NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **104**

CRITERIA FOR USE OF ASPHALT FRICTION SURFACES

WOODROW J. HALSTEAD
Charlottesville, Virginia

Topic Panel

JOHN J. CARROLL, *Federal Highway Administration*
CARLTON M. HAYDEN, *Federal Highway Administration*
HAROLD PAUL, *Louisiana Department of Transportation and Development*
G. C. PAGE, *Florida Department of Transportation*
A. SCOTT PARRISH, *Maryland State Highway Administration*
LAWRENCE F. SPAINE, *Transportation Research Board*

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. NOVEMBER 1983

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an assurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NOTE: The Transportation Research Board, the National Academy of Sciences, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

NCHRP SYNTHESIS 104

Project 20-5 FY 1982 (Topic 14-08)
ISSN 0547-5570
ISBN 0-309-03565-1
Library of Congress Catalog Card No. 83-51531

Price: $6.80

Subject Areas
Pavement Design and Performance
Transportation Safety

Mode
Highway Transportation

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

Each report is reviewed and processed according to procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved by the President of the Academy upon satisfactory completion of the review process.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest to pavement designers, material engineers, and others concerned with upgrading pavements by application of asphalt friction surfaces. Guidelines are presented for deciding when it is appropriate to use various types of friction courses.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

The most common types of asphalt surfaces used to upgrade frictional characteristics of pavements are seal coats, open-graded mixes, and dense-graded mixes. This report of the Transportation Research Board provides information on current engineering practices, legal and regulatory considerations, and criteria for selection of appropriate types of asphalt friction courses.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Damian J. Kulash, Assistant Director for Special Projects. The Principal Investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers. This synthesis was edited by Anne Shipman.

Special appreciation is expressed to Woodrow J. Halstead, Charlottesville, Virginia, who was responsible for the collection of the data and the preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of John J. Carroll, Highway Engineer, Office of Highway Operations, Federal Highway Administration; Carlton M. Hayden, Highway Engineer, Office of Highway Safety, Federal Highway Administration; Harold Paul, Assistant Bituminous Research Engineer, Louisiana Department of Transportation and Development; G. C. Page, Office of Materials and Research, Florida Department of Transportation; and A. Scott Parrish, Chief, Bureau of Research, Maryland State Highway Administration.

Lawrence F. Spaine, Engineer of Design, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

CRITERIA FOR USE OF ASPHALT FRICTION SURFACES

SUMMARY

The primary purpose of an asphalt friction surface on a pavement is to upgrade or ensure the frictional characteristics of the pavement so that loss of control does not occur in normally expected situations when the pavement is wet. The pavement characteristics are only one element of a multiple component system in which each component has a significant effect and interacts with the others to establish the potential for skidding and wet-weather accidents. The four major elements of the system are (a) the driver, (b) the roadway, (c) the vehicle, and (d) the weather.

Frictional demands on the roadway or pavement vary greatly depending on the speed of a vehicle, its design, and the design and condition of its braking system. The skill of the operator also affects the potential for loss of control or skidding. Weather, specifically the wet condition of pavements and the thickness of the water film on the pavement, also affects the available friction to a significant extent. Thus, the ability of a pavement to drain quickly after a heavy rain affects the potential for an accident.

A questionnaire sent to the members of the AASHTO subcommittee on materials reveals that seal coats, open-graded mixes, and dense-graded mixes are the predominant types of friction courses in use. Seal coats are most often used on secondary and low-traffic-volume roads. Both dense-graded and open-graded surfaces are applied to primary and secondary roads. Open-graded mixes generally provide greater protection against hydroplaning and they reduce splash and spray to a greater extent than do dense-graded surfaces. However, some states report difficulties when using open-graded mixes because of stripping and poor durability. Consequently, dense-graded mixes are used to the greater extent.

Agencies having specific criteria for the application of friction courses generally consider the posted speed limit for the highway and the expected volume of traffic when establishing criteria for friction courses. Some agencies rely on the initial design procedure and the type of coarse aggregate to provide adequate frictional characteristics throughout the lifetime of the pavement.

Skid numbers, usually determined by ASTM procedure E 274, are the major means for evaluating the frictional characteristics of pavements. Such numbers are used by many states as one element in their guidelines for determining the frictional characteristics of pavements. However, no state establishes statutory requirements for minimum skid resistance. Guidelines reported range from 30 to 40 for Interstate highways and all highways with legal speeds in excess of 40 mph (65 km/h). Suggested numbers varied from 25 to 40 for urban areas where speed limits are less than 40 mph and for roads where the traffic volume is less than 3000 ADT (average daily traffic).

Legal cases indicate that the state has a responsibility to provide roads with satisfactory skid resistance and when an accident occurs on a known slick pavement,

the state may be guilty of negligence and held responsible for damages resulting from the accident.

Further research is needed to better establish quantitative estimates of the variability of frictional characteristics on different portions of a highway; for example, differences for curves and tangents and differences for lateral displacements. Seasonal variations also need to be more precisely measured and clearly defined. A better understanding of the relative danger from wet-weather accidents as compared to measured skid numbers for various traffic volumes and highway conditions is also needed.

CHAPTER ONE

FACTORS AFFECTING SKID ACCIDENTS

INTRODUCTION

The need for highway surfaces that are not slippery has been long recognized and dates back at least to the horse-and-buggy days. In fact, one of the advertising claims by the Barber Asphalt Company around 1890 was that its asphalt pavements were safer than other types of surfaces. This was based on a survey conducted in 10 cities in 1885 during which the behavior of 800,000 horses was observed over a period of 192 days. It was shown that a horse traveled 585 miles (940 km) before falling on "asphalt" and only 413 miles (660 km) before falling on block or stone (*1*).

The technique of measuring the friction characteristics of the roadway surface has advanced considerably since 1885. However, the basic objective of highway engineers remains the same: to provide a surface that not only adequately supports the vehicle involved but also provides a smooth riding surface that, when used properly, does not permit loss of control or skidding of the vehicle.

Concern for horse-drawn vehicles has long since been supplanted by concern for adequate traction of automobiles and trucks. Sophisticated equipment has been developed to measure the frictional forces between the tire and the road surface, and pavement surfaces have been designed to provide optimum amounts of friction. As stated in the preface to the papers presented at the Second International Skid Prevention Conference (*2*, p. iv):

> The First International Skid Prevention Conference, held in 1958 at the University of Virginia, emphasized the definition of problems and identification of research needs. During the intervening years, numerous techniques have been developed for reducing wet-weather accidents. Most of the basic mechanisms are known, and numerous promising solutions have been identified and demonstrated.
>
> The Second International Skid Prevention Conference was organized to facilitate an international exchange of information on all aspects of wet-weather skidding accidents on highways. Primary emphasis was placed on research results and their application, vehicle industry developments, and operating agency practices and programs known to have a significant influence on reducing wet-weather accidents. The interaction among the driver, the vehicle, and the pavement surface was of prime concern.

The papers presented at the second international conference are published in Transportation Research Records 621, 622, 623, and 624 (*2, 3, 4,* and *5*, respectively). Collectively, they illustrate the complexity of the problem and the many disciplines and technologies that are involved in reaching an optimum solution.

This synthesis has as its objective only a small segment of the total problem: to summarize the criteria used by various agencies as the basis for a decision as to when an asphalt friction surface should be applied to an existing or a newly constructed or reconstructed highway, and to review the primary factors involved. The design and the performance of specific friction surfaces are not within the scope of this synthesis. However, some consideration is given to the relative suitability of different types for different conditions.

SKID RESISTANCE MEASUREMENT AND TERMINOLOGY

In the United States, the American Society for Testing and Materials (ASTM), the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), and individual state agencies have all expended considerable time, money, and effort on developing a means for measuring the frictional characteristics of a pavement surface. Similar efforts have been made in Canada, the United Kingdom, and European countries. Whereas several alternative procedures are available, the technique used most in the United States is measurement with a skid trailer by ASTM method E 274. This procedure measures the locked-wheel frictional forces between a tire of standardized design, size, and inflation pressure, and the wetted road surface at a measured constant speed. The standard reference speed is usually 40 miles per hour (65 km/h) and the results are expressed in terms of a skid number. The skid number is equal to the slide value of braking coefficient multiplied by 100. In the United States this is normally symbolized as SN with a subscript indicating the speed in miles per hour at which the test was made—thus, SN_{40} indicates results of measurements made at 40 mph. It should be noted that in 1976 the AASHTO Subcommittee on Materials voted to designate the results of the trailer measurement as a *friction* number (FN_{40}). This designation was preferred by the AASHTO subcommittee because it better describes the property measured and higher friction numbers refer to higher friction. However, most U.S. literature and publications in the United Kingdom and Europe still refer to skid number (SN) and this is the terminology now used by ASTM. Thus, the terminology skid number (SN) will be used in this report. It is also noted that the term friction number (FN) is used in NCHRP Report 37 (*6*) as a general term to denote the friction coefficient as measured by any appropriate means.

SYSTEM COMPONENTS

As discussed by Beaton (*7*), one of the most important factors in the safe operation of the modern motor vehicle is the development of necessary tire-pavement friction (skid resistance). As he points out, the public often blames the roadway when skidding occurs in wet weather but the roadway is only one element of a four-component system, each of which has a significant effect. This system has been described by Segel as follows (*8*):

1. Drivers—their prudence or aggressiveness in pursuing their travel objectives;
2. Roadways whose properties are variable over space and time;
3. Vehicles and vehicle components varying in design, mechanical condition, and usc; and,
4. The weather.

Each of these basic components is considered in detail by the various papers presented at the Second International Skid Prevention Conference (*2*, *3*, *4*, and *5*).

The Driver

The driver controls the speed and mode of operation of the vehicle and through discretion or lack thereof plays an important part in the prevention of skidding accidents. The driver must realize that there is a significant loss of stopping potential under wet conditions and that a reduction in speed is required, especially under conditions of heavy traffic or on curved and rough roads. Proper recognition of hazardous conditions by the driver and the exercise of caution can go a long way in reducing accidents, even under extremely bad conditions. Conversely, the failure of a driver to adequately adjust to obviously changed conditions (for example, failure to reduce speed in a heavy rain) can cause an accident even though all other components of the system are fully adequate for safety.

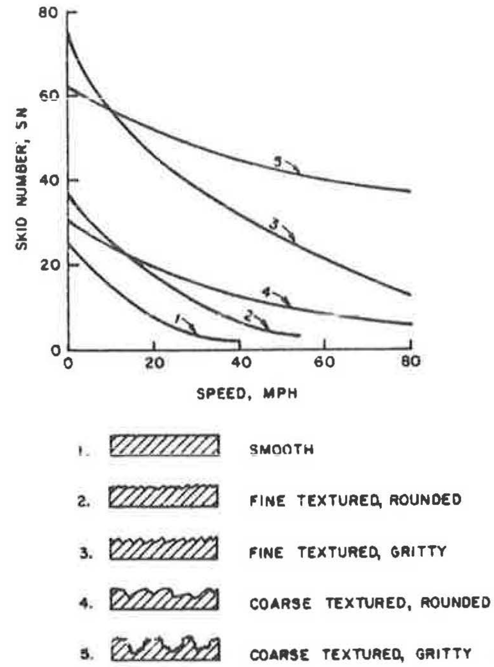
The Roadway Characteristics

The papers by Beaton (*7*) and by Smith (*9*) provide state-of-the-art summaries of the important characteristics of pavements in relation to skidding and wet-weather accidents. These papers provide an update of NCHRP Synthesis 14 (*10*).

Beaton (*7*) emphasizes the different levels of friction and the variability of the skid number with speed for all types of surfaces as well as the different rate of change of the number with increasing speed (speed gradient). These are generally characterized as shown in Figure 1, which originated with NCHRP Report 37. Beaton also discusses the importance of microtexture and macrotexture and the characteristics of aggregates required initially to provide such texture as well as to retain the needed characteristics under traffic (resistance to polishing and wear resistance). Design, construction, and maintenance factors are also discussed.

Smith (*9*) reviews information relating skid numbers to the wet-weather accidents. He reports that no nationally accepted pavement surface characteristics requirements have been established. However, Table 1, taken from NCHRP Report 37, provides tentative requirements for main rural highways based on information available in 1967 at the time of its preparation (*6*).

NCHRP Report 37 represents an effort to determine minimum skid-resistance requirements for pavement friction on main high-speed rural highways and the procedure by which it should



REFERENCE:
NCHRP # 37 "TENTATIVE SKID-RESISTANCE REQUIREMENTS FOR MAIN RURAL HIGHWAYS" PAGE 24, FIG. 24

FIGURE 1 Classification of pavement surfaces according to their wet friction and drainage properties.

be determined. These requirements were proposed as guides for thc dcvclopmcnt of acceptable procedures for new pavements and to determine the need for resurfacing or other means of improving skid resistance of pavements that have become polished. However, the authors of NCHRP Report 37 emphasized that the recommended minimum skid number of 37, measured at 40 mph (65 km/h), was both *minimum* and *tentative.* They stated that specific frictional requirements must be determined for each set of road, vehicle, operator, and weather conditions.

TABLE 1

RECOMMENDED MINIMUM INTERIM SKID NUMBERS[a] (*6*)

MEAN TRAFFIC SPEED, V (MPH)	SKID NUMBER	
	SN[b]	SN_{40}[c]
0	60	—
10	50	—
20	40	—
30	36	31
40	33	33
50	32	37
60	31	41
70	31	46
80	31	51

[a] Skid numbers measured in accordance with ASTM E-274 Method of Test.
[b] SN = skid number, measured at mean traffic speeds.
[c] SN_{40} = skid number, measured at 40 mph, including allowance for the skid number reduction with speed using a mean gradient of $G = 0.5$.

Figure 2, from a report by Holbrook (*11*), illustrates the change in the proportion of wet-pavement accidents to dry-pavement accidents occurring at intersections as the percentage of wet-pavement time increases. Holbrook reports that a wet-accident model developed for such intersections indicates "for all levels of wetness, a skid coefficient less than about [0.30] is accompanied by an accelerating increase in wet accident percentages; although the actual shape of the curve depends on wet time. The model appears useful in designing cost-effective intersection resurfacing plans which minimize wet accident occurrence."

Holbrook further discusses the difficulty in estimating how long a pavement should be considered wet. Different authors have used different ways of estimating wet-time (*12–14*). One such procedure is discussed in the Appendix, but a full discussion of this problem is beyond the scope of this synthesis. However, as Holbrook states, "It is well known that wet pavements reduce tire friction and thereby lengthen vehicle stopping distance. It is also known that this results in increased accident incidence" (*11*).

Also, agreement has not been reached on whether or not a "break" point in skid resistance exists below which wet surfaces are hazardous and above which they are not. Volume 1 of the report of an extensive study of the effectiveness of alternative skid reduction measures conducted by Midwest Research Institute (MRI) for the FHWA illustrates the potentially different conclusions concerning the relationship of wet pavement accidents and skid numbers (14). Figure 3, taken from the MRI report, depicts the straight line relationship developed in the MRI study and indicates a very significant reduction in wet-pavement accident rate as the skid number at 40 mph (65 km/h) increases. Figure 4, also from the MRI report, is based on the findings in a Kentucky study. These indicate a different trend when skid numbers at 70 mph (110 km/h) are used for comparison. Here a "critical" value of skid number, above which further reduction in accident rate does not occur as skid number increases, is indicated. This value occurs between SN_{70} values of 25 to 30, which are equivalent to SN_{40} values of 40 to 45 assuming a mean speed gradient of 0.40 and using the relationship developed in the MRI report, which is:

$$SN_{40} = SN_t - (40 - V_t)(0.52 - 0.06\bar{R})$$

where:

SN_{40} = Skid number adjusted to 40 mph
SN_t = Skid number at test speed
V_t = Test speed
$\bar{R}$ = Mean gradient rating

The authors of the MRI report emphasize that the data used in deriving these two figures were analyzed differently and different assumptions were made; thus they state:

> These contrasting results are not necessarily in conflict, because entirely different approaches were used in this and the Kentucky study. The current study used a formal statistical analysis to develop an accident rate-skid number relationship. The analysis showed that a linear relationship was the "best" only in the sense that there was no other simple function that fit the data significantly better. The Kentucky study used curve-smoothing techniques, such as the moving average method, to develop the relationship graphically. Curve-smoothing techniques are also useful for examining such relationships, but they should not be misinterpreted as representing the "best" statistical relationship between the variables (*14*).

Smith reported also that the Kentucky study found that the ratio of wet- to dry-pavement accidents on rural two-lane roads decreased rapidly as the SN_{40} value increased to about 40; further increases in skid resistance resulted in only a slight reduction in the ratio (*10*). The average ratio was about 0.25 for pavements with SN_{40} values above 40 and increased to 0.60 as SN_{40} values decreaed.

A Louisiana study cited by Smith identifies the drainability of the pavement surface as having a significant effect on wet-weather accidents. Cross slope, width of pavement, and the porosity of the surface are important aspects affecting drainability. The Louisiana study of roadway geometry found that of the ten geometric variables considered, pavement cross slope and the number of roadway access points (conflicts) were the two variables interacting with traffic volume having the greatest effect on accident rates (*15*). However, this finding is not fully supported by the MRI study (*14*). That study found no influence on the accident rate-skid number relationship of pavement texture or exposure to high-intensity rainfall, both of which would be related to drainability.

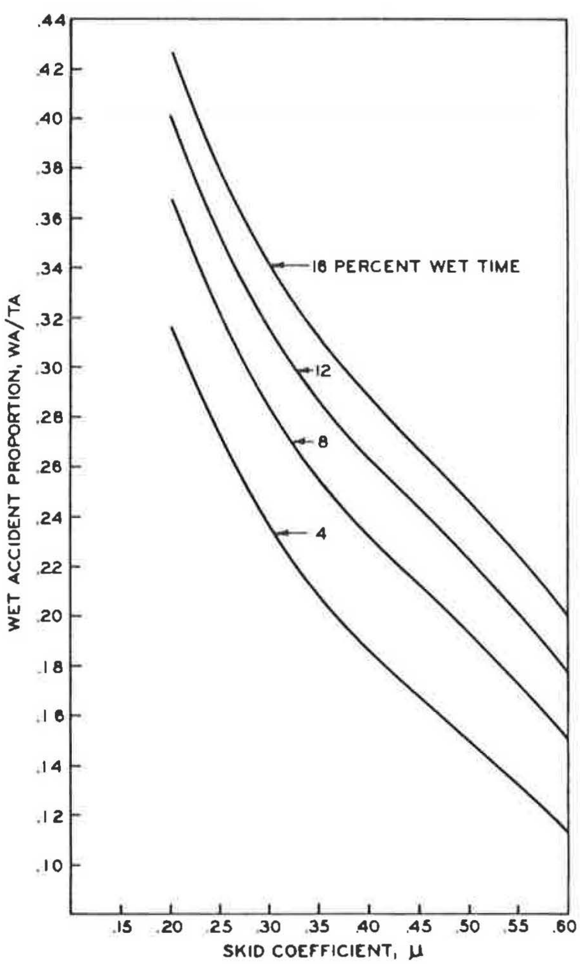


FIGURE 2 Relationship between skid coefficient and wet-weather accidents for various wet-times (skid coefficient × 100 = SN) (*11*).

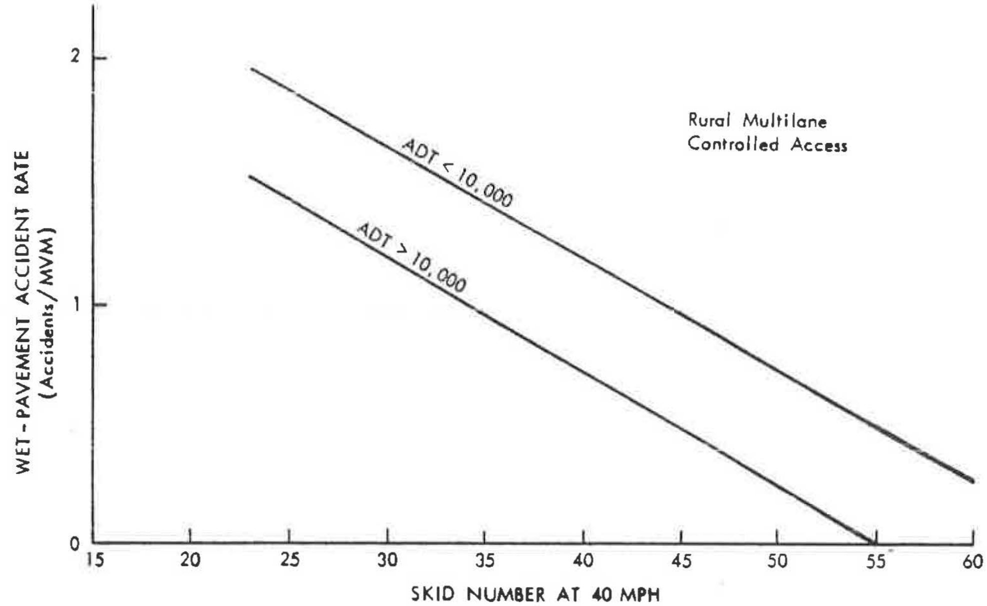


FIGURE 3 Accident rate-skid number relationships developed by Midwest Research Institute (*14*).

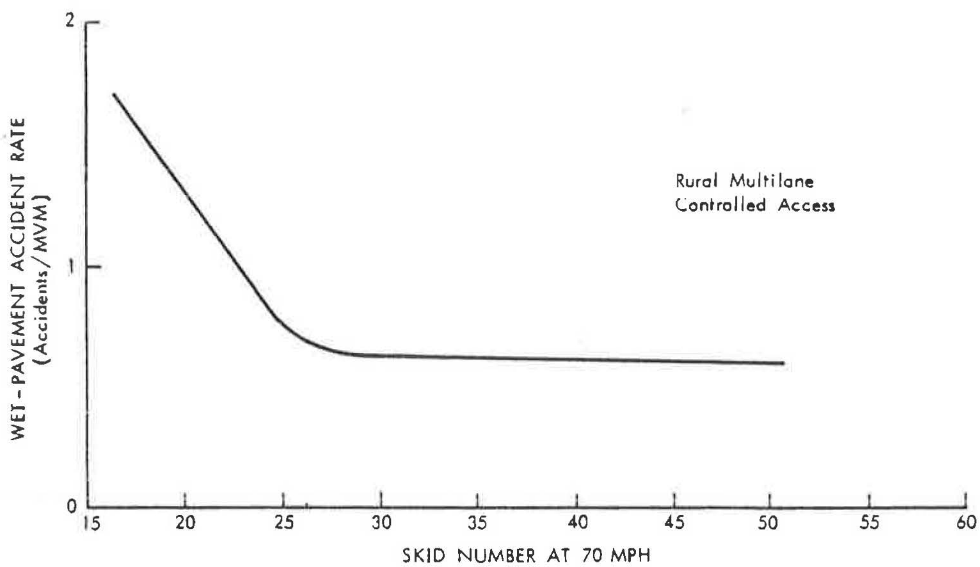


FIGURE 4 Accident rate-skid number relationship from Kentucky study (*14*).

Studies reported by Henry and Saito in 1983 emphasize the relative importance of macrotexture and microtexture in the measured SN_{40} (*16*). Macrotexture is a function of aggregate grading; microtexture is a function of the surface roughness of individual aggregate particles. These authors developed a prediction model for the ratio of skid numbers with the ribbed ASTM E 501 test tire to those with the blank ASTM E 524 test tire at any speed. The model was developed as a function of the macrotexture parameter defined by the sand-patch mean texture depth (MTD). An application of this model permits the prediction of the blank-tire skid number from a measure ribbed-tire skid number and a macrotexture measurement. Another effort of the study was to relate skid resistance with both types of test tires to pavement textures. The results reported show a strong relationship between skid numbers with test tires and pavement macrotexture and microtexture. The authors suggest that if skid resistance surveys were to be performed with both the blank E 524 and the ribbed E 501 test tires, the levels of macrotexture and microtexture can readily be estimated.

Seasonal variations in skid resistance were also investigated by Henry and Saito. Their studies revealed that long-term (seasonal) variations for both tires exhibit almost the same trends, but short-term variations for both tires are significantly different. The short-term variations in skid resistance with the ribbed tire show fairly large fluctuations, which relate to rainfall, pavement temperature, and short-term changes of microtexture parameters. On the other hand, the short-term fluctuation with the blank tire is small and probably negligible.

Another aspect of pavement characteristics often overlooked is that tire wear increases as pavement skid resistance increases; thus, unnecessarily high skid numbers are undesirable because costs of excessive tire wear can become unacceptable to motorists. Therefore, the highway engineer must seek the optimum balance between costs and safety.

Vehicles and Vehicle Components

The most important component of the vehicle with respect to skidding is the design of the tire and its condition. Most people realize that a "bald" tire can result in skidding under conditions that create no problems when the tire treads are relatively new. This relates to the relative ease that the water can be squeezed out between the tire and road surface. With good tire treads, water is forced into the grooves, but with a bald tire, water is retained between the tire and road surface. When a water film exists over the total area of contact of the tire, hydroplaning and loss of vehicle control result.

Another component that is involved in skidding is the operation of the vehicle's braking system. Loss of control often results when wheels become locked. Some vehicles now have braking systems designed to prevent wheel-lock, which greatly improves the ability to come to a sudden stop. Segel (*8*) discusses various aspects of the driver-vehicle system and the tire-vehicle system involved in the maneuvering process and the conditions that may result in a "loss of control." In general, his analysis shows that it is not possible to isolate "friction demand" and "friction available" as separate, distinct entities. He states that "skidding" can be identified as a loss-of-control event in which the "maneuver outcome" departs from the "maneuver demand." He also notes that present trends for smaller and lighter cars are likely to reduce maneuvering limits on both wet and dry roads, thus increasing the danger of skidding.

Weather

The reduction of available friction under snow and ice conditions is so drastic that this condition is easily recognizable, and most of the general public react accordingly by slow speed and cautious braking. Those who do not, quickly suffer the consequences. Unfortunately, the significant reduction in available friction during a rainstorm is not so generally recognized.

Because it is difficult to determine precisely the percentage of time that pavements are wet, several reports provide different estimates of the frequency of wet accidents compared to those occurring on dry pavements. A 1973 report to the U.S. House of Representatives Committee on Public Works estimated that wet-weather accidents are responsible for about 15 percent of motor vehicle injuries and fatalities (*17*). A special study by the National Transportation Safety Board published in 1980 but based on statistics gathered in 1976 and 1977 indicated that 13.5 percent of all fatal accidents occurred on wet pavements (*18*). In this report, pavements were assumed to be wet only about 3.0 to 3.5 percent of the time nationwide and thus wet-weather accidents were said to occur 3.9 to 4.5 times more often than might be expected. This percentage is based on defining wet-time as any hour in which 0.01 in. (0.25 mm) of precipitation occurred at an hourly recording station. The MRI study for the Federal Highway Administration found wet-time in various locations to be approximately 19 percent (*14*). From these reports different conclusions could be drawn concerning the severity of "wet-weather" accidents from an overall system view. However, the different definitions of "wet-pavement" or "wet-weather" is the major cause of such diverse conclusions. It is clearly shown by all data comparing tire pavement friction for wet pavements to dry pavements at the same location that significant reductions of skid resistance occur when the pavement is wet and the increased danger of skidding for the same driving speed is apparent.

At high traffic speeds, the phenomenon of hydroplaning can occur during heavy rain. Lowering the speed limit to 55 miles per hour (90 km/h) has reduced to some extent the probability of hydroplaning, but it can still occur at legal speeds under some conditions.

One important aspect relating to this danger is the relationship of the thickness of the water film on the road surface to the intensity of the rainfall. The cross slope of the pavement has an important effect on how quickly water drains from the surface. For a properly constructed highway with proper drainage, water levels quickly fall once the rainfall ceases. The significant danger occurs when water is retained in ruts or is trapped in low areas because of inadequate or clogged drains.

The relative effects of several factors affecting rainwater depths on pavement surfaces were studied at the Texas Trans-

TABLE 2

EFFECTS OF VARIABLES ON WATER DEPTH (*19*)

Constant	Variable	Resultant Water Depth (in. at 24 ft)	Change (percent)
Texture, 0.03 in., length, 24 ft, intensity, 1.5 in./hr	Cross slope, in./ft		
	1/16	0.074	
	1/8	0.048	-35
	1/4	0.028	-62
	3/8	0.021	-72
	1/2	0.013	-82
	1	0.002	-97
Length, 24 ft, intensity, 1.5 in./hr, cross slope, 1/8 in./ft	Texture, in.		
	0.005	0.059	
	0.015	0.057	-3
	0.030	0.048	-19
	0.050	0.038	-36
	0.075	0.011	-81
	0.125	-0.034	-158
Intensity, 1.5 in./hr, cross slope, 1/8 in./ft, texture, 0.03 in.	Drainage length, ft		
	6	0.013	
	12	0.028	115
	18	0.039	200
	24	0.048	269
	36	0.062	377
	48	0.074	469
Texture, 0.03 in., length, 24 ft, cross slope, 1/8 in./ft	Intensity, in./hr		
	5.5	0.138	
	3.5	0.098	-29
	2.0	0.062	-55
	1.0	0.031	-77
	0.5	0.011	-92
	0.1	-0.014	-110

portation Institute (TTI) (*19*). The authors developed equations relating the variables of pavement cross slope, rainfall intensity, surface texture, and drainage length. Table 2, taken from the TTI report, depicts the effects of these variables on water depth. This study led to recommendations for increases in cross slopes of highways in areas where intense rainfall is likely and a high potential for wet-weather accidents is created. It was also recommended that smooth-textured, dense-graded surfaces not be used on high-speed rural highways. Possible effects of wind velocity and humidity on the drying time of the pavement surface were also considered in this research.

Another TTI study considered the variables associated with wheel spin-down and hydroplaning (*20*). This study included the parameters of pavement texture, water depth, tire inflation pressure, wheel load, and composition and tread design of the tires. Whereas the speed for total hydroplaning is the speed at which the hydrodynamic pressure force is in equilibrium with the load carried by the tire, it was pointed out that "spin-down"

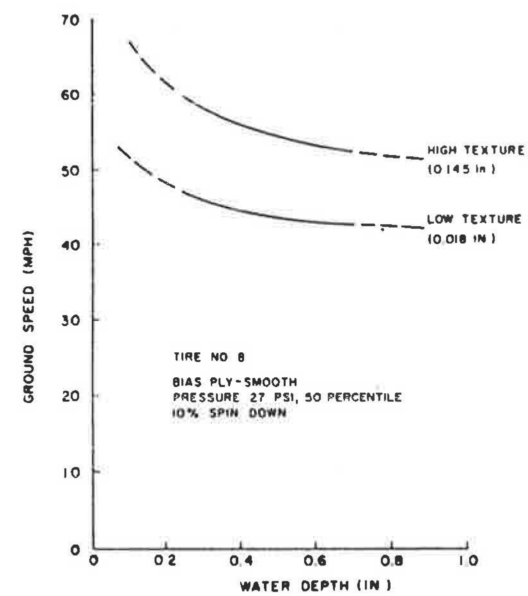


FIGURE 5 Effect of texture on hydroplaning (*20*).

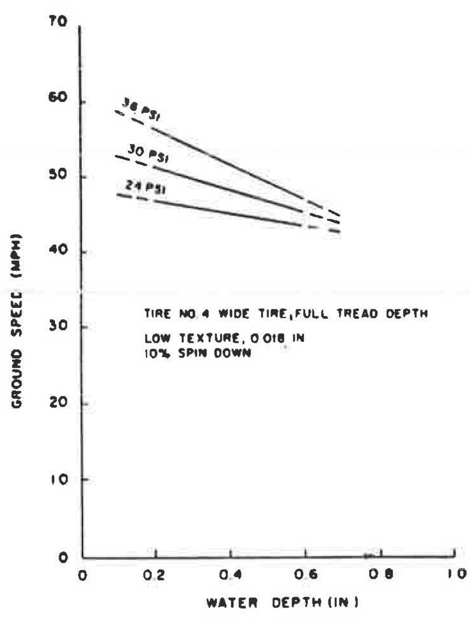


FIGURE 6 Effect of tire inflation pressure on hydroplaning (*20*).

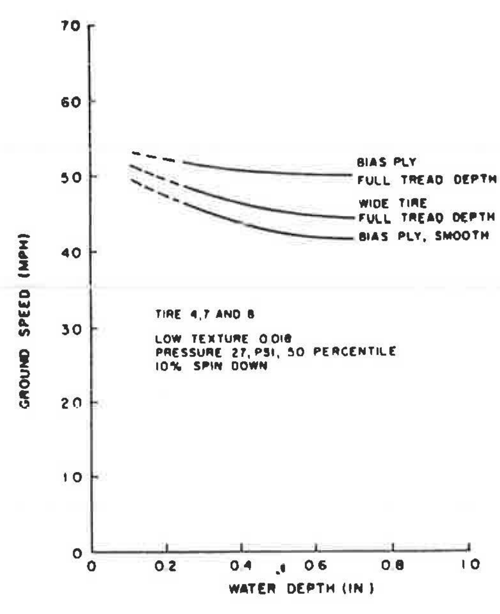


FIGURE 7 Effect of tire type on hydroplaning (*20*).

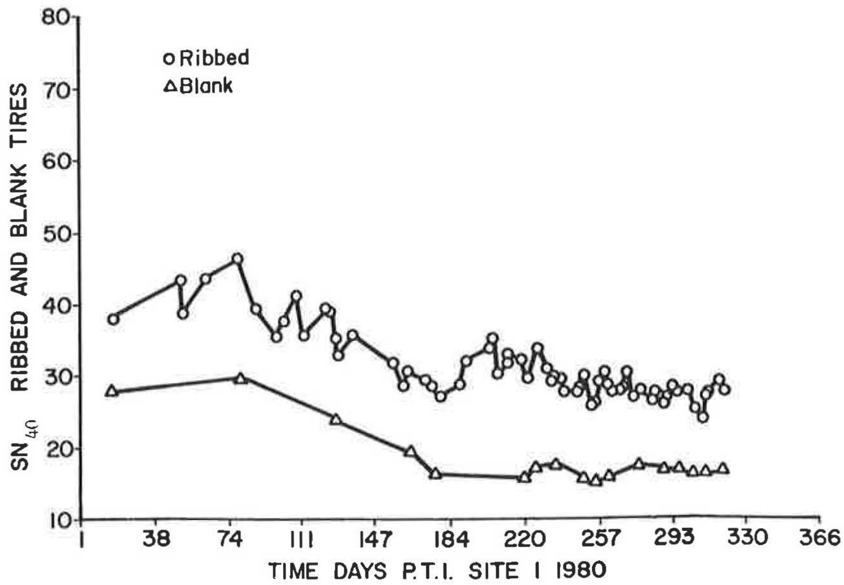


FIGURE 8 Comparison of SN_{40} with the ribbed tire and blank tire for seasonal variations (dense-graded asphalt concrete) (*16*).

or slowing of the wheel rotation was initiated at a slower speed. The speed at which a 10 percent spin-down occurs was used as a criterion of potential loss of control. Figure 5 illustrates the relationship of water depth and critical speeds for different pavement textures. Figure 6 shows the effects of tire inflation pressures and Figure 7 shows the effects of different tire designs. One of the significant conclusions drawn from this study was that a reduction of speed to 50 miles per hour (80 km/h) be considered for any section of highway where water can accumulate to depths of 0.1 in. (2.5 mm).

The importance of the tire tread with respect to skid resistance is illustrated by the work of Henry and Saito (*16*). Figure 8, taken from their report, illustrates the large difference in measured skid resistance for the ASTM ribbed tire and the blank tire. Although the relationships are not exact, the ribbed tire may be considered representative of a tire in "good" condition in use on U.S. highways and the blank tire may be considered representative of a "bald" tire. Although the average motorist would not be expected to be driving on tires with no tread, the potential danger from smooth tires is clearly demonstrated by this figure.

CHAPTER TWO

PRESENT PRACTICES CONCERNING SKID-RESISTANT SURFACES

A major objective of this synthesis was to determine the criteria now used by various agencies for establishing when an asphalt friction surface should be added to a pavement to decrease the probability of wet-weather skidding that would lead to loss of control and accidents resulting in personal injury or property damage. Because the initial survey of published literature revealed very little information concerning such criteria, a short questionnaire was directed to each state and those provinces in Canada that are members of AASHTO. A total of 49 states, the District of Columbia, and four provinces in Canada replied to this questionnaire. The questions asked and replies received are summarized in the following section.

RESULTS OF QUESTIONNAIRE

1. What types of asphalt friction courses are in regular use by your agency? Please indicate below the type of road on which each is used and the relative percentage of each.

There was some confusion concerning whether the percentages requested applied to the percentage of state roads receiving a friction course or the relative percentage of the type of friction course applied. However, the replies show that seal coats, open-graded overlays, and dense-graded overlays are the predominant types of friction surfaces applied. Special sprinkle treatments (polish-resistant aggregate applied to the surface of a hot-mix mat) or "de-slicking" mixes were used a very small percentage of the time—usually for special cases or experimentally. A large majority of the states replying indicated that they used dense-graded overlays to the greatest extent and that they would be applied to all types of highways. Open-graded asphalt friction courses (OFC) were used on Interstate highways and where high speeds were expected. Seal coats were generally used only for low-traffic volumes or rural roads.

There were some geographical differences indicated. In general, the northeastern states with heavy traffic indicated greater use of dense-graded overlays than open-graded friction courses. More seal coats, especially on secondary roads, were used in the west. However, it is not clear whether the reported use was for general maintenance or for special situations where upgrading of friction characteristics was needed. A brief summary based on reported use in each of the FHWA regions follows.

Region 1 (Conn., Maine, Mass., N.H., N.J., N.Y., R.I., Vt.)

Six of the eight states reported using dense-graded overlays as friction courses almost exclusively. In those states, open-graded friction courses were used on only a limited number of Interstate highways. One state uses open-graded friction courses on all its expressways. Only one state reported the use of seal coats. This use was on state roads. One state did not respond to the questionnaire.

Region 3 (Del., D.C., Md., Pa., Va., W.Va.)

Four states reported major use of dense-graded overlays. Open-graded friction courses are used on some Interstate roads. Low use of seal coats is limited to secondary roads. One state reported using open-graded friction courses for all situations (usually primary or Interstate highways).

Region 4 (Ala., Fla., Ga., Ky., Miss., N.C., S.C., Tenn.)

Four states in this region reported substantial use of open-graded friction courses in the recent past, but three of those reported difficulties from stripping in the underlying pavement and have discontinued their use until the cause of trouble can be determined. Dense-graded friction courses are now being used in these states if treatment is necessary. Two states in this region reported use of seal coats for primary and secondary roads, with dense-graded overlays being used on Interstate and primary roads. One state reported using open-graded friction courses on all types of highways without encountering the stripping problem reported by others.

Region 5 (Ill., Ind., Mich., Minn., Ohio, Wis.)

Very little use of open-graded friction courses was reported in this region. Some use of seal coats for secondary roads was reported, but all states in the region generally employ dense-graded overlays as friction courses for all types of roadways.

Region 6 (Ark., La., N.M., Okla., Tex.)

Three of the five states in this region use open-graded friction courses when upgrading of the skid number is required on high-traffic-volume roads. In some cases, such a course is built as a part of the initial construction. Seal coats are extensively used by maintenance forces on secondary roads or low-traffic-volume primary roads. The other two states mostly use dense-graded overlays on primary and Interstate highways when a friction course is needed. In one of these, a limited amount of open-graded friction course is used on Interstate and primary highways.

Region 7 (Iowa, Kans., Mo., Nebr.)

No use of open-graded friction course was reported for this area. One state reported substantial use of sprinkle courses on low-traffic-volume roads with dense-graded overlays on others. Two states reported essentially exclusive use of dense-graded overlays. One state uses mostly dense-graded overlays (95%) but has also used a special "mastic mix" with superior speed gradient for roads carrying more than 1900 vehicles per day.

Region 8 (Colo., Mont., N.D., S.D., Utah, Wyo.)

Substantial use of seal coats was reported in this region for low-volume traffic and dense-graded courses for higher traffic. Open-graded friction courses are used to some extent in two states.

Region 9 (Ariz., Calif., Hawaii, Nev.)

Two of the four states in this region employ open-graded friction courses almost exclusively as a means for upgrading friction values. The other two make substantial use of such courses, but in one case dense-graded courses are used to a greater extent. In the other case, seal coats are used.

Region 10 (Alaska, Idaho, Ore., Wash.)

One state (Alaska) reported no problems with friction values and no use of friction courses. One state reported using mostly seal coats and another mostly dense-graded overlays. Both used open-graded friction courses for a limited number of high-traffic-volume pavements. One state reported the use of open-graded overlays over portland cement concrete, but stated that it had very few problems with slick pavement because of an abundance of high-quality rock for road building.

Canadian Provinces

Four Canadian provinces replied to the questionnaire. Of these, the greatest reported use was seal coats for lower traffic volumes and open-graded friction courses for high-traffic volumes. One province uses dense-graded overlays for its high-volume roads.

2. Does your agency have specific criteria for establishing when a friction course is used? If the answer is yes, a copy of the criteria would be appreciated. If the answer is no, what are the major considerations in reaching a decision?

Thirty of the agencies responding indicated that they did not have specific criteria and 24 replied that they did. Those not having such criteria generally reported that a number of considerations entered into the decision. Those most frequently mentioned were traffic volumes and the skid number. In a number of states a friction course was a part of the initial design and construction; in others the type of aggregate available and the expected volume of traffic determined whether a friction course was applied at the time of construction. Several states reported that friction courses, as such, were not used, either because of excellent sources of aggregates with excellent skid resistant properties and nonpolishing characteristics or generally low volumes of traffic or combinations of the two. The criteria provided will be discussed in more detail in a subsequent section.

3. Do you have reports of specific studies made by your agency in this area?

Fifteen agencies supplied reports of studies relating to skid resistance or friction overlays. Relatively few of these reports dealt directly with the criteria to be used for determining when a friction surface should be applied. However, collectively they indicate the type of concern shown by the agencies.

4. Can you cite specific cases where your agency has been sued for skidding accidents on its highways? On what basis was the case won or lost?

Ten states and one Canadian province indicated that they had experienced lawsuits involving claims against the state because of skidding accidents. These replies are discussed in detail in Chapter 4.

5. In your opinion, is there a minimum skid number that should be used in defining when a pavement is "slippery"? If yes, what is the appropriate minimum for: a. Interstate pavements; b. Urban traffic (controlled speed); c. Rural roads?

Sixteen agencies indicated that a minimum skid number could be used in defining "slipperiness." Such numbers were recommended as guidelines only and not as mandatory requirements.

Almost all agencies pointed out that skidding resulted from a combination of a number of elements and that establishing a minimum skid number could be misleading. A concern was expressed that when any measurement made in the state was less than a recognized minimum, the result would be inappropriately used as evidence of negligence on the part of the agency. The variability of the measurement with time of year and possibly the equipment used for the determination were also cited as creating problems.

SUMMARY OF CRITERIA FOR APPLYING FRICTION SURFACES

Although the specific objective of this synthesis was to review the criteria of various agencies for placing a friction surface over existing pavements, the various documents supplied and comments made indicate that a better question to ask is: What are the various approaches of the agencies toward providing and maintaining adequate skid resistance values on their highways? Many agencies have found that the initial design of a pavement and the materials used establish the levels of skid resistance and the ability of the pavement surface to retain a desirable level of skid resistance. Thus, they do not allow the use of certain aggregates known to have inadequate friction levels on surfaces with high volumes of traffic moving at high speeds. When this is done, a separate friction course is not needed within the design life of the pavement. Others, however, because of limitations on the supply of suitable nonpolishing aggregate, must balance economic considerations with the dangers from skidding accidents to provide maximum cost-effectiveness and safety. In some states a friction course is built as a part of the initial construction for all state highways, but in others the expected speed limit and traffic are considered in deciding whether a friction course is needed or not.

A brief summary of the criteria used by each state replying "yes" to the question concerning specific criteria for applying friction courses follows.

New Jersey

These guidelines for various types of surfaces are based on traffic volumes, speed limits, geometrics, etc. The expected skid number range for each type and the advantages and disadvantages of each one are given.

Slurry seals are listed as providing skid numbers from the mid 30s to the mid 40s when nonpolishing aggregates are used. They are suggested as suitable for spot improvement on a short-term basis for low-speed and low-traffic-volume roadways. The small aggregate size in these surfaces results in lack of high-speed skid resistance.

Fine-aggregate bituminous courses (FABC-Mix 5) provide expected skid numbers in the mid 30s to mid 40s and are suitable for low- or moderate-speed highways where geometrics are up to standard. Lack of surface texture leads to loss of skid resistance at higher traffic speeds. This surface type is not recommended for use where more than normal braking or side forces are expected.

Medium-coarse aggregate bituminous courses (MABC-Mix 4) are expected to provide skid numbers in the mid 40s and are suitable for use on high-speed highways under normal traffic demands; for example, on Interstate and primary routes. These provide more surface texture than FABC-Mix 5, but skid resistance can be lost if polish-prone aggregate is used. For high- or moderate-speed roadways where geometric deficiencies exist on curves or stopping areas, MABC-Mix 9 with crushed gravel is suitable. The expected skid numbers range from 40 to 55. This surface type is considered the best to use if acceptable crushed gravel sources are available. Such aggregates are sold at premium prices and, therefore, costs are high.

Open-graded friction courses containing nonpolishing aggregates are expected to provide skid numbers in a range from 37 to 54. They are considered suitable for high- and moderate-speed roadways when geometrics are up to standard and the availability of crushed gravel is questionable. Adequate drainage must be provided. The interior drainage channels in these surfaces help eliminate the danger of hydroplaning. Difficulties in design and construction are stressed, especially the need for adequate drainage of the water from the pavement. Internal drainage is said to break down during use, but surface texture remains excellent.

New York

Guidelines for open-graded asphalt surface course (OFC) are provided. These include design of the mix and construction techniques. They are stated to be very well adapted to locations on a roadway where there is a high demand for skid-resistant pavement.

Rhode Island

The policy established for high speed roads with speed limits of 50 mph (80 km/h) or greater is:

1. All highway segments where the majority of the readings in any lane are less than $SN_{40} = 26$ *must* be improved at the earliest possible date.
2. For all highway segments on which more than 50 percent of the readings in any lane are less than $SN_{40} = 33$, the entire roadway *should* be improved for skid resistance.
3. For all highway segments where a significant portion of the readings are between $SN_{40} = 33$ and $SN_{40} = 40$, the roadway should be considered for surface improvements based on an estimate of future deterioration of SN_{40}. This estimate should take into account average daily traffic (ADT) data and capacity restraints and be based on any historical trend data currently available.
4. For any highway section where a majority of the skid readings are greater than $SN_{40} = 40$, the roadway should be investigated for localized surface improvement based on individual readings for each lane and taking into account such factors as accident experience, ADT, etc.

Delaware

Uses OFC when ADT is 8000 or more and speed limit is greater than 40 mph (65 km/h).

Maryland

Plant-mix seal (equivalent to OFC) is to be placed on roadways where traffic projections indicate truck volumes greater than 500 trucks per day one way in its 10th year of life and that are posted for 50 mph (80 km/h) or greater. Plant-mix seals are not to be placed on roadways where traffic projections indicate truck volumes less than 500 trucks per day one way in its 10th year of life or on roadways that are posted for less than 50 mph. Plant-mix seals may be allowed on low-volume or low-speed roads where the profile is conducive to hydroplaning or poor transverse drainage is encountered.

Pennsylvania

Circular letter No. C2873-12, dated June 10, 1982, establishes guidelines for identifying low-friction pavements, evaluating remedial treatments, defining responsibilities, and establishing procedures for corrective actions. The criteria for identifying low-friction pavement surfaces are presented in Table 3.

An accident problem is defined as a minimum of five wet-pavement accidents and an average of one wet-pavement accident per 600 ft (180 m) within the most recent three years. In addition, the percentage of wet-pavement accidents must be greater than $(C/S) \times 30$ percent where C equals county rainfall

TABLE 3

CRITERIA FOR IDENTIFYING LOW-FRICTION PAVEMENT SURFACES

Category	Skid Number (SN_{40})	Accident Problem	Action by Engineering District
A	Less than 31	yes	Improvements considered for programming on the Betterment or General Maintenance Programs in a prudent manner consistent with District priorities
B	31-34	yes	Maintain surveillance and take corrective action as required
C	34 or less	no	Maintain surveillance and take corrective action as required
D	35-40	---	Maintain surveillance and take corrective action as required
E	Greater than 40		No further action required

in inches for the past three years and *S* equals statewide average of rainfall in inches for the past three years.

Rainfall data are provided annually by the Bureau of Highway Services, in conjunction with the wet-pavement accident cluster lists.

"Slippery When Wet" signs are installed at all locations where the skid number is 34 or less. Priorities for corrective action are established on the basis of the category; category A receiving top priority.

The Pennsylvania policy was developed after a thorough overall program of research conducted over a number of years. This program was discussed by Gramling in a report presented at the Second International Skid Prevention Conference (*21*). Gramling states:

> Provision of skid-resistant pavement surfaces adequate to meet the needs of the motoring public on a wide range of facilities requires a systematic approach. The system employed should have reliable testing procedures to determine friction, criteria to determine corrective action and predictable specifications for surfacing materials to obtain the desired performance. The Pennsylvania Department of Transportation has adopted procedures based on a long history of research and development to obtain an economical and predictable skid resistant performance for pavements. The testing program, correction criteria and specification development using a Skid Resistance Level (SRL) criterion for aggregates is described.

Pennsylvania's studies showed that their pavements constructed with gravels and sandstones were considerably higher in friction than those constructed with carbonate aggregates. However, their studies also revealed a broad range of skid resistance values within the same type. A wet-pavement accident survey was conducted in 1975 to determine the skid resistance of pavement sites having a high probability of wet-weather accidents; the criteria being a site at which at least five wet-weather accidents had occurred in a three-year period within a 3,000-ft (910-m) section and where the wet-weather accidents were also 30 percent or more of all accidents. This program led to the policy described above.

A significant result of the Pennsylvania research was the establishment of a system for evaluating the skid resistance level (SRL) of their sources of coarse aggregate. The designation is based on the performance of the aggregate in properly designed dense-graded bituminous surfaces. The SRL ratings of aggregates in use are continually reevaluated as additional field data are collected. The ratings assigned Pennsylvania aggregates are given in Table 4.

When corrective measures are needed, Pennsylvania generally uses dense-graded friction courses identified as their ID-2 bituminous concrete. Studies of the performance of open-graded asphalt friction courses in Pennsylvania are summarized by Brunner (*22*). The conclusions reached were that, although the open-graded friction courses could be placed without unusual problems and they initially showed an excellent ability to reduce splash and spray from vehicles during rain, some of them closed up within a year after placement. The surface voids generally disappeared within six months to two years, although one project was reported to retain the voids after three years.

Where the skid numbers for open-graded courses (OFC) were compared to those for dense-graded (ID-2), it was found that

TABLE 4

SKID RESISTANCE RATINGS ASSIGNED TO PENNSYLVANIA AGGREGATES (*21*)

Rating	Aggregate
E - Excellent	Gravels with less than 10% carbonate particles.
H - High	Siltstones, argillites, some quartzites, basalts, gneisses, granites, blast-furnace slags, gravels with between 10 and 25% carbonate particles.
G - Good	Most quartzites.
M - Moderate	Carbonates of Cambrian age, serpentine.
L - Low	Carbonates younger than Cambrian.

the skid numbers obtained for OFC were only about 2 or 3 numbers higher than those obtained for the ID-2 when the coarse aggregate was rated "E"—that is, having excellent skid resistance. A difference of about five skid numbers was obtained when the course aggregate was rated "M"—moderate skid resistance. However, Brunner reported that the OFC was significantly less durable than the dense-graded surface (*22*). He makes recommendations for avoiding early loss of durability, and in general recommends that OFC be used only where thin overlays are desirable and the underlying pavement is structurally sound.

Each wearing surface advertised for bids has a coarse aggregate requirement for SRL based on anticipated daily traffic, as given in Table 5.

Gramling reports that the total system in Pennsylvania appears to be working well (*21*). Further studies are being made to evaluate parameters affecting hydroplaning. The fluctuation of skid numbers with the time of year is also being given consideration.

Virginia

As reported by Runkle and Mahone (*23*), Virginia has developed a systematic program for the identification and treatment of high or potentially high wet-pavement accident sites. The program utilizes accident data and measured skid numbers as a means of identifying potential wet-pavement accident sites. An SN_{40} of 30 is used as one of the criteria for identifying a potential wet-pavement accident site. After a field review of the site and determination of volume of traffic, environmental data, and geometrics of the highway, an estimate of the required SN_{40} is made. Various alternative treatments are then considered with an analysis of the economic break-even point for cost of potential accidents versus cost of remedial measures. A priority ranking of sites is then made for treatments to improve skid resistance. A block diagram of Virginia's system is shown in Figure 9. It is recommended that the SN_{40} value of 30, selected as a tentative minimum, may not be adequate for all conditions, and sites with values of this magnitude may not always have wet-pavement accidents, but it is regarded as a minimum value indicative of the need for a review of the wet-pavement accident experience at the site.

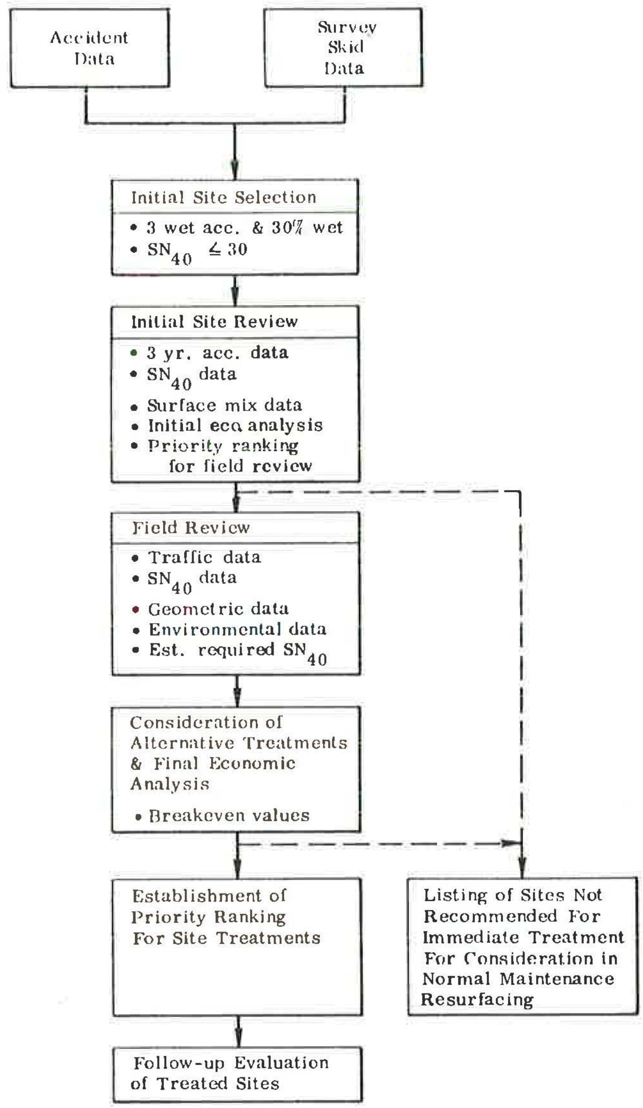


FIGURE 9 Virginia's wet-pavement accident reduction program (*23*).

TABLE 5

REQUIREMENTS FOR SKID RESISTANCE LEVELS OF AGGREGATE FOR VARIOUS TRAFFIC FREQUENCIES (PENNSYLVANIA) (*21*)

ADT	SRL (Skid Resistance Level)[a]
20,000 and above	E
5,000 to 20,000	E, H, blend of E and M, or E and G[b]
3,000 to 5,000	E, H, G, blend of H and M, or E and L[b]
1,000 to 3,000	E, H, G, M, blend of H and L, or G and L, or E and L[b]
1,000 and below	Any

[a]See Table 3 for SRL ratings for various aggregates.
[b]All blends are 50% by weight.

West Virginia

The criteria are to apply a friction course where the ADT is greater than 3000 and at sites with a skid number (SN_{40}) less than 30 for which wet-weather accidents constitute 40 percent or more of the total accidents at the site.

Florida

Criteria are established by Directive No. 0731-18. Friction courses are warranted for all new construction or reconstruction of two-lane and multilane facilities with a design speed of 35 mph (55 km/h) or greater, and a 5-year projected ADT greater than 3000.

A type S (structural) asphalt concrete mix may be used as a surface course in lieu of a friction course on two-lane roads when the 5-year projected ADT is 3000 or less, regardless of design speed.

Open-graded mixes (FC-2 or FC-3) are used for all multilane highways with speeds of 50 mph (80 km/h) or greater. Dense-graded mixes (FC-1 or FC-4) may be used for crossroads and ramps at interchanges when the crossroad design speed is 45 mph (70 km/h) or less. Dense-graded mixes (FC-1 and FC-4) may be used as alternatives to open-graded mix (FC-2) for two-lane highways when the speed is 50 mph or greater. These dense-graded mixes are also used for low-speed facilities (35–45 mph) with turning movements or for intersection improvement projects. Open-graded (FC-2) may also be used if costs are competitive. Modified type 2 surface treatment is included in the specifications as an alternative to maintain satisfactory skid resistance where leveling is required and the two-lane ADT does not exceed 5000 or the four-lane ADT does not exceed 6250. However, this alternative is not now being used.

An inventory of friction numbers (SN_{40}) is maintained for the entire road network. This inventory and special testing is used with accident data to determine the need for improved friction characteristics.

Georgia

Georgia has established the criteria for open-graded friction courses outlined below. However, recent problems associated with stripping have led to discontinuance of their use until the cause of the stripping can be established and corrective action taken.

The decision to apply a friction course for a particular facility is determined on the basis of operating speed and accident potential. A friction course may be warranted if the operating or legal speed is 40 mph (65 km/h) or greater. These criteria may be reduced to 35 mph (55 km/h) for unusual drainage conditions that result in heavy flow or accumulation of storm runoff in the traffic lanes.

Normally, a friction course is not warranted if the ADT does not exceed 3500. However, if a facility has a notorious accident history or identifiable hazardous conditions such as steep grades, deceptive curves, or poor sight distance, traffic volume is waived and accident potential should be the criterion used.

Kentucky

Kentucky has established selection guidelines for bituminous surface courses on federally funded projects. These guidelines require the use of OFC for Interstate highways and other roadways with an ADT above 10,000 with speed limits greater than 50 mph (80 km/h). Bituminous concrete surfaces with nonpolishing aggregate are used when the speed limit is less than 50 mph. Roads with 4000 to 10,000 ADT are classified as medium volume. Where speed limits are 50 mph or greater, OFC is used. Type II sand asphalt and bituminous concrete with nonpolishing coarse aggregate are also acceptable. Roads with ADT of 1000 to 4000 are classified as medium-low-volume roads. The recommended surface is bituminous concrete with a requirement that 40 percent of the sand be natural sand. Roads with ADT below 1000 are classified as low volume. Bituminous concrete with no restrictions on the type of aggregate is acceptable under these conditions.

South Carolina

Similar to the situation in Georgia (and other states), South Carolina has suspended the use of previously established guidelines for use of open-graded friction courses (HPMSC by their designation) because of stripping problems. Their new guide substitutes type 1 binder (dense-graded bituminous concrete) for HPMSC. For all Interstates and federal-aid primary roads where the speed limit is 50 mph (80 km/h) or greater and the ADT is 3000 or more, type 1 binder is now used (previously it was HPMSC). For federal-aid primary roads with speed limits 50 mph or greater but with ADT in the 750 to 3000 range, either type 1 binder or type 2 surface mix can be used. A decision is made on a project-by-project basis. For all other federal-aid, low-traffic-volume roads, the type of surface is decided on a project-by-project basis.

Illinois

Illinois has established a policy statement concerning its skid-accident reduction program. To qualify for improvement on the basis of wet-accident potential the following criteria must be met:

1. There must be a total of at least 3 accidents at a location during the last year.
2. More than 25 percent of these accidents must have occurred on a wet pavement surface. (Accidents occurring on snow/ice-covered pavement surfaces are not considered wet-weather accidents.)
3. The roadway must have a minimum ADT of 1000.

When a wet-pavement, high-accident location has been identified, a traffic engineering evaluation, including skid testing, is made and if it is indicated that upgrading friction characteristics will reduce wet-pavement accidents, a bituminous surface with high-quality friction characteristics is applied. This may be one of three types:

1. Plasticized bituminous hot-mix sand seals or sand-asphalt mixes containing blends of stone screenings and natural sands.
2. Open-graded asphalt friction course (OFC).
3. Class I bituminous concrete surface course, Mixture E with 100 percent crushed slag coarse aggregate (air-cooled blast-furnace or steel slag), limited to CA-13 size.

The sand-asphalt surface is used where posted speeds do not exceed 40 mph (65 km/h). It is also considered for use in rural areas at stop intersections. The OFC is given primary consideration for use on high-speed highways at high-accident locations, such as horizontal and vertical sag curves, interchanges, lane reductions, and heavy wearing areas. Class I bituminous concrete surface mixture with 100 percent slag aggregate is considered intermediate between the sand-asphalt and OFC and can be used as an alternative for either OFC or sand-asphalt mixes.

For rehabilitation, resurfacing, and new construction with bituminous concrete, one of three mixtures is used:

Mixture C is the standard mix contained in the standard specifications. It is used as the surface course on roads and streets with a design ADT of 2000 or less.

Mixture D is similar to Mixture C except that 100 percent limestone is not permitted as the coarse aggregate. Fifty-fifty blends of crushed slag and limestone are permitted. This mixture is used as the surface course on all two-lane roads and streets having a design ADT greater than 2000, on four-lane highways having a design ADT of 25,000 or less, and on six-lane or larger highways having a design ADT of 60,000 or less.

Mixture E requires that the coarse aggregate be either crushed slag or a 50-50 blend of crushed slag and any other crushed aggregate except limestone. This mixture is the only one approved for use on four-lane highways having a design ADT greater than 25,000 and on six-lane (or greater) highways having a design ADT greater than 60,000.

Michigan

The Michigan bituminous pavement design guidelines permit the use of open-graded asphalt friction course where the speed limit is 40 mph (65 km/h) or greater. At present, these courses are not being used because of problems relating to the use of deicing chemicals and poor durability.

Arkansas

Arkansas made a statewide study of skid values of roads within the state on the basis of the type of aggregates available. The findings of this study were then used to establish zones within the state that were likely to require friction courses. In the zones using limestone or novaculite, additional measures are incorporated to provide a skid-resistant pavement surface. These measures may be plant-mix seals, sprinkle treatments, blended aggregates, or other economical alternatives that may develop. In zones where sandstone, gravel, and syenite are normally used, adequate skid resistance is expected without the use of additional measures.

Louisiana

Louisiana's policy is contained in its Engineering Directives and Standards Manual. EDSM No. I.1.1.5 concerns the department's skid accident reduction program. The policy states:

> It will be the policy of the Office of Highways to make every effort to construct and maintain a level of skid resistance on the state maintenance system to adequately accommodate the frictional requirements demanded by the motoring public under normal operational conditions. This will be done to the extent possible within the funding limitations set forth by the Legislature.
>
> The Department, due to the limited funds available and the available materials in Louisiana, cannot attempt to maintain the level of frictional requirements demanded under unusual conditions—such as, heavy rain, speeds in excess of the posted speed limit, emergency stops under panic situations, and other similar conditions.

The surface type used by Louisiana varies according to the expected traffic volume and speed limits. Table 6 gives the Louisiana requirements as shown in EDSM I.1.1.5.

To reduce the danger of hydroplaning, the directive establishes a requirement for a cross slope of 2.5 percent for all new construction. The same cross slope is also required for overlays, except in special cases the slope may be reduced to 2.0 percent when approved by the Chief Engineer. Multilane overlays may be designed in such a manner that the cross slopes will be increased from the high to the low side of the roadway for each lane in order to accommodate proper drainage. The minimum slope used in this case will be 1.5 percent.

Louisiana makes skid tests on a continuing basis and maintains an inventory of all pavements in the state-maintained system.

"Locations identified by an accident rate in excess of normal accident rates attributable to wet-weather roadway conditions, or by an SN_{40} skid number of less than approximately 35, or by a combination of the two, will be reported to the Highway Needs, Priorities, and Programs Engineer for corrective action" (EDSM No. I.1.1.5).

The directive prohibits the use of seal coats for maintenance over portland cement concrete pavements and permits surface treatment seal coats over bituminous concrete surfaces for an ADT/lane up to 600 when maintenance is needed and funds

TABLE 6

ASPHALT SURFACE TYPES FOR VARIOUS TRAFFIC VOLUMES AND SPEED LIMITS (LOUISIANA)

Current Traffic Volume (ADT/Lane)	Type Mixture Including Wearing Surface[a]
Less than 50	Asphaltic Surface Treatment (Expanded clay, slag, stone)
50 to 999	Type 1, 2, or 4
1000 to 1999	Type 1 or 4
2000 to 3000	Type 3
3000+ (Speed limit 45 or less)	Type 3
3000+ or multilane highways with paved shoulders. (Speed limit greater than 45)	Slag or Stone Asphaltic Concrete Friction Course over Type 3

[a]Types 1, 2, and 4 are low Marshall stability mixtures (Types 2 and 4 are rarely used). Type 3 is a high Marshall stability mixutre. The Standard Specifications allow Type 4 mixture as an alternate to the Type 3 mixture provided the Marshall stability acceptance requirements of the Type 3 mixture are met.

The criteria in the table above will be used on all projects where practical. For projects less than one mile in length, asphaltic concrete friction course may be deleted at the discretion of the Road Design Engineer. The Road Design Engineer may make recommendations to the Chief Engineer to deviate from these requirements when other project conditions, such as route continuity, would appear to justify an exception to this policy.

The Director of the Preconstruction Division shall decide whether a required Asphaltic Concrete Friction course shall be constructed under a separate contract or as a part of an overlay or new construction project.

are not available for asphalt concrete overlay. Only expanded clay, crushed slag, or crushed stone is used in such surface treatments.

Resealing of existing asphalt penetration-surfaced routes will be limited to the use of only expanded-clay, crushed-slag, or crushed-stone aggregate.

Texas

Administrative circular No. 22-74 (March 14, 1974) establishes guidelines for the minimum polish value of coarse aggregates for flexible pavements. The polish value is determined by Texas test method 438-A, which is included as an appendix to NCHRP Synthesis 49 (*24*). The method constitutes measuring the friction values of test specimens of the coarse aggregate after polishing in an accelerated polishing machine for nine hours under specific conditions. A British Portable Tester is used to obtain the friction value. The criteria given are:

Present ADT or Type of Highway	Minimum Required Polish Value of Coarse Aggregate for Flexible Pavements
Below 750	No requirements
750–2000	30
2000–5000	33
5000 and above	35
Interstate	35 or specify aggregate type
Special and high-volume highways	Specify aggregate type

South Dakota

South Dakota has a policy of taking action to raise the road surface friction on all their highways. Specific action is taken on all pavements having skid numbers lower than 31.

The Materials Office, through its physical research program, periodically checks and reports road surface friction numbers (SN) for all routes on the state system to the Office of Maintenance. This office takes action as soon as possible after receiving notice of sections with skid numbers lower than 31. "Slippery When Wet" signs are erected immediately on receipt of notice on all sections with low skid numbers. A statement is prepared for each project providing basic information such as: strength, speed limits, roughness, friction index (SN_{40}), ADT, rating by percent formula, length, location, etc. A review is made of alternative methods of improvement (these include overlaying, texturing, grinding, and grooving), including costs and probable effect. Recommendations are prepared and submitted to the Director and Highway Engineer for action.

Nevada

Policy memo No. 206, dated February 4, 1982, establishes a policy for placing open-graded plant-mix surface wearing courses (OFC) on all roadways meeting the following conditions:

1. All high-speed facilities (excess of 40 mph).
2. All low-speed facilities (40 mph or less) where there is stop-and-go traffic and/or abrupt turning movements. This would generally include all arterial streets and highways.

On low-speed facilities (40 mph and less), where stop-and-go traffic and abrupt movements are not a factor, the open-graded plant-mix surface may be eliminated if it is demonstrated that an alternative type of wearing course, such as a chip seal, would be more cost-effective. This is to be evaluated on a project-by-project basis.

Kansas

Friction courses are used on Interstate highways and in metropolitan areas with heavy traffic.

Nebraska

SN_{40} less than 40 for all type of roads is the criterion used for designating slippery road surfaces.

Wyoming

Criteria based on ADT (no details given).

Ontario (Canada)

Directive C-16 on surface course mixes for main highways lists approved mixes based on ADT.

1. For urban freeways, open-graded friction course mixes should be used as the surface course layer in future reconstruction projects.
2. For main highways carrying in excess of 5000 AADT/lane, a dense friction course mix should be used. This surface mix could be used on problem skid locations with lower traffic volumes.
3. For other main highways carrying in excess of 5000 AADT/2 lanes, a standard HL1 mix should be considered. The HL1 mix is a surface course consisting of traprock coarse aggregate or screened steel-slag coarse aggregate, and local fine aggregate.

The use of blast-furnace-slag coarse aggregate in standard HL1 or dense friction-course mixes should be restricted to blending a maximum of 20 percent of the blast furnace slag with steel slag or traprock stone until more service experience is obtained.

New Brunswick (Canada)

A minimum skid number of 30 is cited. "Slippery When Wet" signs posted if necessary.

CHAPTER THREE

NATIONAL REGULATIONS AND LEGAL ASPECTS

BACKGROUND

Highway Safety Program Standard 12, issued by the Secretary of Transportation June 27, 1967, requires every state to have a program of highway design, construction, and maintenance to improve highway safety (*25*). This standard requires that such safety programs include, among other elements, standards for pavement design and construction with specific provisions for high skid resistance qualities and a program for resurfacing or other surface treatments with emphasis on correction of locations on sections of streets and highways with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces. The standard further states that each state is expected to develop a program to reflect individual needs and conditions. As a minimum, such programs are to include:

1. An evaluation of current pavement design, construction, and maintenance practices to ensure that the skid-resistance properties are suitable for the needs of traffic, and
2. A systematic procedure for the identification and correction of hazardous skid-prone locations.

To implement this program, the FHWA issued Instructional Memorandum (IM) 21-3-68 on April 29, 1969, which was superseded by IM 21-2-73, issued July 19, 1973 (*26*). The latter instructional memorandum established the requirement that skid-resistance evaluation for bituminous pavements is to include a determination that the aggregate used in the top layer of future bituminous pavements is capable of providing adequate skid-resistance properties when incorporated in the particular mix and that the mix is capable of providing sufficient stability to ensure the durability of the skid resistance. Similar requirements were included for portland cement concrete pavements. Under IM 21-2-73, materials and designs known to provide inadequate skid resistance are not to be approved for use on federal-aid projects. Use of the traffic records system called for in PPM 21-16 (*27*), which requires correlation of accident experience with highway data, was stipulated. These data, along with a special review of wet-weather accidents and the measurement of pavement frictional characteristics at particular locations, should be used in determining skid-prone locations and needed corrective work.

IM 21-2-73 further stated a requirement that each state establish by December 31, 1975, a statewide inventory of skid resistance measurements called for in the National Emphasis Program of the Highway Safety Program Management Guide. The required program was to be made on a selected sample of surfaces representative of the various combinations of mix designs, aggregates, and construction procedures for pavements that have been exposed to sufficient traffic to allow an appraisal of the skid-resistance performance. This information would then be used to estimate the condition of the remaining pavements for similar conditions of surfacing and traffic and to determine the probable critical location. For these measurements the trailer and procedures given in ASTM E 274-70 were endorsed as the standard to be used. An equivalent device that gives comparable results is permissible.

Locations requiring evaluation for corrective measures could be identified by a high frequency of wet-weather accidents, by a low skid number, or by a combination of the two. Once the location is identified, an examination of the overall geometric conditions in the vicinity of an accident is in order. Appropriate corrective work would be designated after a study is made of the alignments, signing, grades, drainage, cross section and super elevation, skid resistance, obstacles, traffic volume, percentage of time the pavement is wet, and the likelihood of sudden vehicular maneuvers.

The IM further stated that each state should set up general guidelines based on the specific conditions for the identification of highway sections on which a thorough evaluation will be made. Such guides should reflect the total pavement skid conditions within that state, including the available skid resistance data and measurement methods, and a practical skid resistance level that will indicate those sections with priority needs for inclusion in an early corrective program. A guide for the evaluation of current pavement practices to attain skid-resistant qualities was provided as an attachment to IM 21-2-73.

FEDERAL HIGHWAY ADMINISTRATION POLICY

To provide guidance on how to implement IM 21-2-73, Technical Advisory T 5040.17 was issued by FHWA on December 23, 1980 (*28*). This document reflects FHWA policy still in effect in 1983 at the time this synthesis was written. It provides a general overview of factors that should be considered as elements of any skid-accident reduction program. The advisory and its Appendix A are included as an Appendix to this report. (Appendices B, C, and D of the advisory are not included.)

This advisory reviews the existing requirements for skid-resistant pavements and makes recommendations concerning a number of aspects of the problem. Section 2e states:

> Legislative actions in recent years support a general duty of any highway agency to ". . . maintain the roadway in a reasonably safe condition. This would involve, in essence, inspection, anticipation of defects, and conformity with generally accepted standards and practices. . . ." The practical result is that highway agencies should have an organized system to identify and correct hazardous locations in a cost-effective manner, as well as a comprehensive pavement management program to design, construct,

and maintain highways in conformance with reasonable standards. Such a systematic process is the best way to execute the highway agency's duty to maintain a reasonably safe roadway.

In further identifying what is meant by a "program of highway design, construction, and maintenance to improve highway safety," T 5040.17 suggests the program include at least three basic elements. These are described more fully in section 3 of the technical advisory and include:

1. An evaluation of pavement design, construction, and maintenance to ensure that only pavements with good skid-resistance characteristics are used,
2. The detection and correction of locations with a high incidence of wet-weather accidents, and
3. The analysis of skid-resistance characteristics of selected roadway sections to ensure that pavements are being constructed properly, to develop an overview of the skid-resistance properties of highway systems, to provide up-to-date information for the pavement management process, and to provide data for use in developing safety improvement projects and the implementation of cost-effective treatments at appropriate locations.

LEGAL ASPECTS RELATING TO STATES' RESPONSIBILITY

Question 5 of the questionnaire sent to the various agencies asked for opinions concerning recommended minimums for skid numbers for various types of roadways. Only 16 agencies were willing to identify a specific low value. Even in these cases the suggested number was given as a guideline only.

Concern that improper use of the skid number could be made in legal actions against the state if specific minimums were published was expressed by a number of state representatives. It was properly pointed out that many interacting elements combine to establish a hazardous condition on a highway and that the skid number was only one of such elements. There is *no practical skid number* that can be cited as representing a value above which no skidding would occur under all circumstances. Conversely, even the slickest pavement, with the possible exception of those covered with wet ice, can be driven over provided the driving speed is low enough and tire treads are optimum. Most states use the results of skid-resistance measurements as a general guideline for further examination of a potentially hazardous situation, but the impossibility of taking simultaneous action on all such potentially dangerous sites makes it impracticable to establish a minimum below which the pavement would automatically be ruled as "slippery." Consequently, mandatory requirements are generally not considered to be appropriate.

The legal aspects of this problem were discussed by Thomas in a paper presented at the second international skid prevention conference (*29*). He states:

> The basic aspects of wet-weather skid reduction objectives or requirements must be analyzed in order to determine those for which the state might be held liable for negligence. An important legal defense is this: if the department is able to show that a decision is an exercise of discretion, then it may be immune from liability for any negligence in the performance or failure to perform a duty owed to the public.

Thomas further concludes from an analysis of the case law that may pertain to specific objectives or requirements of a skid accident reduction program:

> In addition, should wet-weather skid reduction programs contain errors or mistakes of judgment, or if regulations are predicated on reasonable, but faulty assumptions, or there are unexpected, hazardous results, probably no action could be maintained successfully. The reason is that all of these areas involved high-level planning requiring the consideration of many factors and the application of special expertise.

In summarizing various claims made against states, Thomas responds that:

> It appears that there is no general duty to pave with a particular material or in a particular way, to have uniformity of construction on all streets, or to reconstruct streets immediately where there is a change or unexpected use. . . .
>
> There may be exceptions to this immunity, for obvious, manifest dangers or for unreasonable approval of a design without adequate consideration. Moreover, in a few states there may be a duty to review approved designs where highway hazards result from known "changed conditions."

Thomas (*29*) points out that, in the maintenance of highways, states have been held liable for maintaining highways in a safe condition and that this can apply for failure to apply materials to counteract slippery conditions. Thus, the state has a duty to correct *known* wet-weather skid hazards, or at least to provide adequate warning.

> Aside from the basic questions of liability, it appears that accident data prior to an accident that identifies locations prone to wet-weather skidding accidents would be admissible on the issues of the state's notice of the hazardous nature of the highway.
>
> Regulations setting forth the requirements of a wet-weather skid reduction program would be admissible at trial, particularly where the regulations have the force of law. If the regulations are general and discretionary in nature, they would constitute some evidence of negligence if they were not followed. However, where there was a failure to comply with a specific mandatory requirement, the violation of the regulation could be held to constitute negligence per se.
>
> Finally, a general inventory of hazardous wet-weather skid locations, aside from being admissible on the questions of notice and nature of the hazardous condition, could be a basis for a claim that any highway not in compliance was ipso facto hazardous and that the state has an immediate duty to correct the condition. Cases suggest, however, that the state's decision on which highways to correct first is discretionary, and that, moreover, to impose such a rigid duty to repair all roads at once is unreasonable.

A full review of specific legal cases charging liability against states relating to skid accidents is beyond the scope of this synthesis. However, the type of problem that arises is illustrated by the comment and information supplied by a number of the states in answer to the questionnaire. A summary of the information provided by the 10 states and one province in Canada that indicated they had been sued or claims had been made against them is as follows:

- State 1—One hundred thirty-one claims have been filed totalling $1,874,000.
- State 2—Policy is to settle out of court where the accident has occurred on portions of the highway known to have low skid numbers that were scheduled for improvement but where

lack of funds has precluded improvements of all the recognized substandard conditions.

- State 3—Has had lawsuits; no other information provided.
- State 4—Has had suits in which NCHRP Report 37 has been used in an attempt to show that roads with skid numbers below 40 automatically were unsafe. Such suits have not been successful to date.
- State 5—One suit reported, was dropped without court action.
- State 6—A number of cases have been filed. State has won most on basis of demonstrating that skid resistance was adequate. In this state, which is subject to high intensity rain storms, hydroplaning is a major problem. Two cases involving the same bridge were lost. State was found negligent because of failure to correct a known slippery condition. The condition was caused by loss of coverstone over a seal coat. Another case, involving hydroplaning where water gathered in ruts, was won on the basis of expert testimony that driver had to be driving at excessive speed for hydroplaning to occur.
- State 7—Has lost several cases on basis of negligence because of failure to correct known slippery spots.
- State 8—Cases have been filed relating to accidents occurring in areas where something went wrong during construction with the materials or their application. However, this was not always the major factor.
- State 9—Three tort suits in recent years. One case ruled against claimant. Other two were settled out of court for $40,000.
- State 10—One case was settled on factors other than skid number.
- Canadian Province—Very few cases. One recent. All dropped or pending.

Summary of Legal Aspects

Although laws and regulations may vary from state to state and legal decisions will vary from case to case, the information provided suggests several principles that relate to legal actions against a state for damages where accidents have been attributed to loss of control.

1. The state does have a responsibility to maintain roads in a generally safe condition. Freedom from unexpected slippery spots is a reasonable requirement and the state has a duty to correct *known* wet-weather skid hazards or at least provide adequate warning (*29*).
2. Skid numbers, as measured by the equipment and procedure described in ASTM E 274, provide useful guidelines as an aid in identifying potentially hazardous conditions when the pavement is wet. However, such numbers are not appropriate as a mandatory requirement. Not only do the skid numbers themselves vary with the season of the year, the change in skid number with speed varies depending on the type and condition of the road surface. Also, the skid number, determined using a standardized tire, is not specifically related to the ability of a vehicle in use to make sudden stops in traffic. The condition and type of tires and brakes and skill and attention of the driver all enter into the situation.
3. Generally, cases have been lost or settled out of court when it was shown that the state was aware of a hazardous condition but had not taken proper action to correct the condition or to adequately warn the motorist.
4. Cases are usually won when it can be shown that the vehicle was traveling at excessive speed just before loss of control or that proper judgment was not exercised for existing conditions.

CHAPTER FOUR

GUIDELINES FOR ADEQUATE PAVEMENT SURFACE CHARACTERISTICS

As stated earlier, a major purpose of this synthesis is to consider the criteria being used by various states and provinces for the application of friction surfaces to highways. However, such criteria must be considered within the overall framework of the necessary actions of the state or province to reduce the occurrence of wet-weather accidents on its highways. Guidelines have been published by AASHTO (*30*). These guidelines were the results of a joint task force comprised of representatives from AASHTO, the American Road and Transportation Builders Association (ARTBA), and Associated General Contractors (AGC). The general principles involved in the total program are discussed in Technical Advisory T 5040.17, issued by the FHWA (see Appendix) (*28*). The actions taken by the states generally are related to their efforts to provide safe highways and to comply with the requirements outlined by FHWA. Generally, such actions can be broadly categorized as follows:

1. Major emphasis is applied to using the proper materials and design in construction of the highway. Where good skid-resistant aggregate is available and extremely heavy traffic is not encountered, this procedure provides an adequate level of pavement skid resistance throughout the lifetime of the pavement and no special friction course is used or needed. For states in areas of heavy rainfall, proper cross slope for optimum drainage to reduce the danger of hydroplaning is a major consideration.
2. A decision to apply a friction course at the time of construction is made on the basis of the expected speed limits and the ADT expected to be encountered. The type of surface course depends on the level of the speed limit and the amount of traffic.
3. Potentially hazardous conditions are identified by maintaining wet-weather accident records and an inventory of skid numbers. Priority for corrective measures is given to locations

for which wet-weather accidents are significantly higher than accidents during dry weather. Skid numbers are used to identify potentially hazardous sites and to initiate further investigation of conditions at the location.

4. Corrective action is based on the range of skid numbers determined with consideration given to the amount of traffic expected and the speed limits.

ADEQUATE SKID NUMBERS

As has been emphasized throughout this report, there is no direct relationship between the danger of skidding accidents and the skid number as measured at 40 mph (65 km/h) by ASTM test method E 274. Nevertheless, all states recognize a responsibility to build and maintain a highway surface that provides generally consistent and adequate friction characteristics so that under normal operating conditions and behavior, loss of control through skidding in wet weather does not occur. What constitutes *adequate* is a matter of judgment and varies depending on the speed vehicles travel and the amount of traffic congestion.

Economic considerations are also important. In areas where good high-quality nonpolishing aggregate is plentiful at competive prices, all classes of roads and highways can be built with excellent skid resistance regardless of the needs. However, when such aggregates are not locally available and must be hauled long distances, costs become a major consideration. It then becomes necessary to balance such costs against needs. Such economic considerations may influence the levels of skid numbers considered adequate for given sets of conditions in different areas of the country.

The range of skid numbers suggested by those states and provinces providing guidelines ranged from 30 to 40 for Interstate or all highways for which the speed limit was in excess of 40 mph (65 km/h). Twelve of the 16 agencies suggested a number between 35 and 40 for these conditions. For urban areas where speed limits are likely to be less than 40 mph and for rural low-speed roads (less than 40 mph) and relatively low traffic, less than 3000 ADT, the suggested guide numbers varied from 25 to 40.

The consensus established by these numbers is that a skid number equal to or greater than 40, measured at 40 mph (65 km/h), provides adequate surface characteristics for "normal" conditions of wet-weather driving. For highways having speed limits above 45 mph (70 km/h) and heavy traffic, a skid number (SN_{40}) less than 30 is generally considered an indication that corrective measures should be taken as soon as possible. When the skid numbers range between 30 and 40, the action to be taken varies with the conditions encountered. Some states use the same number for rural roads as for high-speed roads. Generally, all such sites are monitored carefully and where wet-weather accidents occur, the corrective actions are taken as soon as possible. In some instances, reduced speed limits and/or warning signs are considered adequate until resurfacing is needed from the overall performance standpoint.

In evaluating whether or not indicated skid numbers are adequate, recognition must be given to the time of year measurements are made. A number of researchers have shown that skid numbers for a given section of pavement are highest in the spring and then generally decrease to their lowest values in late summer or fall. Seasonal variations as great as 30 skid numbers have been reported to FHWA by various states, with more typical variations in the range of 5 to 15 (*31*). A study by Runkle and Mahone in Virginia developed monthly correction factors for that state that would be applied to predict the minimum values expected during the year on the basis of the month in which the measurement was made (*32*). These correction factors varied from 0 in July and August to 3.7 in December, January, and February. In 1978, FHWA initiated a three-year research program with the Pennsylvania Transportation Institute of the Pennsylvania State University to collect frequent skid-resistance measurements of pavements in various geographical areas of the United States and to develop prediction models to describe seasonal variation in skid resistance. A paper by Saito and Henry presented at the 1983 Annual Meeting of the Transportation Research Board describes the development of a basic mechanistic model to predict the seasonal and short-term variations in skid resistance as a function of environmental and traffic conditions (*33*). The complete report on the FHWA study is also available (*34*).

CRITERIA FOR TYPE OF ASPHALT FRICTION COURSE

Different agencies use different mix designs for various conditions of traffic and speed. However, a general consensus is indicated as follows:

1. Sprinkle treatments. These treatments have been used experimentally in several states (*35*) and a few states are beginning to use them extensively. They are economical where quality aggregates must be shipped long distances because less quality aggregate is needed to obtain a skid-resistant surface.

2. Seal coats. These are used extensively for secondary roads and where traffic volumes are relatively low. Generally, a good polish-resistant coarse aggregate will be utilized for these seal coats. However, some slurry seals are used for low-volume and low-speed roads.

3. Open-graded asphalt friction courses. These are specially designed, open-graded asphalt mixes applied as a thin course—usually 3/4- to 1-in. (19- to 25-mm) thick. They have been shown to provide excellent skid-resistance properties and offer the best means of reducing the danger of hydroplaning (*24*). They also reduce the splash and spray behind vehicles during wet weather and thus have been used extensively on Interstate and primary highways carrying high volumes of high-speed traffic and large trucks. Although some states use such surfaces extensively and apparently have encountered very few problems with respect to durability, others, especially those in the southeastern part of the United States, have reported serious problems. In comments attached to the replies to the questionnaire for this study, Georgia, North Carolina, South Carolina, and Tennessee all reported difficulties with stripping of the asphalt from the aggregates in the pavement below the open-graded friction course. Other states have reported similar problems. Most of these states have discontinued the use of OFC until the cause of the problem can be discovered and corrected. A study by Tennessee attributed the problem to the entrapment of water caused by the clogging of drainage channels in the OFC after a period of use (*36*). It was also reported that loss of aggregate resulted in low skid numbers because of exposed asphalt films after loss of aggregate.

Synthesis 49 (*24*) emphasized the need for placing OFC over sound pavement and providing adequate drainage channels through proper design of the friction course. It also cautioned against paving over ruts that would trap water and possibly lead to stripping. Whether the problems experienced in the southeast and other states are inherent in normal deterioration of OFC under traffic or whether they can be eliminated by improved leveling of the underlying pavement and better design of the OFC is not known at this time. Further discussion is beyond the scope of this synthesis. However, such sensitivity to construction procedures and questions concerning durability lead to the greater use of dense-graded courses.

4. Dense-graded overlays. These are applied either as thin surfaces primarily for sealing and improving skid resistance or they are applied in thicker courses for structural improvement. When such overlays are properly designed, skid numbers are increased to acceptable levels. States report that such overlays are applied to all classes of roadways. Generally, such courses do not reduce the danger of hydroplaning as well as open-graded mixes. However, with the national speed limit at 55 mph (90 km/h), the danger from hydroplaning has been reduced, and a number of states consider the use of dense-graded surfaces as the most cost-effective procedure. At the present time some attention is being given to designing dense-graded surfaces with optimum macrotexture to provide good skid resistance at all legal speeds.

RESEARCH AND IMPLEMENTATION NEEDS

This synthesis has as its major emphasis the criteria used for applying asphalt friction courses. A complete evaluation of all the aspects of wet-pavement accidents was not intended, nor was it included. However, the reviews made indicate that the major problems faced by the states is how to build and maintain highways with adequate surface properties so that under normally expected wet-weather situations and legal speeds, accidents from skidding or loss of ability to stop within usual distances do not occur. The degree to which this can be accomplished is to a large extent dependent on economic conditions, the local availability of suitable materials, traffic conditions, rainfall patterns in the state, and possibly other considerations. The need is to better understand the interrelations between these various factors. For example, one question that needs to be resolved is whether or not the proportion of wet-pavement accidents in the total accidents continues to decrease as skid numbers increase or whether there is a "critical" value above which no further advantage is attained. This could have a significant economic impact. The need for an economic balance between increased skid numbers and excessive wear of tires must be recognized. There is a point beyond which such wear and the accompanying dangers from using "bald" tires would outweigh any advantage from higher skid numbers.

Continuing efforts are also needed to quantitatively establish the variability of the skid number with the characteristics of the equipment making the determination. Although considerable efforts are now under way or have been recently completed to develop quantitative evaluations for seasonal variations in skid number, this phenomenon needs to be better understood and the factors causing such variations identified. The general applicability of predictive models developed for this purpose should be established. Another area relating to skid measurements themselves is the better understanding of the roles of macrotextures and microtextures.

Significant differences in measured values of the skid number are obtained depending on whether a standard treaded tire or a blank (bald) tire is used in making the skid test. These differences are related to the microtexture and macrotexture of the surface. Further studies are needed to determine if a more significant characterization of the pavement surface can be made with respect to the potential for wet-weather accidents by using combinations of results from the two types of tires than by present standard treaded tires. Another related facet of the problem is whether or not previously developed relationships for converting measurements at 40 mph (65 km/h) hold for measurements at higher speeds. Should actual measurements be made at 55 mph (90 km/h) instead of 40 mph, even though there is a recognized increased danger and potential damage to measuring equipment at the higher speed? There is also a need to establish the extent of differences in measured skid numbers on tangents and curves and also for different lateral areas of the pavement.

Only when all these factors and their interrelations are better understood can more specific criteria be established for applying friction courses in a cost-effective manner for all types of highways and traffic conditions.

REFERENCES

1. Halstead, W. J., and J. Y. Welborn, "History of the Development of Asphalt Testing Apparatus and Asphalt Specifications." Proceedings of the Association of Asphalt Paving Technologists, Vol. 43A (February 1974).
2. "Skidding Accidents—Tires, Vehicles, and Vehicle Components." *Transportation Research Record 621* (1976) 171 pp.
3. "Skidding Accidents—Pavement Characteristics." *Transportation Research Record 622* (1976) 110 pp.
4. "Skidding Accidents—Wet-Weather Accident Experience, Human Factors, and Legal Aspects." *Transportation Research Record 623* (1976) 87 pp.
5. "Skidding Accidents—Ancillary Papers." *Transportation Research Record 624* (1976) 150 pp.
6. "Tentative Skid-Resistant Requirements for Main Rural Highways." *NCHRP Report 37* (1967) 87 pp.
7. Beaton, J. L., "Providing Skid Resistant Pavements." *Transportation Research Record 622* (1976) pp. 39–50.
8. Segel, L., "Tire-Vehicle System Elements Bearing on the Probabilities of Loss of Control." *Transportation Research Record 621* (1976) pp. 1–7.
9. Smith, H. A., "Pavement Contributions to Wet-Weather Skidding Accident Reduction." *Transportation Research Record 622* (1976) pp. 51–59.
10. "Skid Resistance." *NCHRP Synthesis of Highway Practice 14* (1972) 66 pp.
11. Holbrook, L. F., "Prediction of Wet Surface Intersection Accidents from Weather and Skid Test Data." *Transportation Research Record 623* (1976) pp. 29–39.
12. Hankins, K. D., "The Use of Rainfall Characteristics in Developing Methods for Reducing Wet Weather Accidents in Texas." Report No. 135-4, Texas State Department of Highways and Public Transportation (July 1975).
13. Karr, J. I., and M. Guillory, "A Method to Determine the Exposure of Vehicles to Wet Pavements." California Business and Transportation Agency, Department of Public Works, Division of Highways (January 1972).
14. Blackburn, R. R., D. W. Harwood, A. D. St. Johns, and M. C. Sharp, "Effectiveness of Alternative Skid Reduction Measures. Volume 1: Evaluation of Accident Rate-Skid Number Relationships." Report No. FHWA-RD-79-22, Federal Highway Administration (November 1978).
15. Dart, O. K., and L. Mann, Jr., "Relationship of Rural Highway Geometry to Accident Rates in Louisiana." Highway Research Record No. 312 (1970) pp. 1–16.
16. Henry, J. J., and K. Saito, "Skid Resistance Measurements with Blank and Ribbed Test Tires, and their Relationship to Pavement Texture." Presented at 62nd Annual Meeting of the Transportation Research Board, Washington, D.C. (January 1983).
17. "Highway Safety, Design and Operations." Report of the Subcommittee on Investigations and Review to the Committee on Public Works, U. S. House of Representatives (July 1973).
18. "Special Study—Fatal Highway Accidents on Wet Pavement—The Magnitude, Location, and Characteristics." Report No. NTSB-HSS-80-1, National Transportation Safety Board (February 1980).
19. Gallaway, B. M., J. G. Rose, and R. E. Shiller, Jr., "The Relative Effects of Several Factors Affecting Rainwater Depths on Pavement Surfaces." *Highway Research Record No. 396* (1972) pp. 59–71.
20. Martinez, J. E., J. M. Lewis, and A. J. Stocker, "A Study of Variables Associated with Wheel Spin-down and Hydroplaning." *Highway Research Record No. 396* (1972) pp. 33–44.
21. Gramling, W. W., "Development and Implementation of a Program to Reduce Skid Accidents." *Transportation Research Record 622* (1976) pp. 85–90.
22. Brunner, R. J., "Performance of Open-graded Asphalt Friction Courses in Pennsylvania." Pennsylvania Department of Transportation (January 1979).
23. Runkle, S. N., and D. C. Mahone, "Virginia's Wet Pavement Accident Reduction Program." *Transportation Research Record 622* (1976) pp. 91–99.
24. "Open-Graded Friction Courses for Highways." *NCHRP Synthesis of Highway Practice 49* (1978) pp. 39–44.
25. "Highway Safety Program Standard 12." U. S. Department of Transportation (1967).
26. "Skid Accident Reduction Program." Instructional Memorandum 21-2-73, Federal Highway Administration (July 1973).
27. "Highway Safety Improvement Program—PPM 21-16." Federal Highway Administration (May 3, 1972).
28. "Skid Accident Reduction Program." FHWA Technical Advisory T 5040.17, Federal Highway Administration (December 23, 1980).
29. Thomas, L. W., "Legal Implications of Regulations Aimed at Reducing Wet-Weather Skidding Accidents on Highways." *Transportation Research Record 623* (1976) pp. 48–50.
30. "Guidelines for Skid Resistant Pavement Design." American Association of State Highway and Transportation Officials (1976).
31. Rice, J. M., "Seasonal Variations in Pavement Skid Resistance." *Public Roads*, Vol. 40, No. 4 (March, 1977).
32. Runkle, S. N., and D. C. Mahone, "Variations in Skid Resistance over Time." VHTRC 80-R33, Virginia Highway and Transportation Research Council (February 1980).
33. Saito, K., and J. J. Henry, "Mechanistic Model for Predicting Seasonal Variations in Skid Resistance." Presented at the 62nd Annual Meeting of the Transportation Research Board, Washington, D. C. (January 1983).

34. Henry, J. J., and K. Saito, "Prediction Model for Seasonal Variations in Skid Resistance." Final Report, Federal Highway Administration (1982).
35. Weber, H. H., Jr., "Sprinkle Treatment of Asphalt Surfaces—State-of-the-Art Review." Demonstration Project No. 50, Interim Report, Federal Highway Administration, Report No. FHWA-DP-50-13 (November 1982) 96 pp.
36. Rorie, B. E., "Tennessee's Experience with Stripping of Asphalt from Aggregate Surfaces in Bituminous Mixes." Tennessee Department of Transportation (March 1982).

APPENDIX

FHWA TECHNICAL ADVISORY T 5040.17
Skid Accident Reduction Program

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

SUBJECT	FHWA TECHNICAL ADVISORY
SKID ACCIDENT REDUCTION PROGRAM	T 5040.17 December 23, 1980

Par. 1. Purpose
2. Background
3. Skid Accident Reduction Program
4. Pavement Design, Construction, and Maintenance
5. Wet Weather Accident Location Studies
6. Pavement Skid Resistance Testing Program

1. PURPOSE. To provide guidance for State and local highway agencies in conducting skid accident reduction programs.

2. BACKGROUND

   a. This Technical Advisory provides a general overview of factors that should be considered as elements of any Skid Accident Reduction Program. This Technical Advisory supports current Federal Highway Administration (FHWA) policy and will be revised as appropriate to reflect changes in policy as they occur.

   b. The existing requirements for skid resistance pavements are contained in several documents including Highway Safety Program Standard No. 12, Highway Design Construction and Maintenance (23 CFR 1204.4), Federal Highway Program Manual (FHPM) 6-2-4-7, Skid Measurement Guidelines for the Skid Accident Reduction Program. Other sources of technical advice are cited in the appropriate sections of this Technical Advisory.

   c. Highway Safety Program Standard 12 (HSPS No. 12) states that every State shall have a program of highway design, construction, and maintenance to improve highway safety. This program shall provide that "there are standards for pavement design and construction with specific provisions for high skid resistance qualities." The HSPS No. 12 also requires that each State have a "program for resurfacing or other surface treatment with emphasis on correction of locations or sections of streets and highways with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces." In discharging the responsibilities of FHWA, the Division Administrator should determine the acceptability of specification requirements and construction practices for placing, consolidating, and finishing both asphalt concrete and portland cement concrete pavements. Such determinations will rely on the highway agency to research, evaluate, and document the performance of the various aggregates, mix designs, and construction practices used.

d. Even though the use of studded tires is beyond the control of most highway agencies, their use can cause significant wear on the pavement surface texture. For example, grooves sawed in concrete pavements have worn completely down in as short a time as 2 years. States are encouraged to ban or restrict the use of studded tires.

e. Legislative actions in recent years support a general duty of any highway agency to "... maintain the roadway in a reasonably safe condition. This would involve, in essence inspection, anticipation of defects, and conformity with generally accepted standards and practices."* The practical result is that highway agencies should have an organized system to identify and correct hazardous locations in a cost-effective manner, as well as a comprehensive pavement management program to design, construct, and maintain highways in conformance with reasonable standards. Such a systematic process is the best way to execute the highway agency's duty to maintain a reasonably safe roadway.

3. SKID ACCIDENT REDUCTION PROGRAM. Each highway agency is encouraged to develop and manage a skid accident reduction program to reflect the individual needs and conditions within the State. The purpose of a skid accident reduction program is to minimize wet weather skidding accidents through: identifying and correcting sections of roadway with high or potentially high skid accident incidence; ensuring that new surfaces have adequate, durable skid resistance properties; and utilizing resources available for accident reduction in a cost-effective manner. A program comprised of at least the following three basic activities, if faithfully implemented, should enable the highway agency to comply with HSPS No. 12.

---

* Engineering and Government Liability, David C. Oliver, FHWA, an unpublished paper presented to the American Road and Transportation Builders Association Local Officials Meeting, St. Louis Missouri, August 23, 1978.

a. The evaluation of pavement design, construction, and maintenance practices through its pavement management program to ensure that only pavements with good skid resistance characteristics are used.

b. The detection and correction of locations with a high incidence of wet weather accidents utilizing (1) the State and local accident record systems, and (2) countermeasures for locations with high wet weather incidences, to ensure that existing highways are maintained in a safe condition.

c. The analysis of skid resistance characteristics of selected roadway sections to:

(1) ensure that the pavements being constructed are providing adequate skid resistance,

(2) develop an overview of the skid resistance properties of highway systems,

(3) provide up-to-date information for the pavement management process, and

(4) provide data for use in developing safety improvement projects and the implementation of cost-effective treatments at appropriate locations.

4. PAVEMENT DESIGN, CONSTRUCTION, AND MAINTENANCE

a. Pavement Design

(1) Current pavement design practices should be evaluated to ensure that skid resistance properties are durable and suitable for the needs of traffic. Consideration of skid resistance levels, texture, aggregate availability, traffic volume, traffic speed, type of facility, rainfall, construction and maintenance practices, and accident experience are basic elements in such evaluations. Evaluations should document the compliance with the requirement for skid resistant surfaces and provide basic data for use in choosing corrective actions for locations with high wet weather accident rates.

(2) One principal result of the evaluations is the development of a performance history for each particular pavement used by each highway agency. The performance of the existing pavement designs

should be monitored and new designs should be evaluated to ensure that only skid resistant pavement surfaces are used. Information should be gathered as to the durability of a mix and the loss of skid resistance under traffic.

(3) The level of skid resistance needed for a particular roadway depends primarily on the traffic volume, traffic speed, type of facility, and climate with additional consideration warranted at special locations such as steep hills, curves, intersections, and other sites which experience high demands for pavement-tire friction. It is desirable to have one or more "skid resistant mixes" which have durable and higher than usual frictional properties for use in these special areas.

(4) A pavement surface may provide adequate skid resistance at low speeds, yet be inadequate for high speed conditions. Pavement surfaces, therefore, should be designed on the basis of properties at expected operating speeds.

(5) The American Association of State Highway and Transportation Officials (AASHTO) Guidelines for Skid Resistant Pavement Design, 1976, provide detailed information on the design of surfaces for both flexible and rigid pavements. The major considerations follow:

(a) Flexible Pavements

1 The skid resistance evaluation of bituminous pavements should include a determination that the aggregate used in the top layer of future pavements is capable of providing adequate skid resistance properties when incorporated in the particular mix and that the mix should be capable of providing sufficient stability to ensure the durability of the skid resistance.

2 A bituminous pavement surface should contain nonpolishing aggregates. It is essential for good skid resistance that a mix design be used which allows good exposure of the aggregates. This

requires that the pavement surface mixture be designed to provide as much coarse aggregate at the tire-pavement interface as possible.

3 The open graded asphalt friction course (OGAFC), with a large proportion of one size aggregate, provides excellent coarse texture and exposes a large area of coarse aggregate. Guidance for this mix can be obtained from FHWA Technical Advisory T 5040.13, Open-Graded Asphalt Friction Courses, January 11, 1980.

(b) Rigid Pavements

1 The evaluation of portland cement concrete (PCC) pavements should include a determination that the finishing procedures, mix design, and aggregates provide the initial texture and necessary surface durability to sustain adequate skid resistance.

2 In PCC pavements, the initial and early life skid resistance properties depend primarily on the fine aggregates for microtexture and on the finishing operation for macrotexture. Specifications for texturing concrete pavements should be carefully selected and enforced to ensure a macrotexture pattern appropriate to the type of facility.

3 Regardless of the finishing or texturing method used, adequate durable skid resistance characteristics cannot be attained unless the fine aggregate has suitable wear and polish resistance characteristics. Research by the Portland Cement Association indicates that the siliceous particle content of the fine aggregate should be greater than 25 percent.

4 If pavement evaluation studies indicate that the coarse aggregates will be exposed by the surface wear and have a significant effect on skid resistance of pavement, it too should have a suitable polish resistance characteristic.

5 Metal tines, preceded by burlap or another type of drag finish, are recommended as being the most practical and dependable method of providing texture in PCC surfaces. Additional guidance can be obtained from FHWA Technical Advisory T 5140.10, Texturing and Skid Resistance of Concrete Pavements and Bridge Decks, September 18, 1979.

b. Pavement Construction

(1) Highway agencies are encouraged to adopt a policy of "prequalifying" aggregates to be used in surface courses. Prequalifying is a method by which aggregates can be classified according to their friction, texture, wear, and polish characteristics. Classifications should reflect performance related to traffic volume, operating speed, percent trucks, climate, geometric design, and other appropriate factors. Design procedures should be established to ensure that aggregates can be selected for each project which are suitable to the needs of traffic.

(2) Prequalification may be accomplished by one of the following, or a combination of both:

(a) A systematic rating of all fixed sources of aggregates (e.g., a commercial quarry which obtains aggregate from the same location for many years). Ratings should be based on standardized laboratory tests such as the American Society for Testing and Materials (ASTM) D 3319, Recommended Practices for Accelerated Polishing of Aggregates Using the British Wheel, or ASTM D 3042 Test for Insoluble Residue in Carbonate Aggregates, combined with data obtained from skid resistance tests of pavements in service. Other tests may be added or substituted if shown to predict pavement performance.

(b) An evaluation and in-service history of the geologic or petrographic types of aggregates commonly used. Thus, when a new aggregate source is proposed, it can be accepted with minimum testing if an in-service history has been established for that type of aggregate.

(3) Based on prequalification of aggregates, construction plans and specifications should define the friction quality of aggregate which will be acceptable. The following steps should be followed to assure acceptability of the as-constructed pavement surface course:

(a) After the contractor has identified the particular aggregates and asphalt to be used on a project, it is recommended that a mix design be performed with the actual ingredients being used. Aggregates should be checked to determine if they are from prequalified sources or are an acceptable petrographic type.

(b) Macrotexture and void content are important considerations in asphalt mixes. Since asphalts are often blended from several sources of crude oil that vary in temperature-viscosity characteristics, the mixing temperature should be determined for each project after establishing the characteristics of the selected asphalt. Allowable tolerances for asphalt content, mixing temperatures, and gradation should be established for each asphalt mix.

(c) Job control of asphalt mixes should be designed to ensure that desired skid resistance properties are obtained. It should be recognized that small changes in aggregate gradation or asphalt content may significantly affect the macrotexture of finished surfaces.

(4) The frictional properties of pavement surface types should be randomly tested within 6 months after opening to traffic to verify that the anticipated characteristics are present. Evaluation tests should involve direct measures such as the skid tester (ASTM E 274), or an acceptable alternative, but may use surrogate measures such as those which evaluate texture (for example, ASTM E 303, Standard Method for Measuring Surface Frictional Properties Using the

British Pendulum Tester; and sand patch tests as described in the American Concrete Paving Association Technical Bulletin No. 19, Guidelines for Texturing Portland Cement Concrete Highway Pavements, Measurement of Texture Depth by the Sand Patch Method).

(5) In cases where the skid resistance properties of a pavement are found to be questionable or inadequate, appropriate warning signs should be placed immediately as an interim measure. A complete evaluation and any remedial action needed should be effected as soon as possible.

c. Pavement Maintenance. The same procedures and quality standards used in construction should be used in the maintenance operations.

5. WET WEATHER ACCIDENT LOCATION STUDIES. The purpose of this type of study is to identify locations with high incidence of wet weather accidents, determine corrective measures, and take appropriate actions in a timely and systematic manner. This activity should be conducted as part of the highway agency's safety improvement program and should make effective use of the agency's accident data file. Items to be considered for retrieval from the accident and traffic records are total accidents (rate), wet weather accidents (rate), and the wet/dry ratio.

a. Identification of Wet Weather Accident Sites

(1) Accident records, which are developed in compliance with Highway Safety Program Standard No. 9, Identification and Surveillance of Accident Locations, should be searched at least annually to identify sites which have a high incidence of wet weather accidents. It is essential to have a standardized highway location reference system for correlating data from different sources. Accident rates at a site will be of greatest value if:

(a) the traffic volume is relatively high (i.e., approximately 1,500 vehicles per day or greater),

(b) the period of accident data is at least two years, and

(c) rainfall data are available for the same period as the accident data.

(2) Rainfall patterns for the years in which skid resistance and accident data were compiled should be acquired for each area in the highway agency's jurisdiction. A suggested method is presented in Appendix A.

(3) There are several methods in use by highway agencies to evaluate wet weather accident locations. One such method is the Wet Safety Factor (WSF), which is presented in Appendix A.

b. Field Review. A list of all sites ranked in order of WSF or another appropriate measure should be prepared as the basic list of candidate sites for remedial treatments. The selected locations should then be skid tested and reviewed by a team representing various disciplines such as highway materials, design, construction, maintenance, traffic and safety. See Appendix B for skid testing procedures. The review team should determine probable reasons for the high incidence of accidents and recommend corrective actions. Once the review team has recommended appropriate corrective treatments, a priority list of projects can be prepared based on benefits and expected costs.

c. Priority Program. An assessment should be made of the benefits relative to the cost of providing remedial treatments for high priority projects. A number of highway agencies have their own methods for conducting benefit cost analyses of alternative remedial treatments. Some of these remedial methods are tied into traffic engineering or pavement management programs. A specific program for evaluating the benefits and cost of alternative treatments is presented in reference 1, Appendix C.

d. Evaluation

(1) Evaluation of completed projects as required in Highway Safety Program Standard No. 9 and FHPM 8-2-3, Highway Safety Improvement Program, should be well documented and should include a representative sample of completed projects. A sampling plan should be established, using accepted statistical methods, to evaluate projects with a range of such variables as classes of roadways, traffic volumes, types of countermeasures, pavements used, and other pertinent factors. On hazard elimination

projects, these data should be correlated with accidents and traffic exposure and other pertinent factors in before/after analysis. See reference 2 in Appendix C.

(2) The evaluation of completed safety projects should be a continuing process to ascertain the long-term performance of corrective actions such as skid resistant overlays. The evaluations should address at least:

(a) the overall effectiveness of the program in reducing accident rates at the corrected sites,

(b) the adequacy of the various materials, designs, or methods used, and

(c) recommendations for changes in the program, practices, or needed research and development.

(3) As a secondary benefit, the evaluation process should provide input to an overall pavement management process.

6. PAVEMENT SKID RESISTANCE TESTING PROGRAM

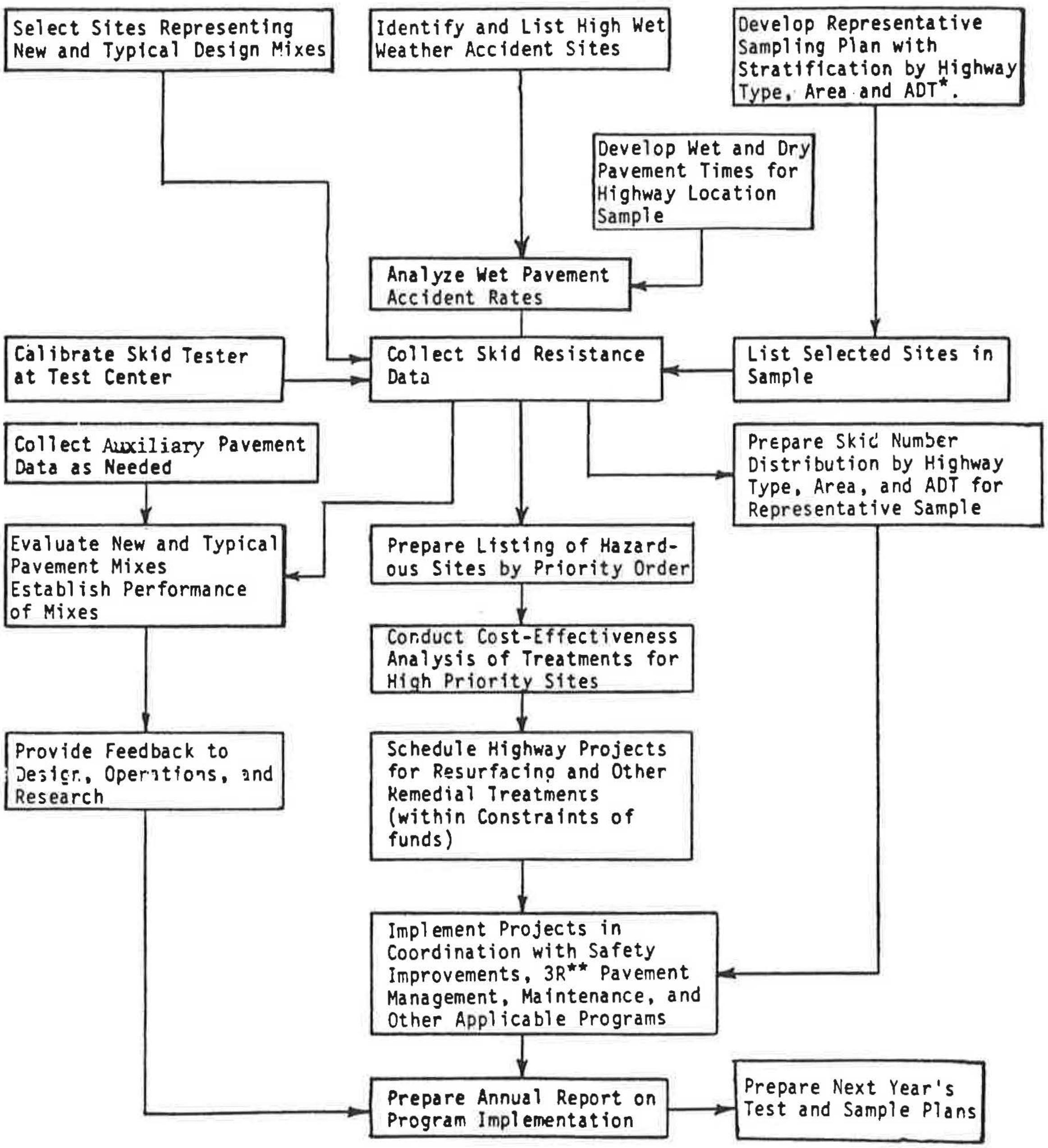
a. General Description of Program. The actual testing of pavement friction provides basic data for use in the three activities introduced in paragraph 3. Figure 1 graphically presents the interrelation between these activities. The upper portion of Figure 1 provides an overview of data to be collected to serve the safety, construction, and maintenance functions of highway organizations concerned with the skidding properties of pavement surfaces. The lower portion of Figure 1 indicates the various uses of the skid testing data, along with weather and accident data. Some of these data are evidence of the durability of particular surfaces, while other data provide a general overview of the skid resistance characteristics of the highway system.

(1) Skid resistance testing should be organized to support the following activities:

(a) Pavement evaluation studies in which measurements of the skid resistance of test sections are made to determine the skid characteristics of typical mix designs. Sufficient numbers of measurements should be

Figure 1

MODEL SKID ACCIDENT REDUCTION PLAN



*ADT: Average Daily Traffic

**3R: Resurfacing, Restoration and Rehabilitation made to determine the level of pavement friction, wear rates, and speed gradient of the pavement under various traffic exposures. These test sections should include the new projects to be tested as described in paragraph 4b(4).

(b) Evaluation of friction characteristics at locations which have a high incidence of wet weather accidents.

(c) System status for which measurements of the skid resistance of a representative sample of roads are made to develop the general levels of pavement friction on all roads in the highway agency's jurisdiction.

(2) Accurate location of sites or road sections requires the use of a standardized reference system. Often each element of the State which collects highway data uses its own reference system. For example, police accident reports may locate accidents by distance to a landmark, pavement records may be kept by project number and geometric features may be identified by station. A unified reference system has many benefits, especially in pulling together technical data for identifying and analyzing locations with a high incidence of wet weather accidents.

(3) Pavement evaluation study sites and wet weather accident sites should be identified by the element within the highway agency responsible for those programs. The skid testing can then become a routine matter for the element charged with operation of the skid test equipment.

(4) A total skid inventory of all roads and streets in a highway system has proven to be impractical and is not necessary to carry out an effective skid accident reduction program. Roads and streets which are used primarily by vehicles traveling at low speeds are not highly susceptible to skid accidents and accordingly can be eliminated from routine sampling of highway sites. For urban areas, this means that most city arterials would be sampled but residential streets and roadways with low speed limits would not. Nearly all rural highway sections could be sampled, since such roads are liable to high-speed use.

(5) Another practical consideration in determining which roads should be sampled is traffic volume. In urban areas, most roads with high speeds have moderate to high traffic volumes whereas this is not the case for rural highways. Relatively few rural roads are used by more than 1,000 vehicles per day. On a cost-effectiveness basis, such roads can seldom justify resurfacing on the basis of safety considerations alone; therefore there is little benefit in routine sampling of low-volume rural roads.

(6) Highway sections within the constraints of higher speeds and volumes need not be tested every year, since few roads vary substantially in skid resistance in any two or three-year period. Beyond this period, however, roads may lose significant skid resistance and may pose a serious danger to users. Using these criteria as part of a sampling plan will permit most if not all highway agencies to make maximum use of skid resistance data without increasing the amount of skid testing undertaken.

(7) Skid resistance measurements should be made with a calibrated locked-wheel skid tester using the ASTM E 274 method and supplemental procedures described in Appendix B or an acceptable alternative method. Locations such as intersections and sharp curves which are not easily measured with the locked-wheel skid tester at the standard speed of 40 miles per hour should be tested at a lower speed. Such tests should be supplemented with texture measurements to permit extrapolation of available skid resistance to operating speeds. Alternative methods of measuring pavement friction properties may be used provided they correlate well with the locked-wheel skid tester.

(8) In analyzing the skid numbers obtained, the time of year the measurements were taken has to be considered. Several States have published the results of their analyses and have developed methods for correcting skid number measurements taken during various periods and for different pavement surface types. See references 5 and 6 in Appendix C.

b. Specific Data From Sample Sites. In conjunction with skid resistance measurements, pavement wet time and accident records are desirable for each roadway section in the sample. The highway location system should be used for correlating data from different sources. An example of specific data which is desirable at each sample site is given in Appendix D.

c. Sites With Low Skid Resistance. When sites with low skid resistance are identified during the testing of system status, these sites should be analyzed for corrective action. This can be done through a pavement management program, a high hazard elimination program, or other efforts. If the high hazard elimination program is used, the analysis should be in accordance with FHPM 8-2-3.

R. D. Morgan
Associate Administrator for
Engineering and Traffic Operations

Lorenzo Casanova
Associate Administrator for
Safety

Appendixes

EVALUATION OF WET PAVEMENT TIME AND ACCIDENT DATA

A.1 The quantity of rainfall (inches) recorded by weather stations may be used to calculate the percentage of pavement wet time. Wet pavement time (WPT) may be estimated from total annual rainfall in inches (AR) as follows:*

$$WPT = 3.45 \ln (AR) - 5.07$$

Dry pavement time may be estimated by subtracting the amount of wet time and ice and snow periods from the total time in the period analyzed. Data from rainfall stations maintained by the National Oceanic and Atmospheric Administration's Weather Service may be used for wet and dry pavement time estimates for various areas within a State.

Isohyetal maps may be used to develop site wet pavement times. If ice and snow cover pavements for a significant portion of the time, a map for dry time should be prepared as well. Figure A-1 provides an example of a wet time map drawn from isohyetal charts.

A.2 Wet Safety Factor (WSF)

There are a number of ways to evaluate the relative safety of the subject location, one of which is the wet safety factor (WSF) approach.** For each wet weather accident location, a WSF may be developed. This factor is expressed as follows:

$$WSF = (DA)(PWT)/(WA)(PDT)$$

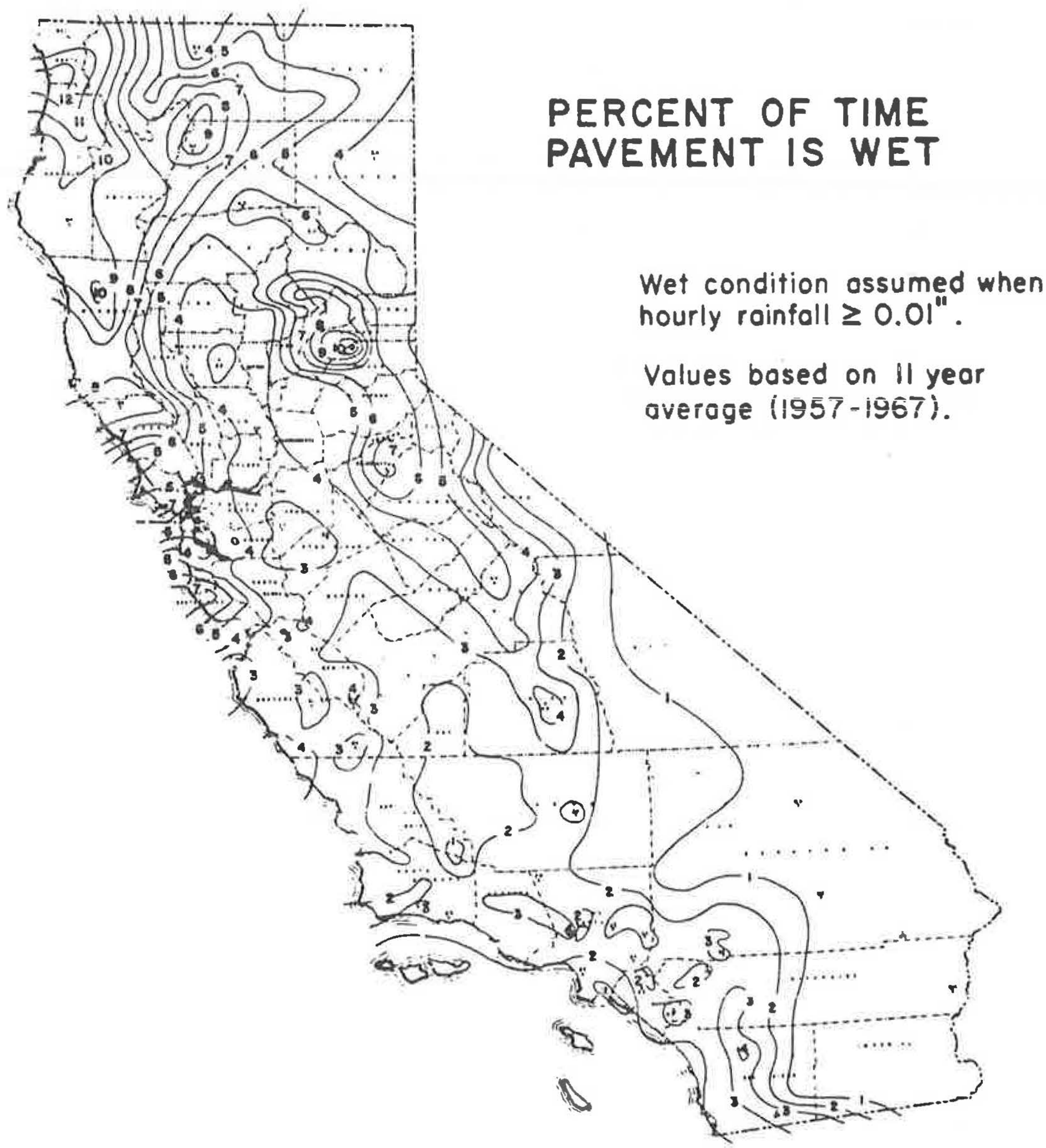
where:
- DA = number of dry weather accidents
- WA = number of wet weather accidents
- PDT = percent of dry pavement time
- PWT = percent of wet pavement time

---

* This equation is based on a relationship developed by K.D. Hankins in "The Use of Rainfall Characteristics in Developing Methods for Reducing Wet Weather Accidents in Texas," Texas State Department of Highways and Public Transportation Study No. 135-4, July 1975.

** The WSF is a generalized form of an index referred to as the "skid trap ratio" and recommended for use in NCHRP Report 37, Tentative Skid-Resistance Requirements for Main Rural Highways," by H. W. Kummer and W. E. Meyer, Highway Research Board, Washington, D.C., 1967.

Figure A-1



[1] "A Method to Determine the Exposure of Vehicles to Wet Pavements," by James I. Karr, California Business and Transportation Agency, Department of Public Works, Division of Highways, January 1972.

This factor is the reciprocal of the risk of having a wet pavement accident relative to having a dry pavement accident. On a specific roadway section, each of these variables must be developed for the same time period; otherwise, traffic exposure must be taken into account. Criteria may be developed for further consideration of pavement sections. A WSF less than 0.67 suggests a wet weather problem. This criteria is based upon the conservative estimate of the overall likelihood of a wet weather accident being 1 1/2 as great as a dry pavement accident. This estimate assumes that wet weather accidents at the site or road section under consideration are attributable entirely to a skidding problem. A low WSF in most cases is due to poor skid resistance. However, traffic engineering evaluations may reveal deficiencies in sight distance, road markings, inadequate drainage, etc. Auxiliary information obtained during the test program should provide indications of the safety problems.