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# DEPARTMENTAL RESEARCH

Report Number: 45 - 2

## SKID RESISTANCE GUIDELINES for SURFACE IMPROVEMENTS on TEXAS HIGHWAYS

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SKID RESISTANCE GUIDELINES FOR SURFACE IMPROVEMENTS

ON TEXAS HIGHWAYS

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Research Report 45-2

Determining and Evaluating Skid  
Characteristics of Texas Pavements  
Research Project 1-8-63-45



Conducted By

Highway Design Division, Research Section  
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## A B S T R A C T

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 pre-selected rural sections that represented a sample of Texas Highways. The skid resistance values were obtained through the use of a towed trailer employing the locked wheel principal on artificially 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 miles per hour, respectively, were selected as guidelines for considering surface improvements. In addition, skid resistance values of 0.31 and 0.24 at 20 and 50 miles per hour, respectively, were recommended as minimum values.

## I. Introduction

### Background

When discussing skid resistance of roadway surfaces with interested personnel, the first topic inevitably relates surface friction and accidents. After obtaining equipment to measure skid resistance such as the two wheeled test trailer recently developed by the Texas Highway Department<sup>1</sup>, the question immediately forms - 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 to the vehicle by the pavement surface after the brake application.

Mr. K. A. Stonex, of the General Motors Corporation, defines skidding 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.<sup>2</sup> How the vehicle reacts when 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 sliding sideways to a position approximately 180° to the position before brake application, much as an inverted pendulum swings about its pivot.<sup>2</sup> 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 indicative that skidding is related to weather conditions. It is a common opinion that the number of accidents as well as the injury rate increases on wet roadways. Investigators both in this country and abroad have made detailed studies of accidents, skidding, and weather conditions. Mr. C. G. Giles and Barbara E. Sabey, of the Road Research Laboratory, United Kingdom, reports

that eight percent of the total number of personal injury accidents in dry conditions involved skidding; whereas, 27 percent of the total number of accidents on wet roads involved skidding.<sup>3</sup> Virginia investigators report 0.66 percent of the total number of accidents on rural roads in dry conditions were skidding accidents and 14.65 percent of the total number of accidents on wet roads were skidding accidents.<sup>4</sup> 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 involves slippery road conditions as a cause in Germany.<sup>5</sup> The Road Research Laboratory of the United Kingdom reports that urban areas, even though they have the majority of accidents, are by no means the chief areas, since over 1/3 of all skids on wet roads occur on rural roads.<sup>3</sup>

The enumerated studies indicate that skidding accidents occur chiefly on a wet surface, and coefficients are lower under wet conditions. Therefore, it must follow that many accidents are in some way related to skid resistance.

A few years ago a slick section of pavement in San Antonio, Texas, was "deslicked" by using a method of sawing small closely spaced longitudinal grooves in the concrete surface.<sup>6</sup> 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 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 obtained 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 the following is given:



TABLE 1

Section	Coefficient		*Accidents		Percent Reduction In Accidents
	Before	After	Before (1963)	After** (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

\* Accidents are given per 100 million vehicle miles based on one year of observations.

\*\* "After Accidents" have been extrapolated to a yearly basis from seven months of information.

Even though there is a reduction in accidents on the sawed concrete from 1963 to 1964, the reduction of accidents on the overlaid sections is 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 area. The AASHO Guide<sup>7</sup> refers to stopping sight distance and super-elevation, both of which use minimum coefficient values described as "stopping distance" of a vehicle. Other agencies have set minimums; among those are England<sup>3</sup>, Michigan<sup>8</sup>, and Virginia<sup>9</sup>.

#### Objective

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 the more specific applications.

## II. Method of Analysis

During the initial background study and after a review of the information available, 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 skid resistance tests be performed on 517 sections which were previously selected by Texas Transportation Institute in connection with pavement structure research study.<sup>10</sup> This decision was based on two reasons:

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 representative sample of Texas Highways.

Since the 517 test sections are predominantly rural, fifteen 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 pre-selected 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

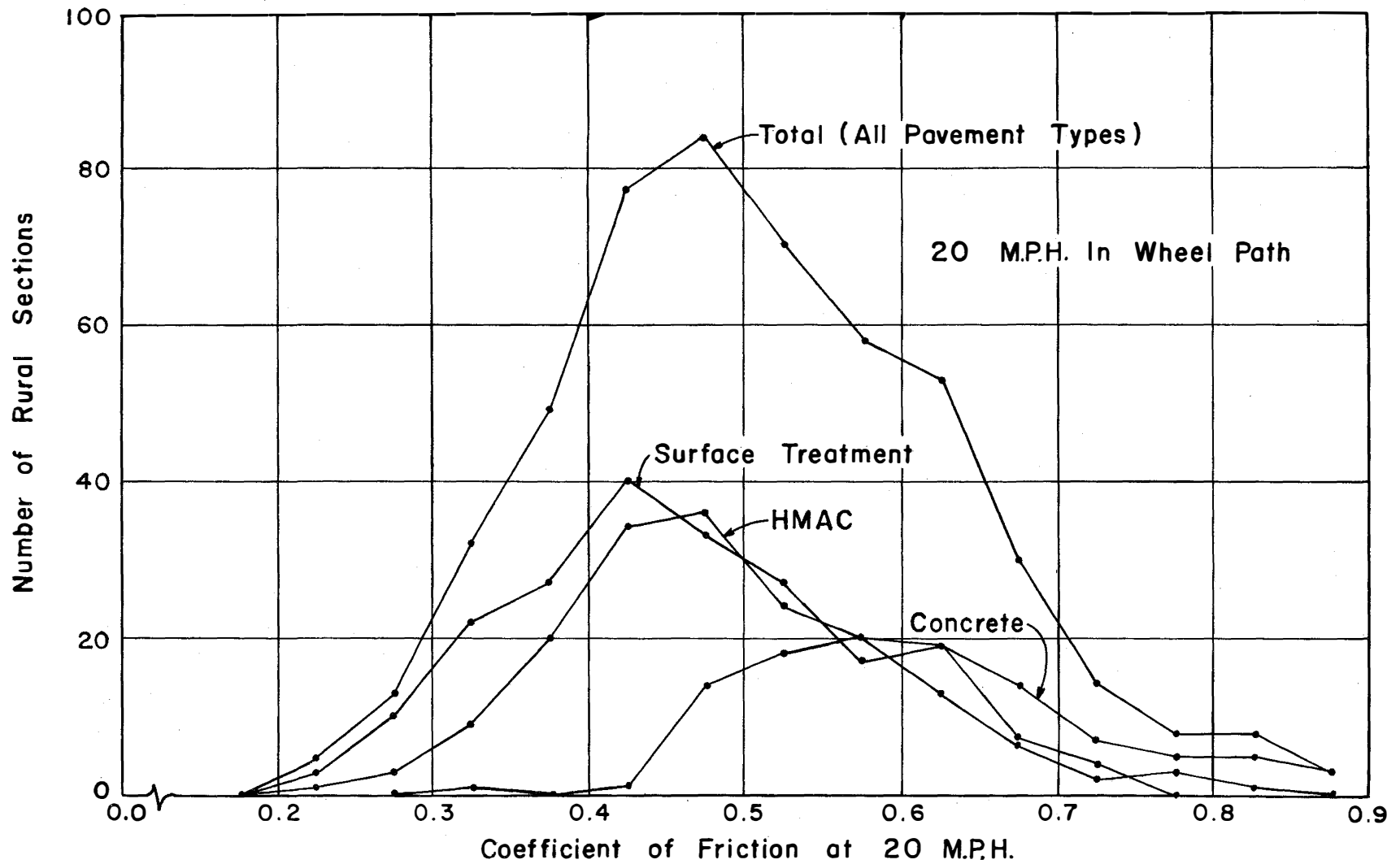
obtained directly from the police department files for each of the two cities. In both cities, the skid resistance values were obtained on the outside lanes and these were used for comparison purposes.

Rural. The rural tests were made on the 517 pre-selected 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 miles per hour in the inside wheel path, 50 miles per hour in the inside wheel path, and at 20 miles per hour with the left wheel or test wheel between the wheel paths. 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.<sup>11</sup>

Figures 1 and 2 portray the inside wheel path coefficient of friction frequency distributions for the 517 test sections for testing velocities of 20 miles per hour and 50 miles per hour, respectively. Note that the statewide average based on this sample is 0.506 at 20 miles per hour and 0.391 at 50 miles per hour.

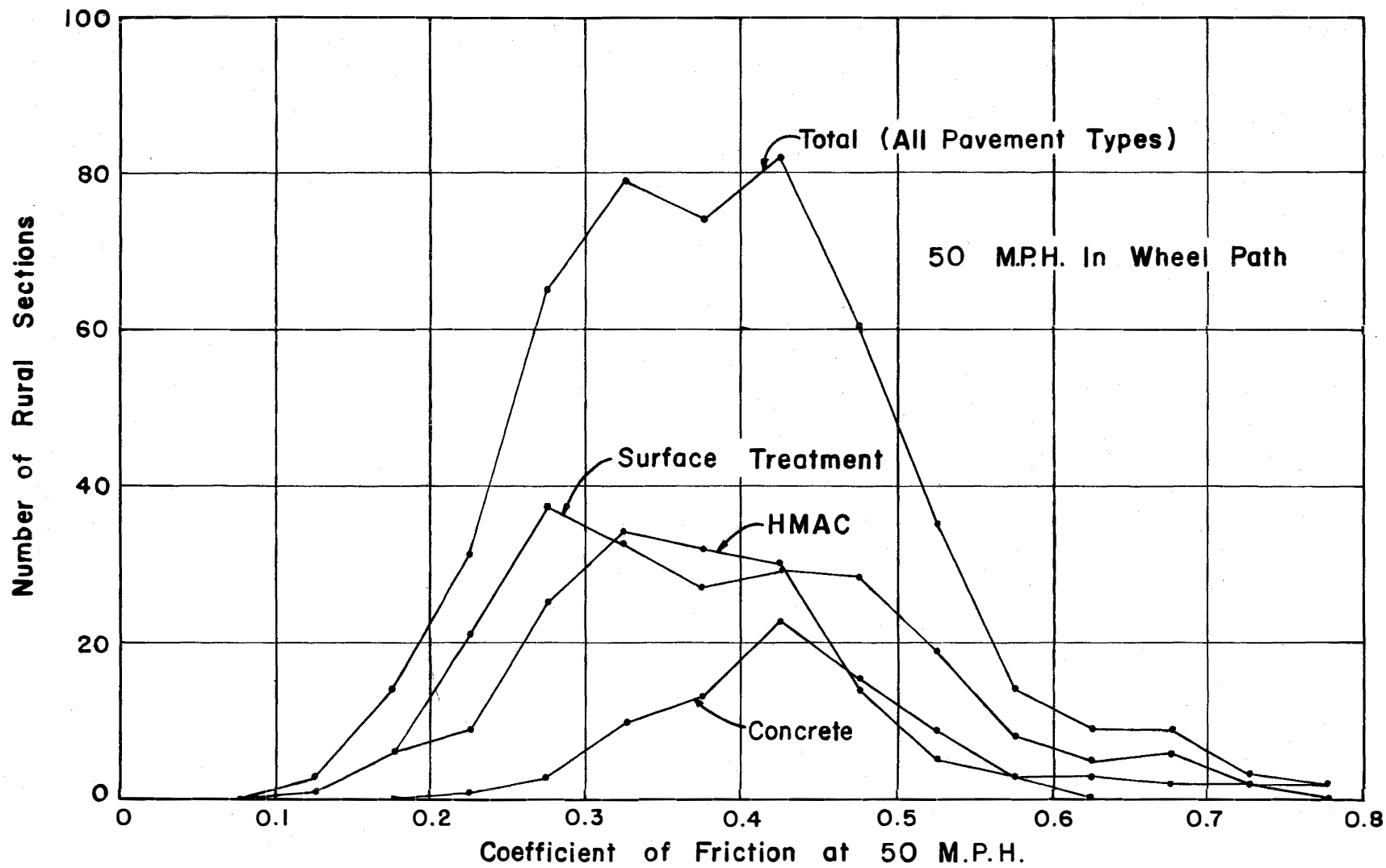
#### Selection of Accident Type

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 result in several different circumstances: (1) avoiding the accident, (2) speed reductions sufficient to result in only minor damage, or (3) complete loss of control thereby leading to an accident. All skidding accidents may not be caused by brake applications in that it has been reported that 35% of skidding accidents occurred before brake application.<sup>4</sup> 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



NUMBER OF RURAL SECTIONS COMPARED WITH COEFFICIENT OF FRICTION AT 20 M.P.H.

Figure 1



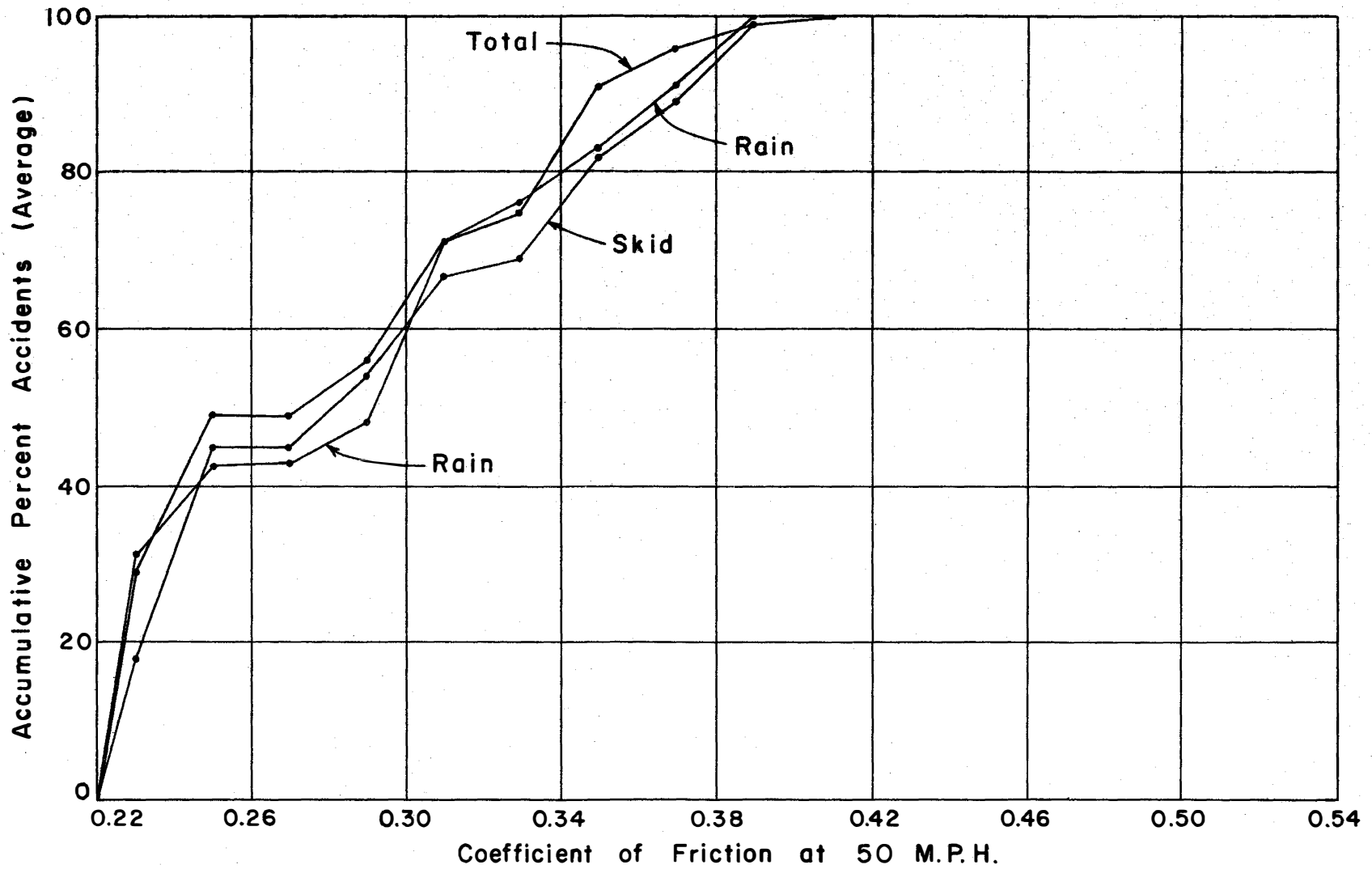
NUMBER OF RURAL SECTIONS COMPARED WITH COEFFICIENT OF FRICTION AT 50 MPH.

Figure 2

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?

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 in which skidding was involved were selected. These 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 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 travelled 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.<sup>11</sup>

Figure 3 shows the results of the urban study which was used as a pilot study for the selection of accident type. The data indicates that the three accident types are closely associated. Skid accidents trailed total accidents in average cumulative percent and the rain accidents curve was the most variable of the three. This information led to the decision of selecting 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.



STUDY OF AVERAGE ACCUMULATIVE PERCENT ACCIDENTS & COEFFICIENT OF FRICTION FOR AUSTIN & SAN ANTONIO ON IH 35

Figure 3



### III. Presentation of Results

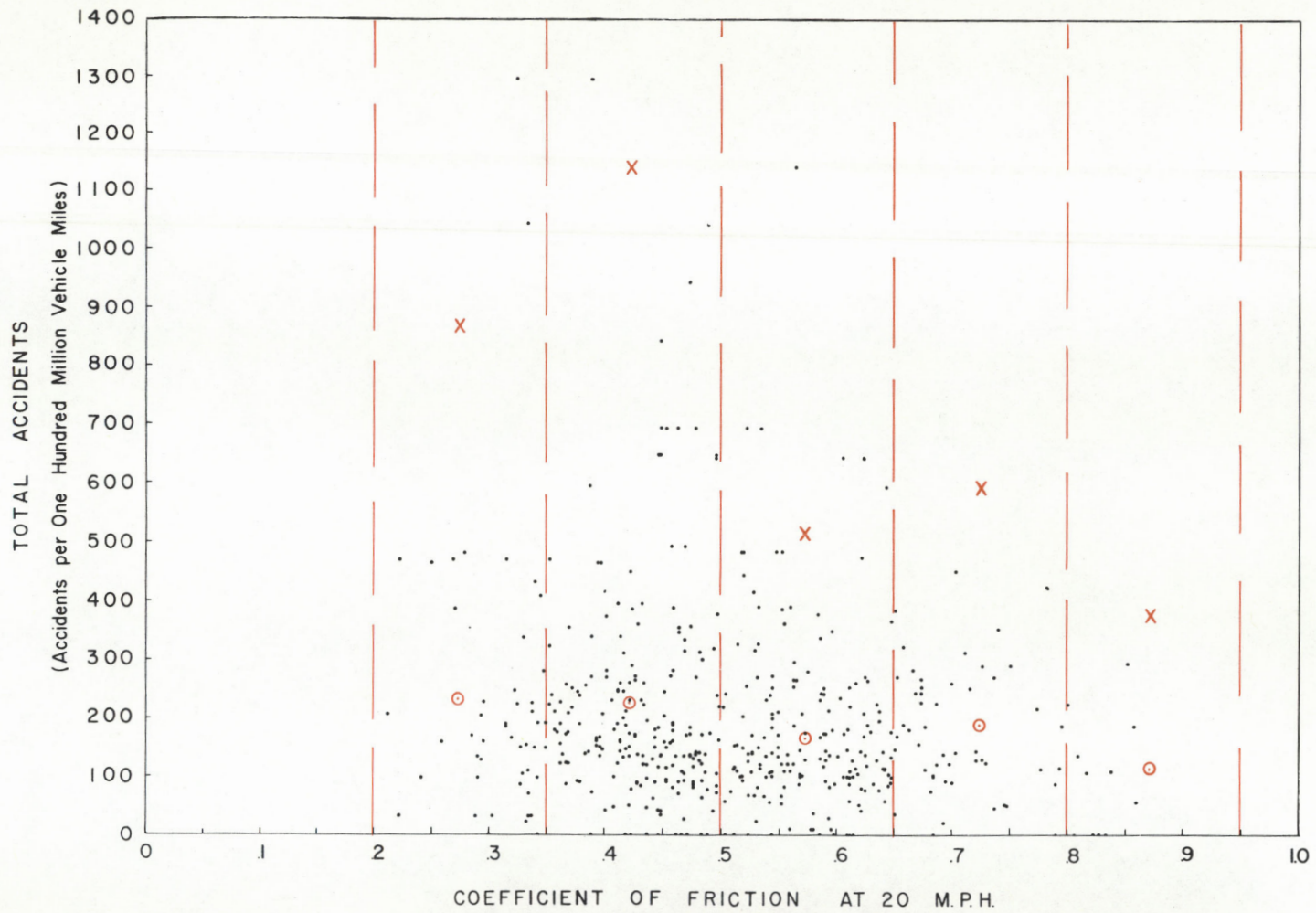
Although numerous reports have associated accidents and skid resistance, no studies have been reported in this country that attempt to arrive at a minimum skid resistance value through the use of accident data.

In this study, the accident data for the test sections described previously was 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; whereas, the second method used a cumulative frequency distribution curve.

#### Direct Comparison

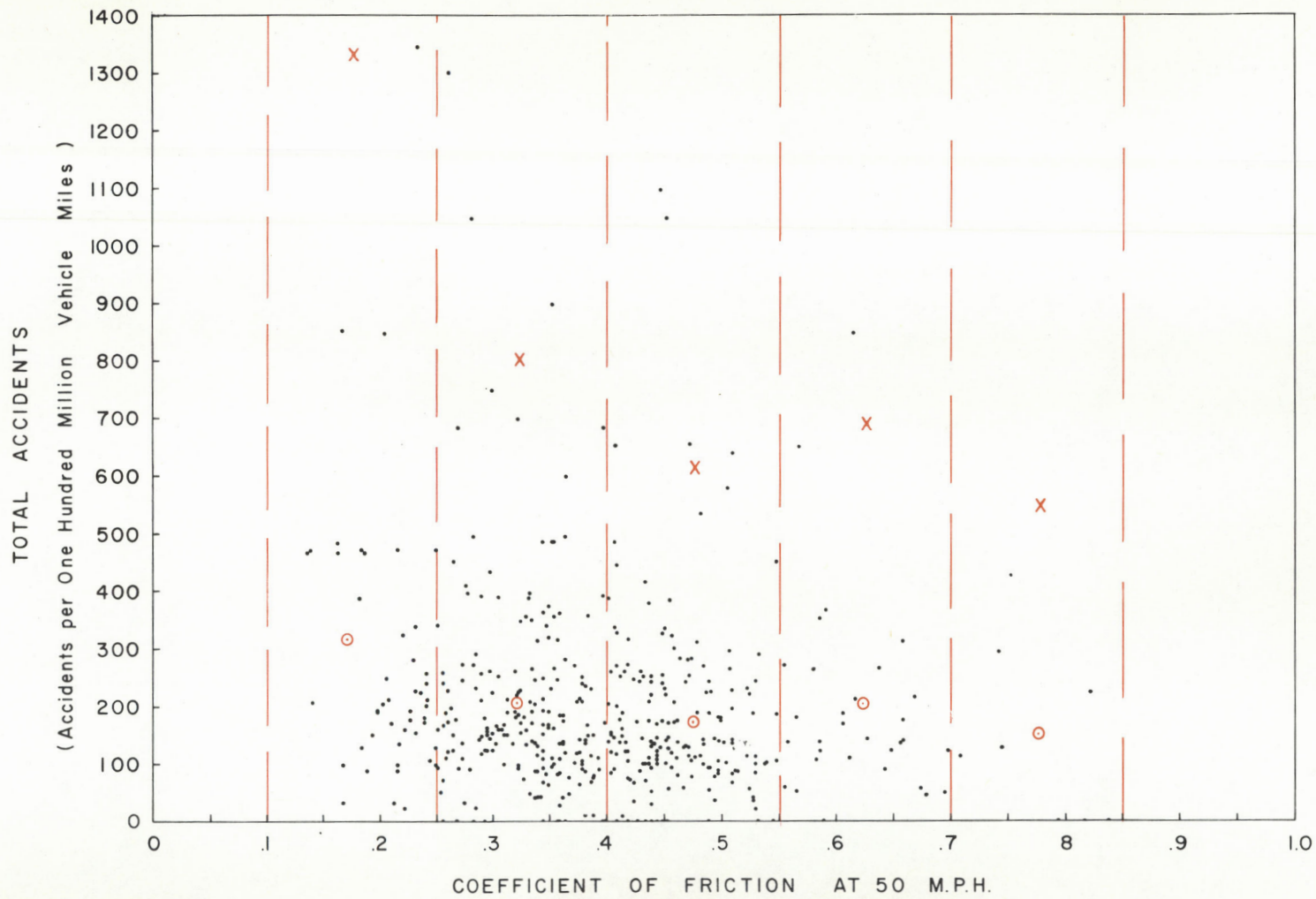
In this method, the accident rate per one hundred million vehicle miles for each given test section was plotted in terms of coefficient of friction for the test section. This type of analysis was run using both total accidents for a section and the fatal injury accidents for the section.

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 miles per hour and at 50 miles per hour, respectively. Although there is a wide scatter of points, the data does indicate that accidents are in general terms, inversely proportional to the coefficient of friction, or in other words, there is an indication that the accident rate increases as the coefficient decreases. Even though the number of sections experiencing accidents do not increase with a decrease in skid resistance, it appears the number of accidents on any one section does increase as the skid resistance decreases. Since the statistical term "standard deviation" is a measure of scatter about the mean, this method can be used to measure the accident rate "variation" from the mean.



**COMPARISON OF TOTAL ACCIDENTS AND COEFFICIENT OF FRICTION AT 20 M.P.H.**

FIGURE 4



**COMPARISON OF TOTAL ACCIDENTS AND COEFFICIENT OF FRICTION AT 50 M.P.H.**

FIGURE 5

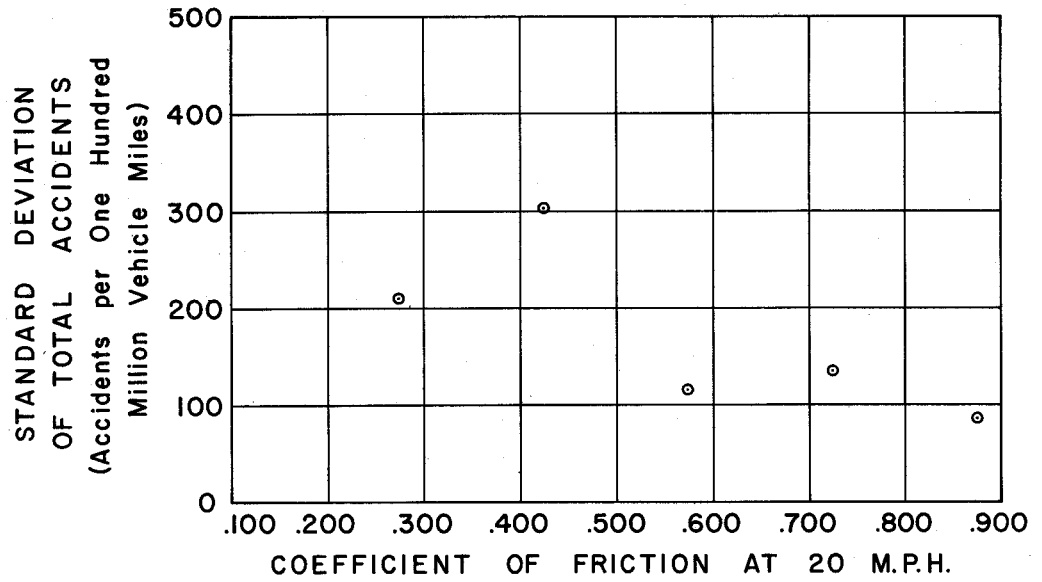
The coefficients were therefore grouped into classes with the class interval equal to 0.15 as shown by the vertical dashed lines in Figures 4 and 5. The mean of the accidents in any one class has been plotted as a large circle and a point three standard deviation away from the mean has been plotted with a large "X".

Figures 6 and 7 indicate a plot of the standard deviation and coefficient of friction. Using the larger variations as a guide, larger accident rates can be expected in the lower coefficient ranges and this rate decreases to a relatively constant value between coefficients of 0.3 to 0.4 at 50 miles per hour and from 0.45 to 0.55 at 20 miles per hour.

Fatal and Injuries. Figures 8 and 9 portray the number of fatal and injury accidents experienced in a section of roadway in lieu of the total accidents used in the previous graphs. Figures 8 and 9 are for 20 miles per hour and 50 miles per hour, respectively. Figures 10 and 11 indicate the variation experienced in this accident type. The trends and observations noted with total accidents are verified by these graphs. At 20 miles per hour, a rapid increase in fatal and injury accidents is experienced when the coefficient of friction decreases below a value of 0.45 to 0.55. At 50 miles per hour, the increase in fatal and injury accidents is experienced as the coefficient of friction decreased below 0.3.

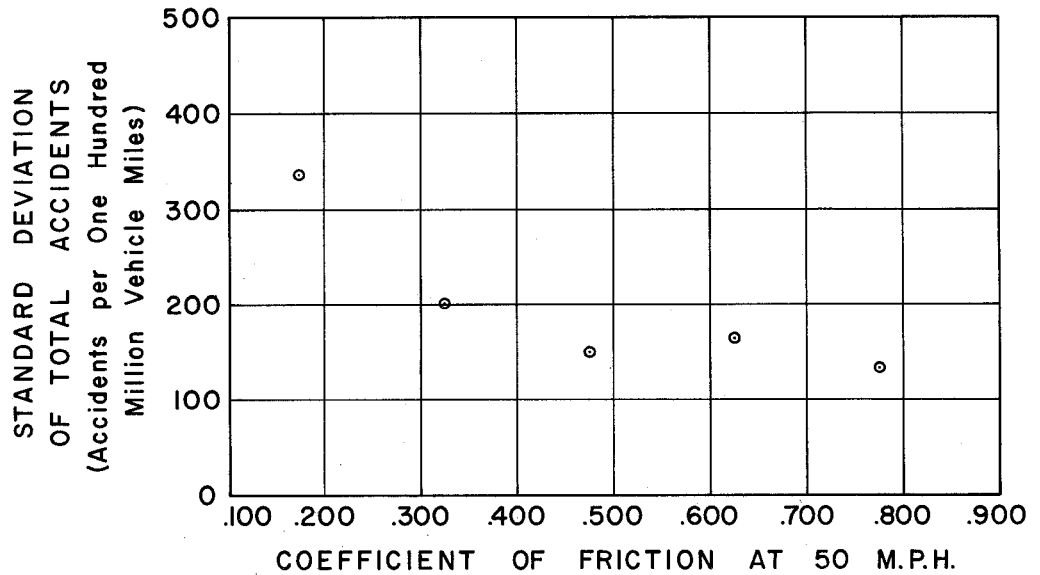
#### Cumulative Comparison

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 forms a normal distribution pattern rather than a factorial type arrangement, as would be the case for a planned experiment (see Figures 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 due to 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



VARIATION OF ACCIDENT RATE OF TOTAL ACCIDENTS WITH COEFFICIENT OF FRICTION AT 20 M.P.H.

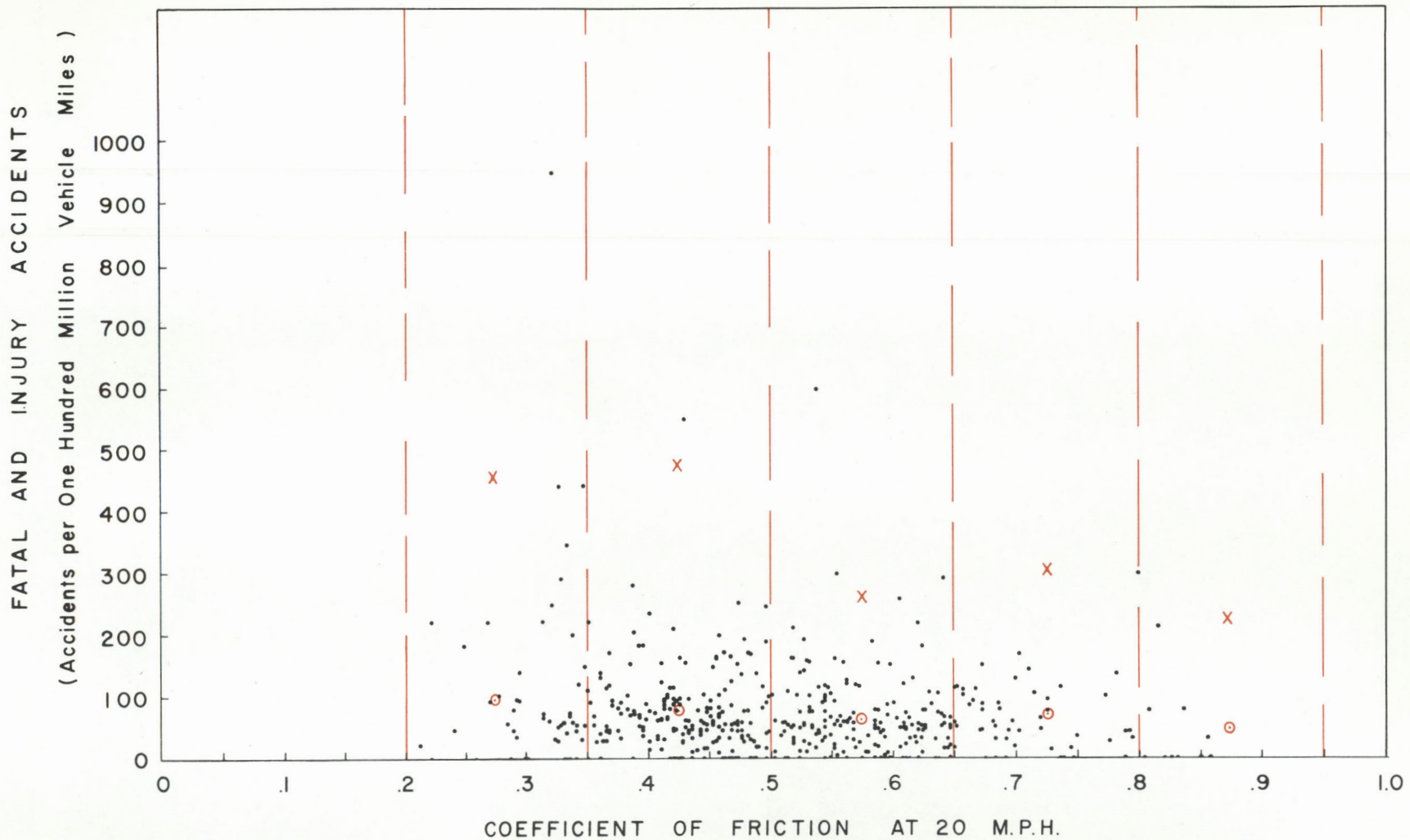
FIGURE 6



VARIATION OF ACCIDENT RATE OF TOTAL ACCIDENTS WITH COEFFICIENT OF FRICTION AT 50 M.P.H.

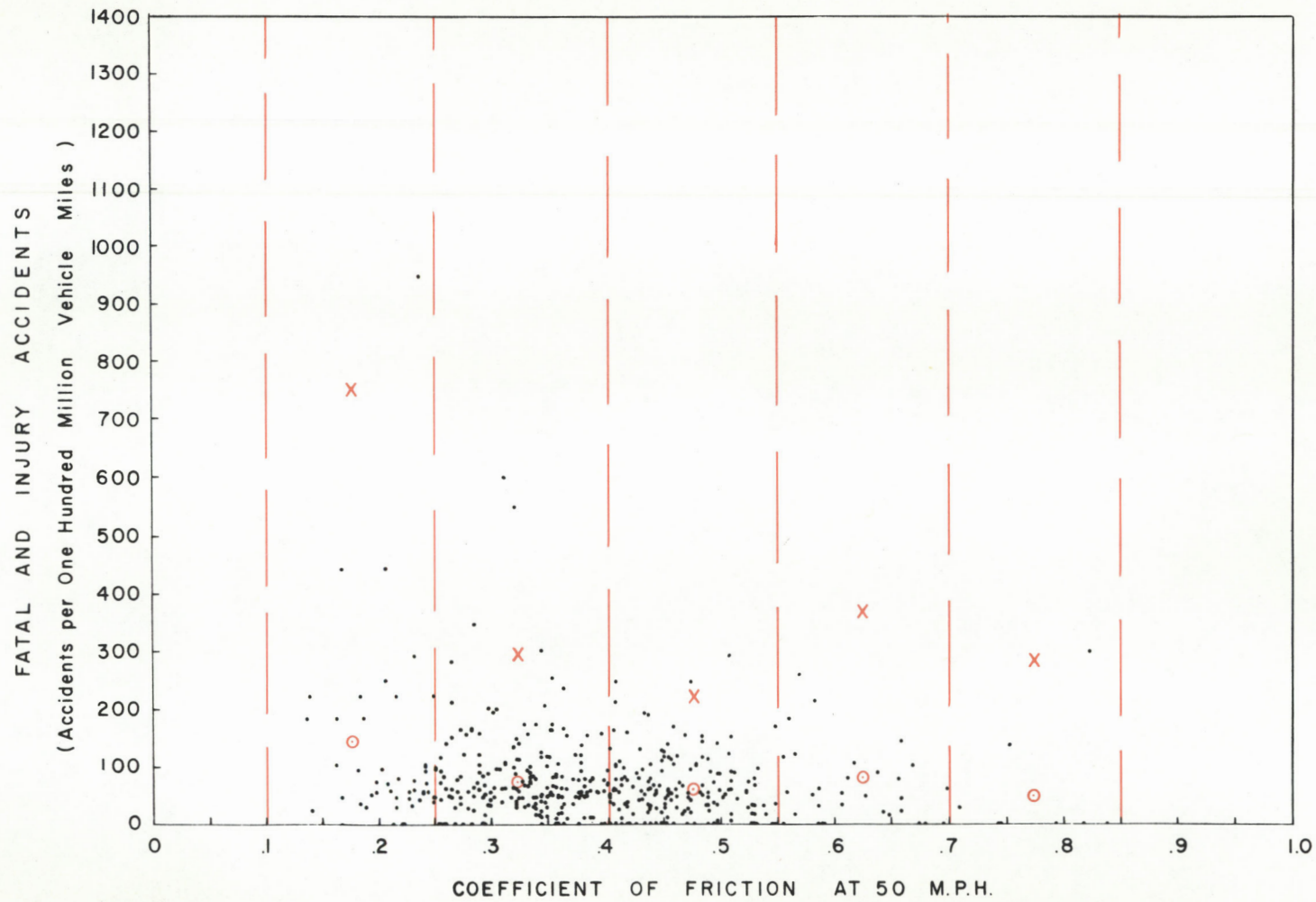
FIGURE 7





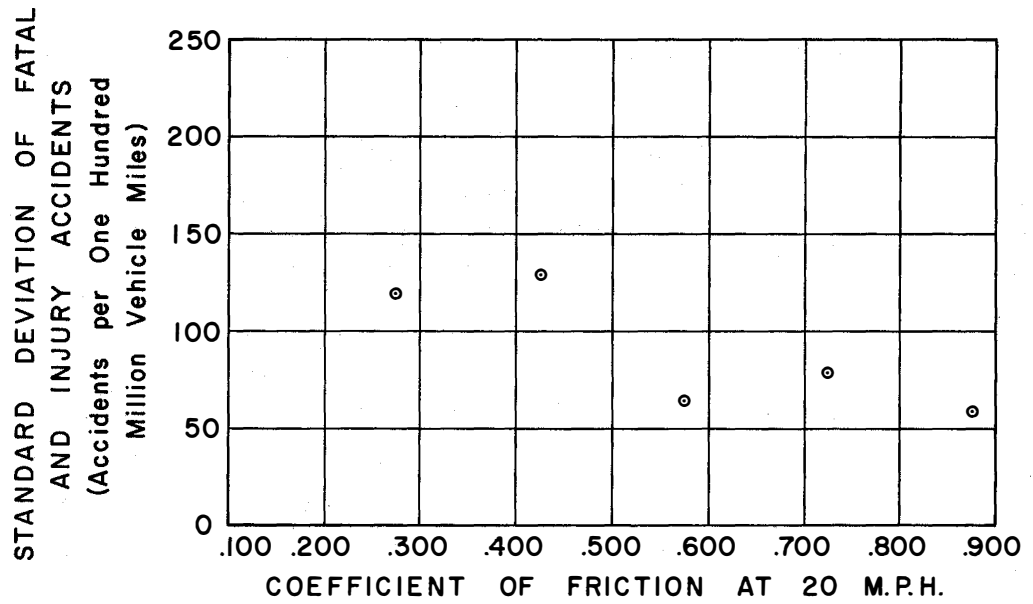
**COMPARISON OF FATAL AND INJURY ACCIDENTS AND  
COEFFICIENT OF FRICTION AT 20 M.P.H.**

FIGURE 8



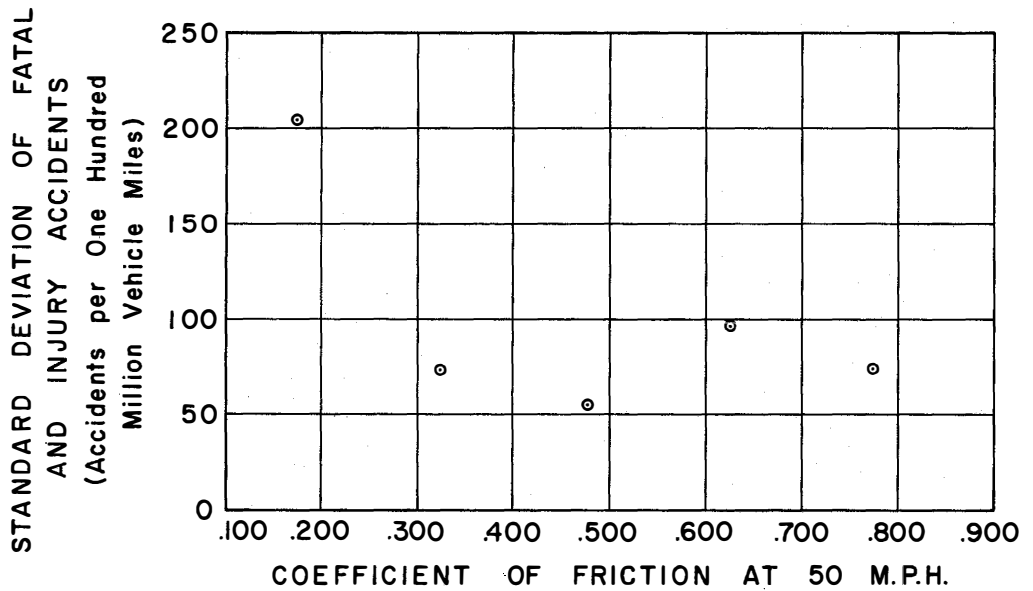
**COMPARISON OF FATAL AND INJURY ACCIDENTS AND  
COEFFICIENT OF FRICTION AT 50 M.P.H.**

FIGURE 9



VARIATION OF ACCIDENT RATE OF FATAL AND INJURY ACCIDENTS WITH COEFFICIENT OF FRICTION AT 20 M.P.H.

FIGURE 10



VARIATION OF ACCIDENT RATE OF FATAL AND INJURY ACCIDENTS WITH COEFFICIENT OF FRICTION AT 50 M.P.H.

FIGURE 11

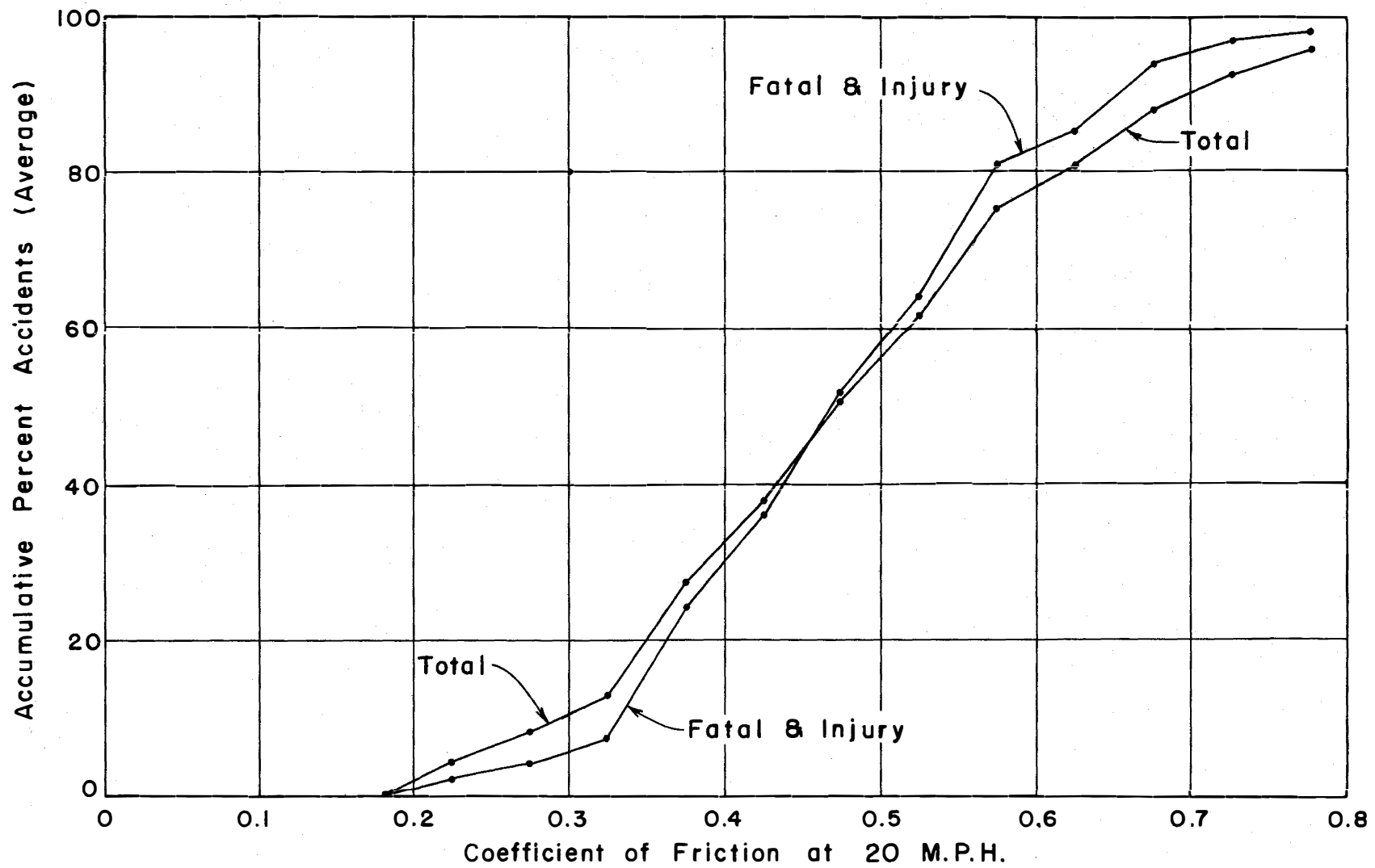


range. The frequency curve was then compiled on the basis of these values. As a result, a coefficient range at the extremes of the distribution has the same influence as one near the mean.

Figures 12 and 13 show these cumulative percentages for 20 and 50 miles per hour, respectively. Both total accidents and fatal and injury accidents are shown on these graphs. At 20 miles per hour, 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 miles per hour, 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 miles per hour than at 20 miles per hour.

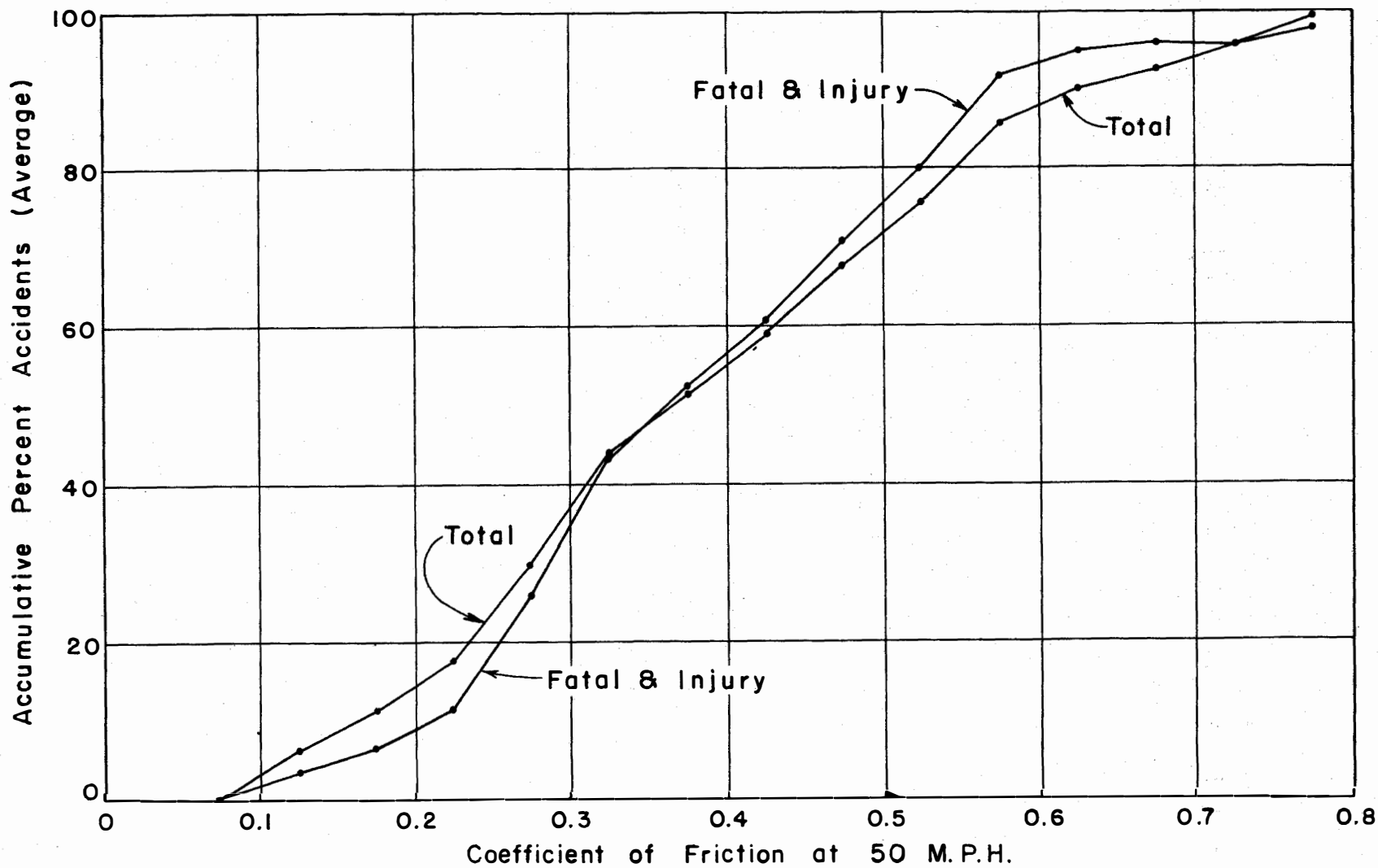
#### Summary

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 miles per hour, the data indicates that an increase of accidents is experienced when the coefficient of friction decreases below a value that is in a range of 0.45 to 0.55. At 50 miles per hour, this value appears to be between 0.20 and 0.30. From purely an accident standpoint, the previously enumerated values may be considered as minimum levels for roadways in the State.



STUDY OF AVERAGE ACCUMULATIVE PERCENT ACCIDENTS & COEFFICIENT OF FRICTION AT 20 M.P.H.

Figure 12



STUDY OF AVERAGE ACCUMULATIVE PERCENT  
ACCIDENTS & COEFFICIENT OF FRICTION AT 50 M.P.H.

Figure 13

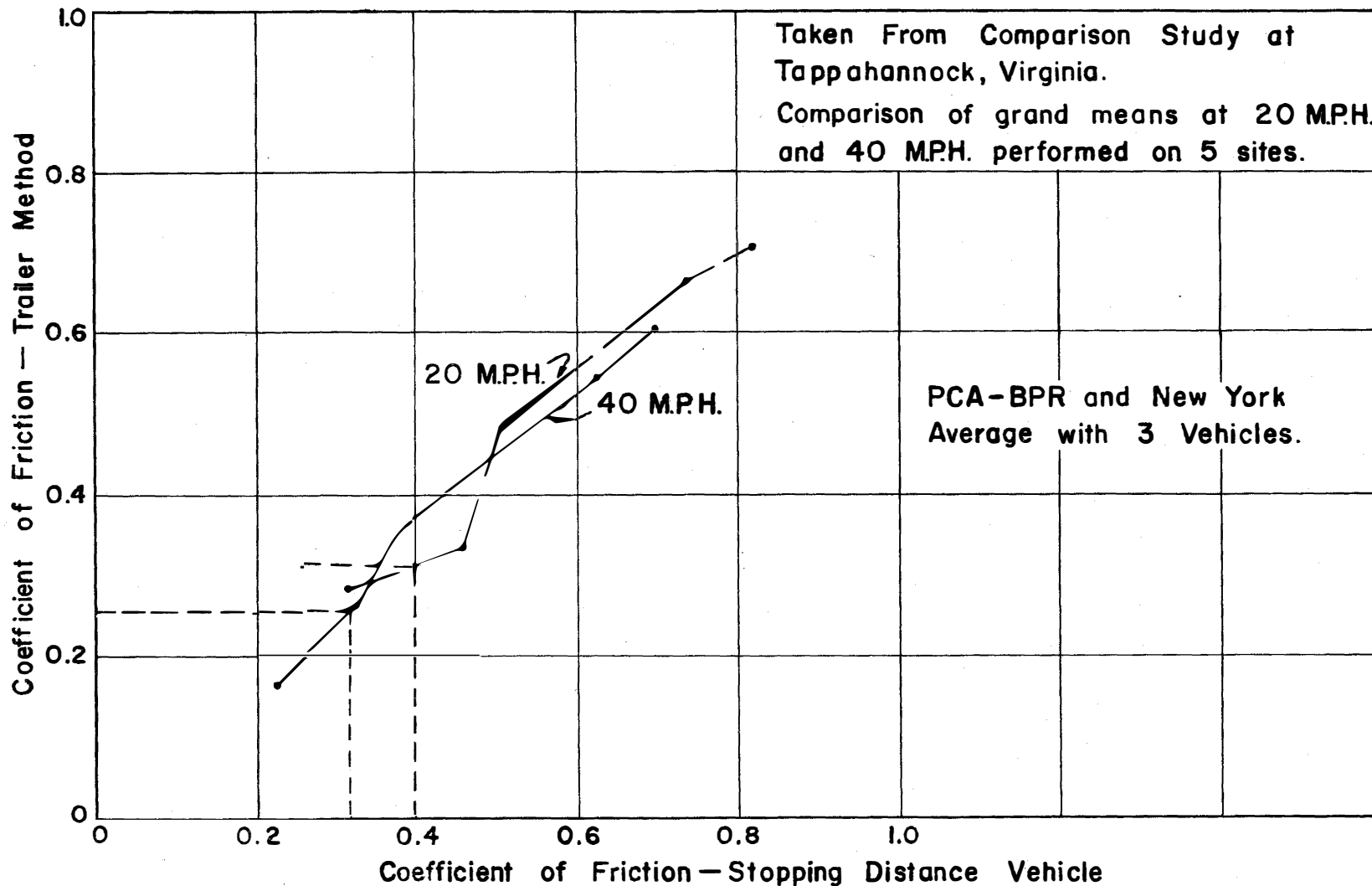
#### IV. Discussion of Results

At this point, it is again emphasized that the accident data obtained in this report was in no way correlated to driver characteristics, vehicular characteristics, or geometric characteristics. The authors fully recognize that pavement skid resistance is only one of many factors contributing to accidents, but the results of this study point out its importance. The size of sample used in this study correlated with experience on specific locations certainly lend credence to the approach used.

In this chapter, 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. 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 was available in this state, and it is necessary to correlate the two methods, the work performed at Tappahannock, Virginia, was used as a basis.<sup>12</sup> Figure 14 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



**COMPARISON OF STOPPING DISTANCE VEHICLE  
VS. TRAILER COEFFICIENT OF FRICTION**

Figure 14

that was used as the criteria for stopping distance in the AASHO Guide, a minimum design coefficient as measured with the trailer method may be obtained. The minimum design coefficients on wet pavement using the stopping distance method are 0.4 and 0.3 at 20 and 50 miles per hour, respectively. Using these values with Figure 14, the minimum design coefficient as measured by the trailer method is found to be 0.31 and 0.25 for 20 and 40 miles per hour, respectively. On the basis of straight line extrapolation a minimum design coefficient value of 0.24 at 50 miles per hour would be obtained using the stopping distance coefficient of 0.3 at 50 miles per hour. Therefore, the minimum coefficient of friction from the design standpoint would be 0.31 and 0.24 at 20 miles per hour and 50 miles per hour, respectively, as measured by the trailer method.

#### Accident Minimum

From strictly an accident standpoint, the data discussed in the previous chapter indicate accident rates increase when the skid resistance decreases below the values in a range of 0.45 to 0.55 at testing speeds of 20 miles per hour and 0.2 to 0.3 at 50 miles per hour. Although it is not known to what extent all the accidents used in the analysis are related to skid resistance, the inter-relation between the two factors is evident, and it should be taken into consideration.

#### Composite Minimum

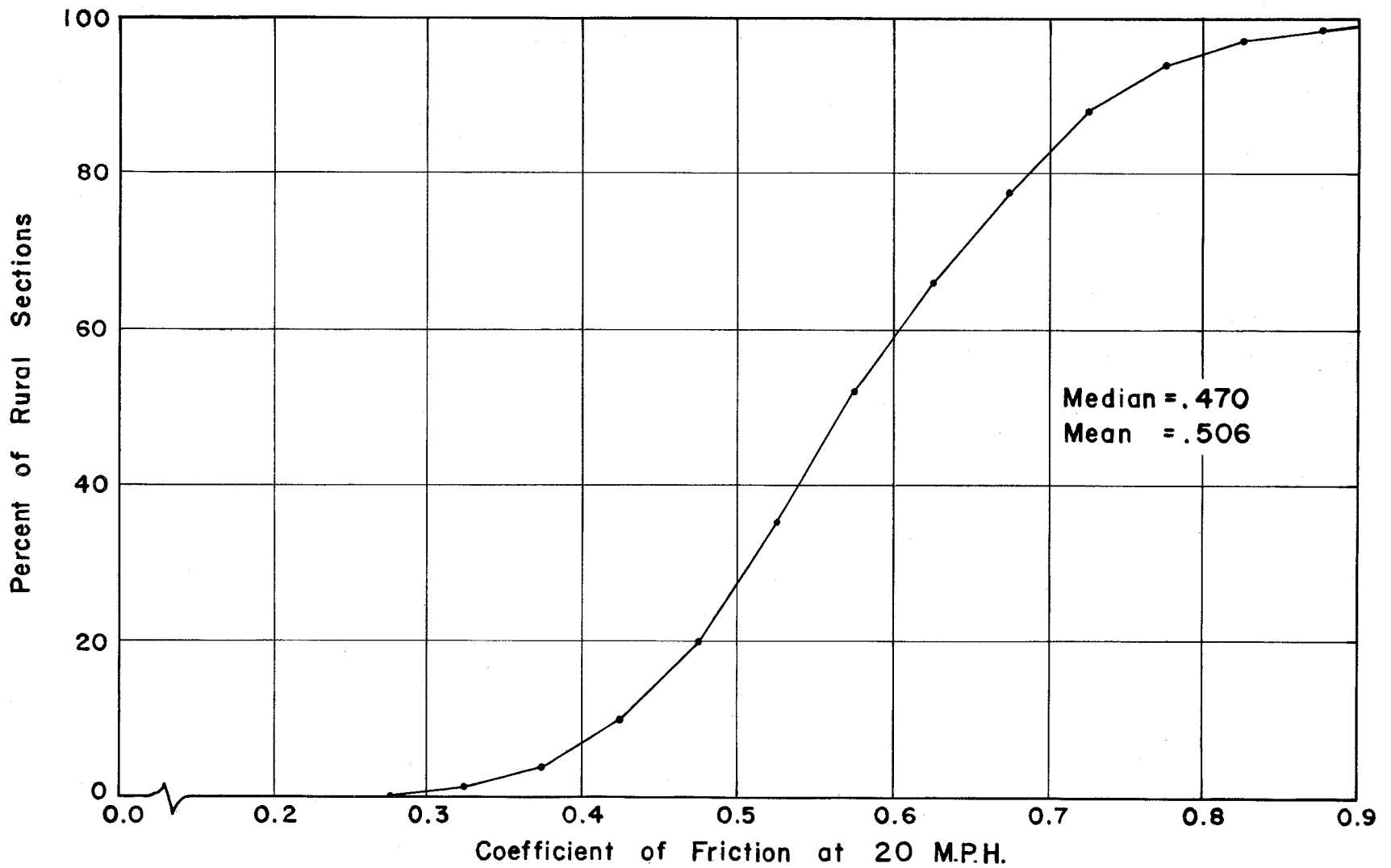
From a logical standpoint, the design coefficient for stopping distance as established by AASHO is an absolute minimum value that can be tolerated on the highway system. Consideration of the accident data brings forth the question, is this the minimum coefficient value to be maintained for safety? It is evident from the data 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 be 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 energy of impact, since the energy 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 miles per hour with an accident minimum of 0.45 to 0.55 at 20 miles per hour, it is recommended that the Texas Highway Department use as a guide a minimum coefficient value of 0.40 at 20 miles per hour. Even though the coefficient at 20 miles per hour is related to coefficient at 50 miles per hour, it is also recommended that the Highway Department use as a guide a minimum coefficient value of 0.30 for 50 miles per hour. These composite minimums should be used as another guide for scheduling surface improvements on a section of highway.

#### Implications of Composite Minimum

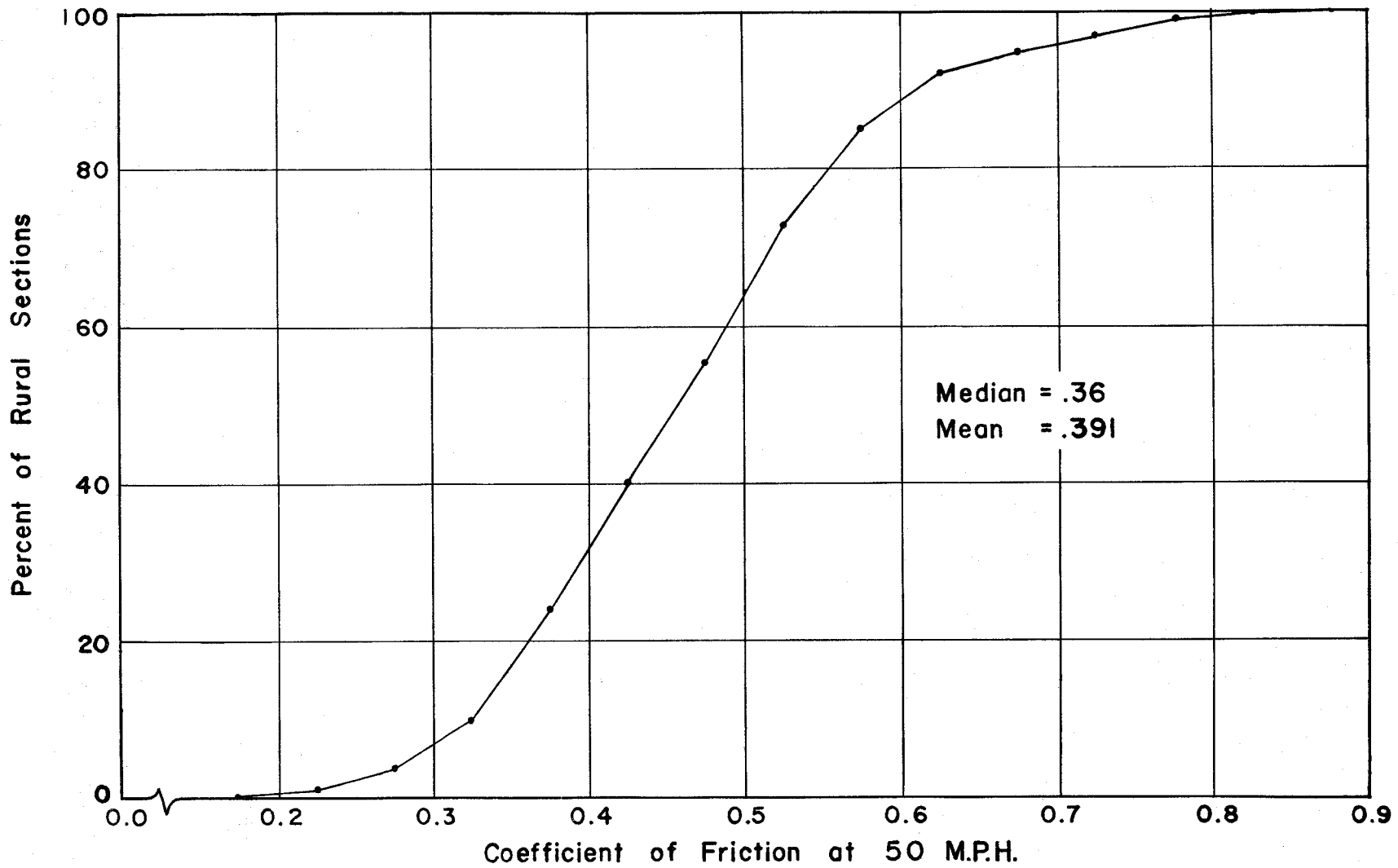
After selection of a composite minimum, the immediate question arises, what percent of the highway system is below this minimum? Figures 15 and 16 indicate a cumulative frequency distribution of the coefficient of friction for the 517 pre-selected rural sections at testing velocities of 20 miles per hour and 50 miles per hour, respectively. If the selection of these test sections represents a sample from all Texas highways, then it may also be assumed that this selection represents all highways in the State. Entering Figure 15 with the composite minimum value of 0.40, it may be postulated that 27% of Texas highways do not meet this minimum value at the present time. Upon first consideration, this percentage seems large; however, if Figure 15 is entered with the absolute design minimum of 0.31, it is found that eight percent of Texas highways do not comply with the design minimum at the present time. Investigating these



ACCUMULATIVE PERCENT OF RURAL SECTIONS COMPARED WITH  
COEFFICIENT OF FRICTION AT 20 M.P.H.

Figure 15





ACCUMULATIVE PERCENT OF RURAL SECTIONS COMPARED WITH  
COEFFICIENT OF FRICTION AT 50 M.P.H.

Figure 16

percentages for a testing velocity of 50 miles per hour, Figure 16 is entered with the composite minimum coefficient of 0.30. This analysis shows that 32% of Texas highways do not meet this value, and again using the absolute design minimum of 0.24, the data indicates 14% of Texas highways are deficient.

These composite minimums should be used as another guide for surface improvement. Economical 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 improvements where feasible. The design minimums should be considered as absolute minimums.

## V. 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 miles per hour, 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 miles per hour and 50 miles per hour 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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