type

It is difficult to define accidents caused by skidding, for in almost every accident the brakes will be applied. In an emergency situation, brake application may have various

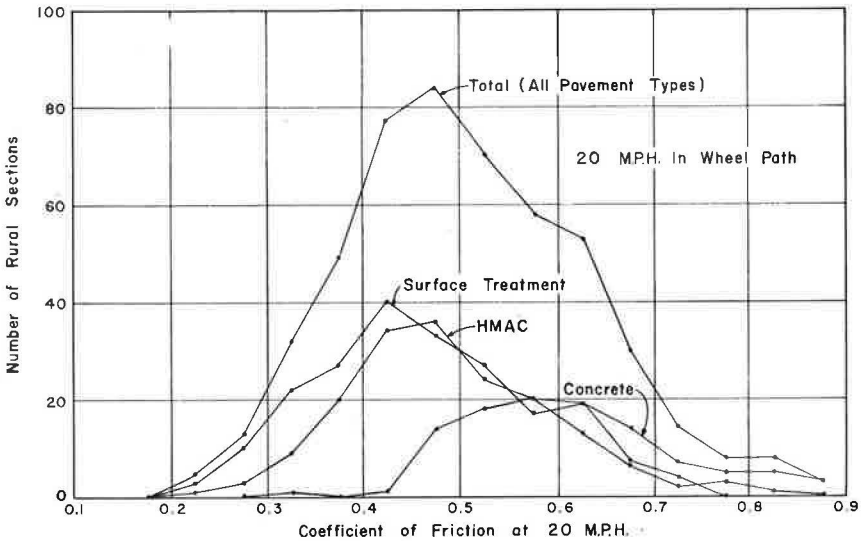

Figure 1. Number of rural sections compared with coefficient of friction at 20 mph.

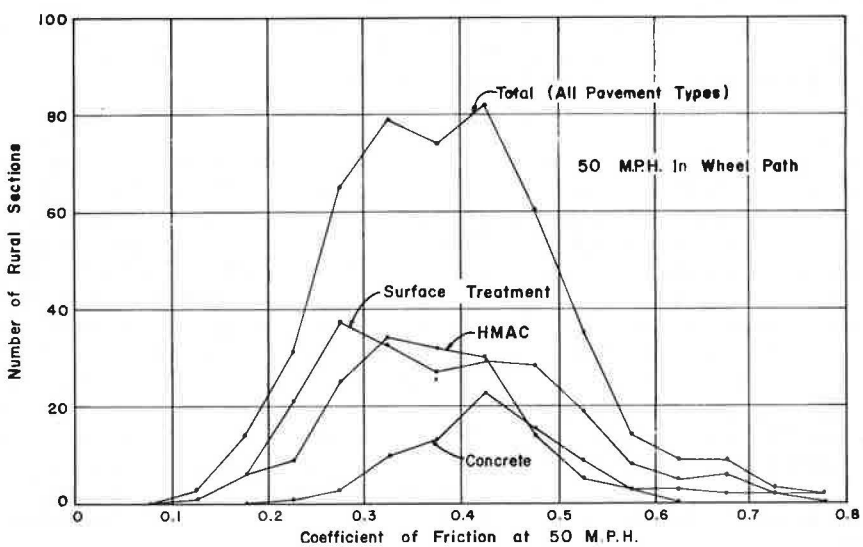

Figure 2. Number of rural sections compared with coefficient of friction at 50 mph.

results: (a) avoiding the accident, (b) speed reduction sufficient to cause only minor damage, or (c) complete loss of control thereby causing the accident. All skidding accidents may not be caused by brake applications, since it has been reported that 35 percent of skidding accidents occurred before brake application (4). There is then indecision as to which accident type to select for correlating with the coefficient of friction. Should the study be based on total accidents, assuming that the percent of skidding accidents occurring within the total number stays constant; or rain accidents, assuming that skidding occurs more frequently on the wet pavement; or skidding accidents, which in the present case are hand-selected, taking considerable time and expense?

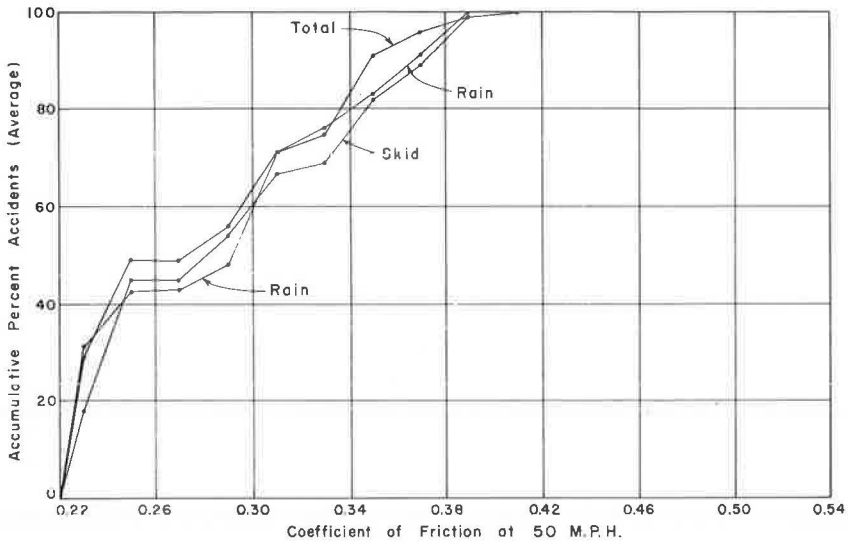

Figure 3. Study of average cumulative percent accidents and coefficient of friction for Austin and San Antonio on I-35.

The accidents selected in the urban areas were of three types: skid accidents, rain accidents, and total accidents. In an effort to "purify" the skid accidents selected, only those accidents caused by skidding were selected. Such accidents would be of the type in which the driver applied the brakes for speed reduction, lost control of the vehicle because of skidding, and the vehicle hit another object. The rain accidents actually occurred in a rain or a mist. The accidents are also a function of the vehicular density, especially those accidents on freeways with short gap or headways as compared with those accidents which occur in sparsely traveled sections. The section length also would influence the number of accidents. Therefore, in an effort to standardize the data, the accidents per length per average daily traffic were selected on a one-year basis. This standardization is called "Accidents Per 100,000,000 Vehicle Miles" (11).

Figure 3 shows the results of the urban study, which was used as a pilot study for the selection of accident type. The data indicate that the three accident types are closely associated. Skid accidents trailed total accidents in average cumulative percent, and the rain-accidents curve was the more variable of the three. This information led to the decision to select total accidents as a study tool for the rural investigation. One limiting feature is the possibility that all total accidents are not reported, depending upon the severity of the accident and the driver involved. However, accidents in which an injury or fatality occurs would in all probability be reported. Therefore, on the basis of this hypothesis, fatal and injury accidents were also included as a study tool.

PRESENTATION OF RESULTS

Although numerous reports have associated accidents with skid resistance, no studies have been reported in this country that attempt to arrive at a minimum skid resistance value through the use of accident data.

In this study, the accident data for the test sections described previously were used to investigate the effect of skid resistance on accidents. In order to develop future study guidelines, two different methods of analysis were used. One method was to directly compare accident data on a section of roadway with its coefficient of friction; the second method used a cumulative frequency distribution curve.

Direct Comparison

In this method, the accident rate per one hundred million vehicle miles for a given test section was plotted in terms of coefficient of friction for the test section. This

type of analysis was run using both total accidents for a section and the fatal and injury accidents for the section.

Total Accidents.—Figures 4 and 5 show the total accidents experienced on a section of roadway in terms of the coefficient of friction for that roadway at 20 mph and at 50 mph, respectively. Although there is a wide scatter of points, the data do indicate that accidents are, in general terms, inversely proportional to the coefficient of friction, or in other words, the accident rate tends to increase as the coefficient of friction decreases. The line to the right edge of the data can be designated as a line of maximum accidents. A section may have a low skid resistance and still have a low accident rate, but in no case will the accidents exceed that predicted by the line of maximum accidents. The change for a high accident rate increases as the skid resistance decreases. The line of maximum accidents clearly shows the inverse trend between these two parameters.

Using the line of maximum accidents as a guide, there is a very sharp increase in the number of accidents when the skid resistance drops below 0.45 for values obtained at 20 mph, whereas the rapid increase is noted near 0.35 for tests at 50 mph.

Fatal and Injury Accidents.—Figures 6 and 7 show the number of fatal and injury accidents experienced in a section of roadway instead of the total accidents used in the previous graphs. Figures 6 and 7 are for 20 mph and 50 mph, respectively. A line of maximum accidents has also been placed to the right of the data on both of these graphs. The trends and observations noted with total accidents are verified by these graphs. At 20 mph, a rapid increase in fatal and injury accidents is experienced when the coefficient of friction decreases below a value of 0.40. At 50 mph, the increase in fatal and injury accidents is experienced at 0.35 as was the case with total accidents.

Cumulative Comparison

Another method of comparison is to use the data and construct a cumulative frequency distribution curve. One complicating factor in making this type of analysis is that the data form a normal distribution pattern rather than a factorial type arrangement, as would be the case for a planned experiment (see Figs. 1 and 2). Therefore, a coefficient value near the mean skid resistance of all the test sections will show a much greater total number of accidents because of the greater number of test sections in this range. In order to offset this phenomenon, an average accident rate for each coefficient range was calculated on the basis of the number of sections in the particular range. The frequency curve was then compiled on the basis of these values. As a result, a coefficient range at the extremes of the distribution has the same influence as one near the mean.

Figures 8 and 9 show these cumulative percentages for 20 and 50 mph, respectively. Both total accidents and fatal and injury accidents are shown on these graphs. At 20 mph, the slope of the line starts decreasing between 0.45 and 0.50 for the total accidents, but in the case of fatal and injury accidents, there is no sharp break in the curve until a value between 0.5 and 0.6 is reached. At 50 mph, the slope begins to decrease at a coefficient value between 0.30 and 0.35 for both the total accidents and the fatal and injury accidents. The point of change is much more clear-cut at 50 mph than at 20 mph.

It is interesting to note that the two methods of analysis give critical values approximately equal although the values vary for speed as would be expected. For 20 mph, the data indicate that an increase of accidents is experienced when the coefficient of friction decreases below a value that is in a range of 0.4 to 0.5. At 50 mph, this value appears to be between 0.30 and 0.35. Purely from an accident standpoint, the previously enumerated values may be considered as minimum levels for roadways in the State.

DISCUSSION OF RESULTS

At this point, it is again emphasized that the accident data obtained in this report were in no way correlated to driver characteristics, vehicular characteristics, or geometric characteristics. The authors fully recognize that coefficient of friction is not the only cause of accidents, but the results of this study point out its importance.

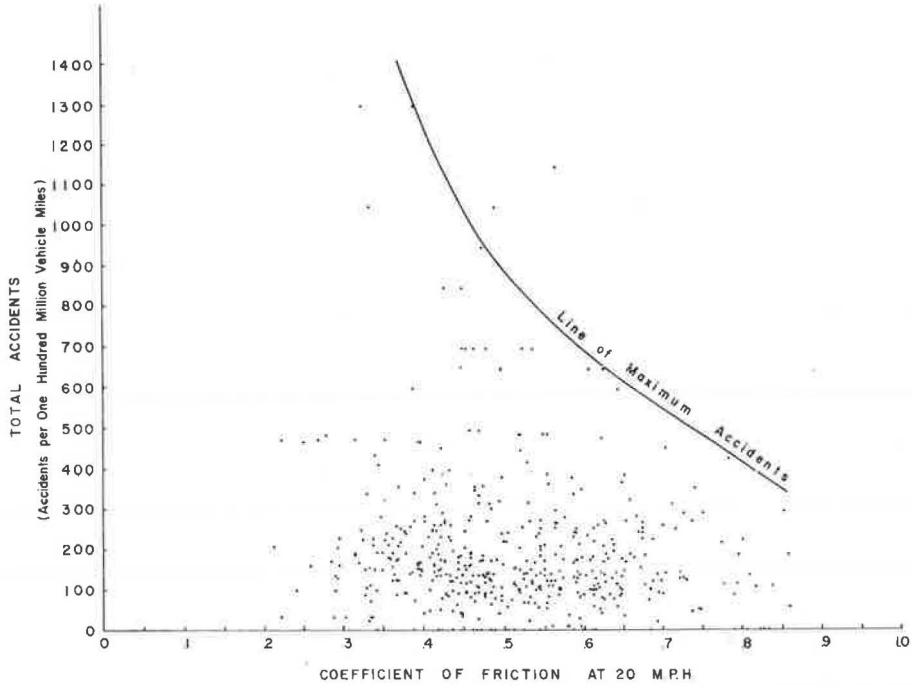

Figure 4. Comparison of total accidents and coefficient of friction at 20 mph.

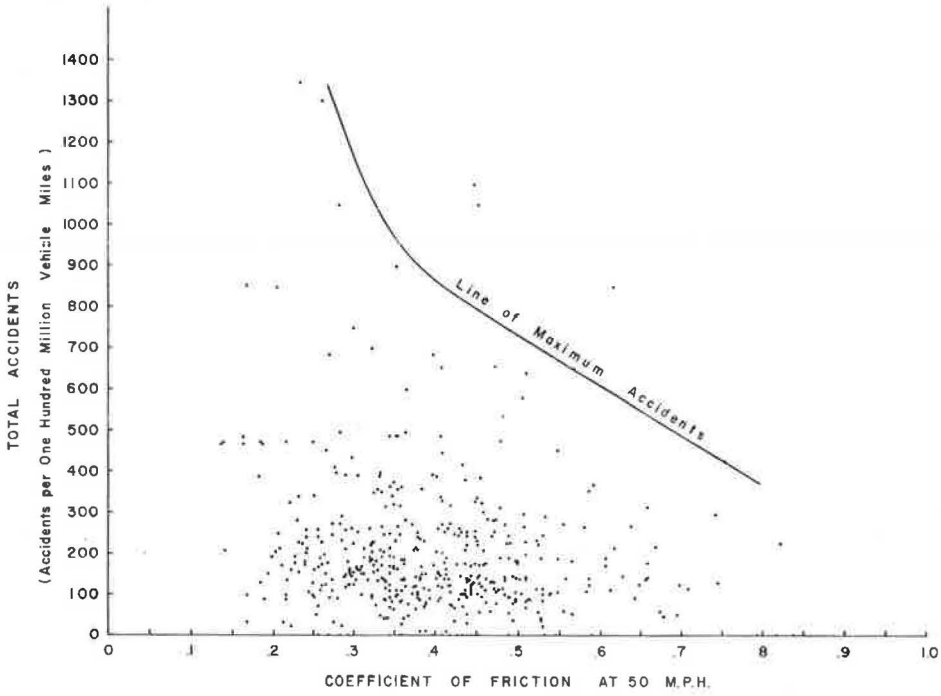

Figure 5. Comparison of total accidents and coefficient of friction at 50 mph.

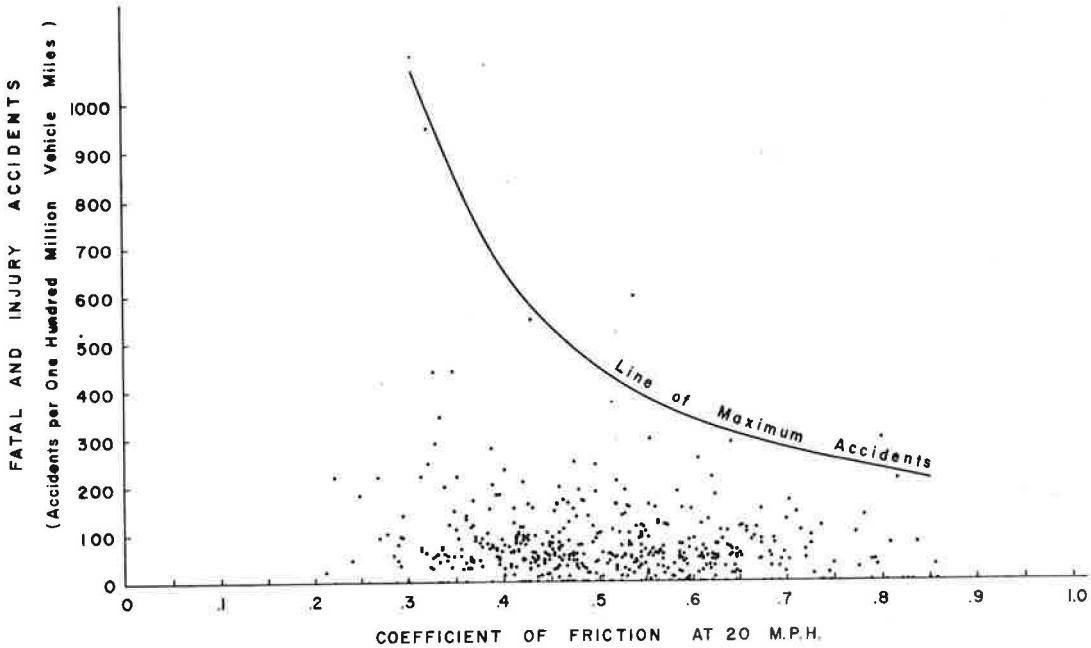

Figure 6. Comparison of fatal and injury accidents and coefficient of friction at 20 mph.

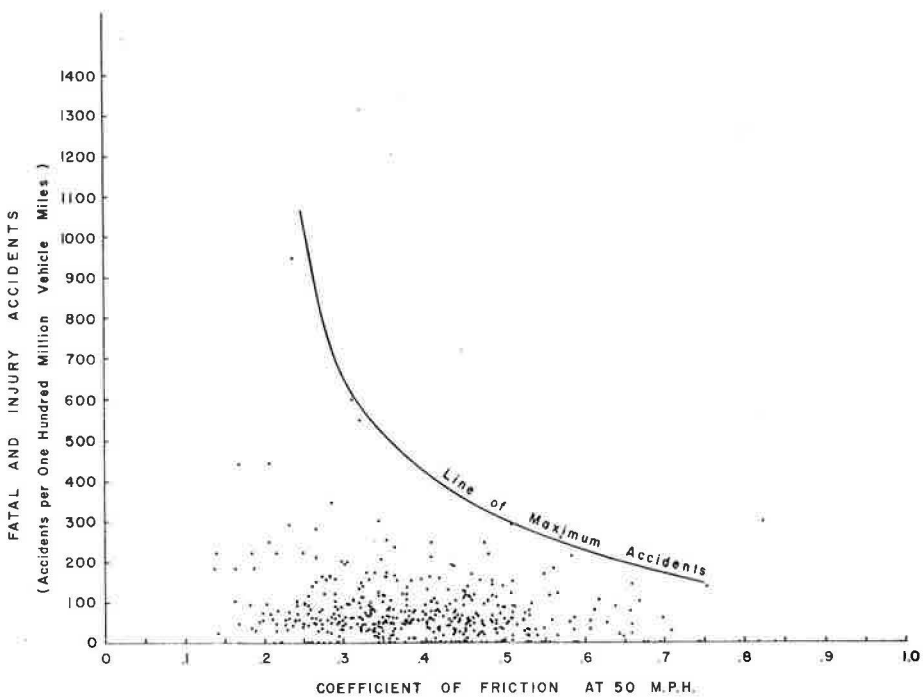

Figure 7. Comparison of fatal and injury accidents and coefficient of friction at 50 mph.

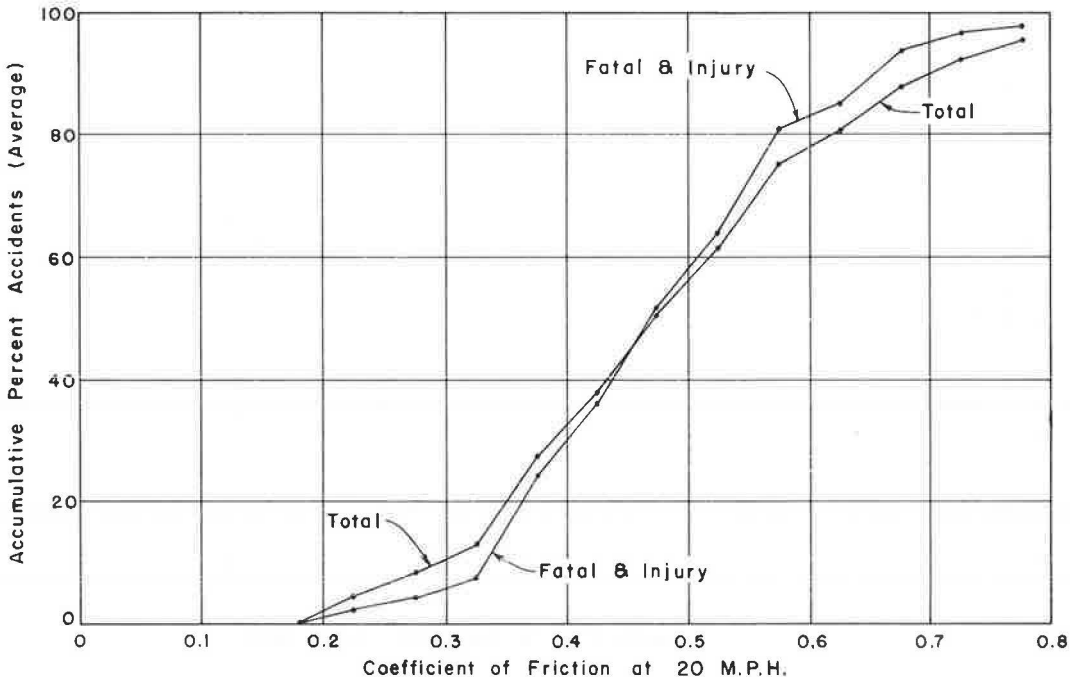

Figure 8. Study of average cumulative percent accidents and coefficient of friction at 20 mph.

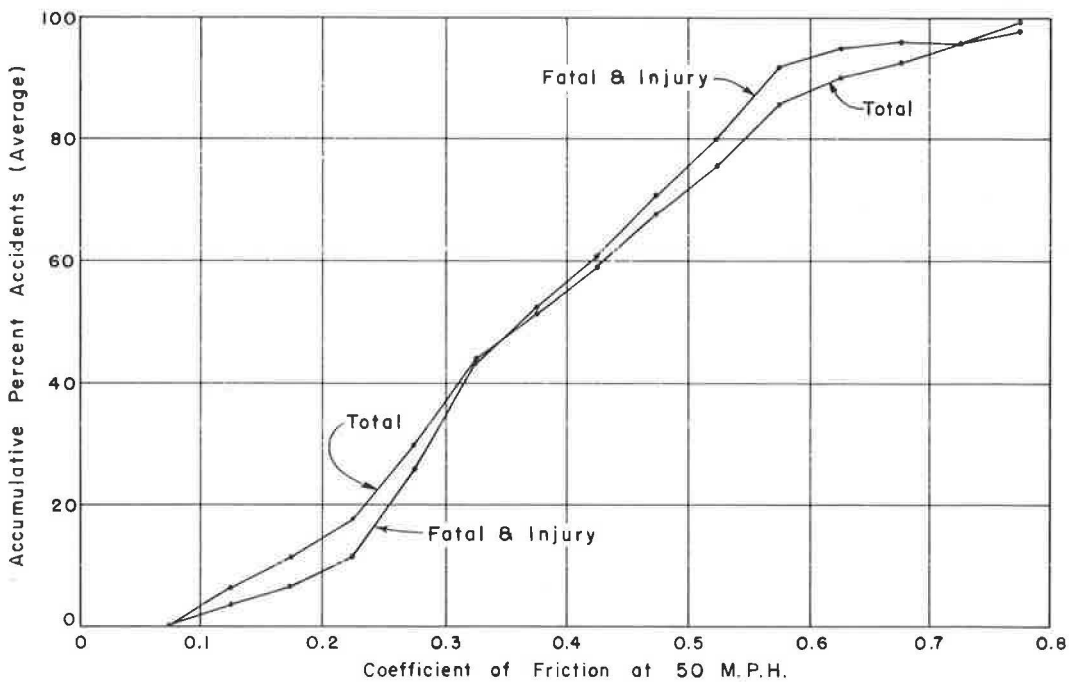

Figure 9. Study of average cumulative percent accidents and coefficient of friction at 50 mph.

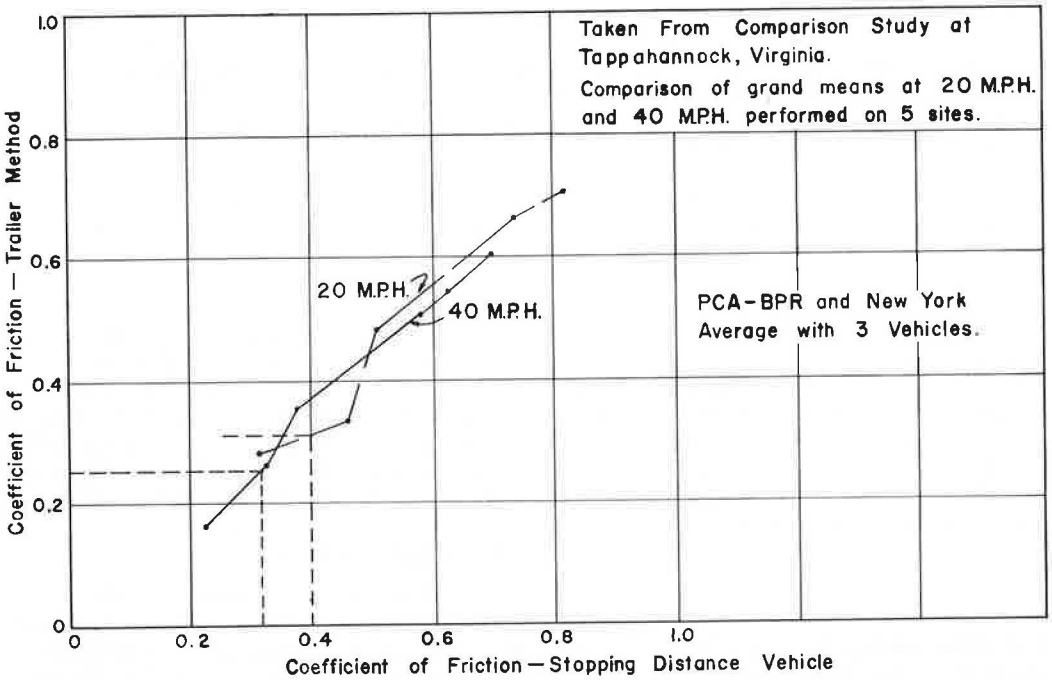

Figure 10. Comparison of stopping distance vehicle vs trailer results.

The size of sample used in this study, correlated with experience on specific locations, certainly lends credence to the approach used.

In this section, a composite minimum coefficient of friction to be used as another guide for skidproofing will be derived from both design and accident minimum coefficients of friction.

A design minimum coefficient of friction is stated in AASHO's policy on geometric design, which is the basis of design in most states. D. W. Loutzenheiser, Chief of Highway Design Division, Bureau of Public Roads, has a very good discussion of this topic in the report "Skid Resistance Values Used in Geometric Design" (12). This minimum coefficient is based on an assumed speed, an adequate perception, reaction time, and the assumption of good brakes or good vehicular characteristics. The minimum was established on the basis of data derived by the stopping distance vehicle method. The values obtained by this method are probably more closely associated with accidents, in that it parallels the "panic stop" situation. Since very little stopping distance data were available in Texas, and it is necessary to correlate the two methods, the work performed at Tappahannock, Virginia, was used as a basis (13). Figure 10 is a correlation of the two methods in which the three sedans were selected from the stopping distance information, and the New York, Portland Cement Association, and Bureau of Public Roads trailers were selected from the trailer information. These three trailers were chosen because their design is similar to the design of the Texas trailer.

Using the above relationship in connection with the curve showing the skid resistance in terms of velocity that was used as the criterion for stopping distance in the AASHO Guide, a minimum design coefficient as measured with the trailer method may be obtained. Table 2 was constructed using Figure 10 and a straight-line interpolation from 20 mph through 40 mph to obtain the minimum design coefficient value at 50 mph.

Accident Minimum

Strictly from an accident standpoint, the data discussed in the previous section indicate that accidents increase when the skid resistance decreases below the values in a

TABLE 2

Speed (mph)	Minimum Design Coefficient by Stopping Vehicle Method	Minimum Design Coefficient by the Trailer Method
20	0.4	0.31
40		0.25
50	0.3	0.24

TABLE 3

Speed (mph)	Recommended Composite Coefficient of Friction
20	0.40
50	0.30

range of 0.4 to 0.5 at testing speeds of 20 mph and 0.3 to 0.35 at 50 mph. Although it is not known to what extent all the accidents used in the analysis are related to skid resistance, the inner-relation between the two factors is evident, and it should be taken into consideration.

Composite Minimum

From a logical standpoint, the design coefficient for stopping distance as established by AASHO is an absolute minimum value that can be tolerated on the highway system. Consideration of the accident data brings forth the question, is this the minimum coefficient value to be maintained for safety? Loutzenheiser (12) refers to the AASHO design for Safe Stopping Distance and states:

> The friction factors used entail a substantial safety factor for good pavement, weather and tire conditions, but only a very low factor for the combination of pore conditions. Even in this case, there is a potential safety factor in the perception-reaction distance component and likely lower speed operations during adverse circumstances.

The accuracy of this statement is evident from the data reported. The statement, in conjunction with the data, indicates that the composite minimum should be greater than the design minimum from a standpoint of driver safety. Although this variation in design accident minimums may by hypothesized to be a result of vehicle characteristics or driver characteristics, the fact is that the variation exists and a composite minimum must be determined.

The selection of a composite minimum will not eliminate all accidents, but certainly the severity of the accident can be reduced. A reduction in impact velocity due to an improved skid resistance has a large effect on the force of impact, since the force is decreased by the square of the velocity. The number of vehicles is increasing on Texas highways and recently the speed limits were increased. Many roadways experience small headways and gaps and increasing the coefficient value cannot be expected to prevent all accidents, but it can be expected to reduce the severity and number of accidents.

Combining the design minimum of 0.31 at 20 mph with an accident minimum of 0.40-0.45 at 20 mph and the design minimum of 0.24 at 50 mph with the accident minimum of 0.30-0.35 at 50 mph, the composite figures in Table 3 are recommended for use by the Texas Highway Department. These composite minimums should be used as another guide for scheduling surface improvements on a section of highway.

Implications of Composite Minimum

After selection of a composite minimum, the immediate question arises, what percent of the highway system is below this minimum? Figures 11 and 12 indicate a cumulative frequency distribution of the coefficient of friction for the 517 preselected rural sections at testing velocities of 20 mph and 50 mph, respectively. If the selection

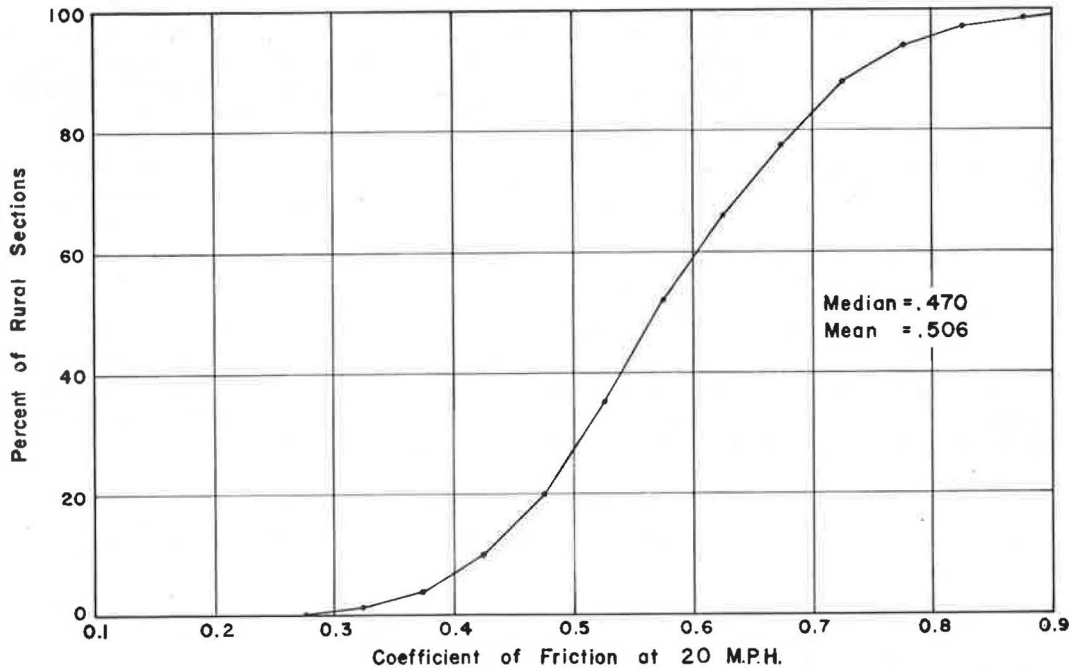

Figure 11. Cumulative percent of rural sections compared with coefficient of friction at 20 mph.

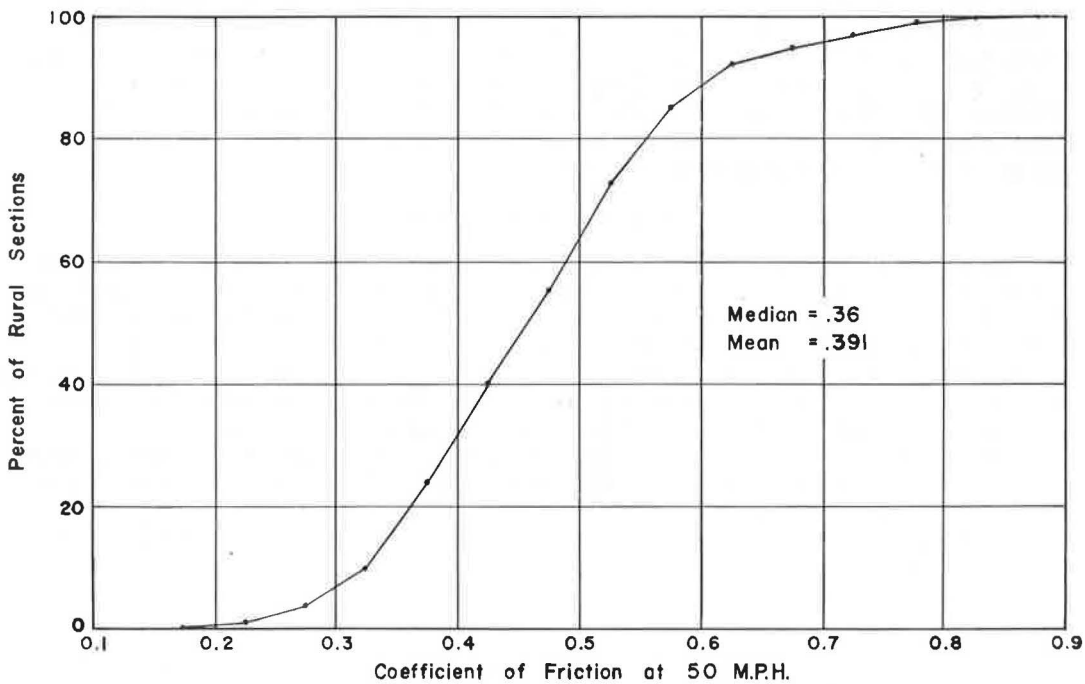

Figure 12. Cumulative percent of rural sections compared with coefficient of friction at 50 mph.

of these test sections represents a random sample from all Texas highways, then it may also be assumed that this selection represents all highways in the state. Entering Figure 11 with the composite minimum value of 0.40, it may be postulated that 27 percent of Texas highways do not meet this minimum value at the present time. Upon first consideration, this percentage seems large; however, if Figure 11 is entered with the absolute design minimum of 0.31, it is found that 8 percent of Texas highways do not comply with the design minimum at the present time. Investigating these percentages for a testing velocity of 50 mph, Figure 12 is entered with the composite minimum coefficient of 0.30. This analysis shows that 32 percent of Texas highways do not meet this value, and again using the absolute design minimum of 0.24, the data indicate 14 percent of Texas highways are deficient.

These composite minimums should be used as another guide for surface improvement. Economic considerations along with other overall project needs would preclude the use of these values as absolute minimums at the present time, but the composite minimums should be used as positive guides for surface improvement where feasible. The design minimums should be considered as absolute minimums.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of this study the following conclusions and recommendations are warranted:

1. The number of accidents experienced on a highway is related to the magnitude of the surface's skid resistance. The smaller the skid resistance, the greater the chance of a high accident rate.
2. The composite minimum coefficients of 0.4 and 0.3 at testing velocities of 20 and 50 mph, respectively, should be used as another guide for programming pavement surface improvements. When the skid resistance decreases below this value, surface upgrading should be considered
3. The design coefficients of 0.31 and 0.24 at 20 mph and 50 mph should be considered as absolute minimum values. When the roadway skid resistance decreases below these values, an immediate surface improvement program should be undertaken.
4. It is recommended that the Maintenance Engineer in each district institute an inventory program to determine the level of skid resistance on each project in his area. This inventory should be kept current in order to provide another method of evaluating the program needs for seal coats, overlays, etc.

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