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A Summary of the Illinois Skid-Accident Reduction Program: March 1980 - March 1984

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16. Abstract

This report summarizes the activities of the Illinois Skid-Accident Reduction Program from March 1980 through March 1984. Major policy advancements during the period covered by this report were the enactment of Illinois Department of Transportation Policy TRA-15, Safety Improvement Construction Program and TRA-16, Skid-Accident Reduction Program. TRA-15 is directed towards identifying high-accident locations and conducting a safety program addressing those and other potentially hazardous locations on a priority basis. TRA-16 is directed towards three basic activities: (1) incorporating adequate skid-resistance during construction/rehabilitation; (2) identifying, analyzing, and improving wet-pavement locations; and (3) program evaluation and reporting.

Accomplishments were discussed, including the development of present field test programs and data base, results of findings from experimental projects and studies, results of laboratory coarse aggregate evaluations, changes in practice, and a list of future work.

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State of Illinois
DEPARTMENT OF TRANSPORTATION
Bureau of Materials and Physical Research

A SUMMARY OF THE ILLINOIS SKID-ACCIDENT REDUCTION PROGRAM
March 1980 - March 1984

By

P. G. Dierstein and J. E. LaCroix

August 1984

FOREWORD

This report summarizes the activities of the Illinois skid-accident reduction program from March 1980 through March 1984. Prior activities undertaken from 1964, when the program was initiated, through 1980, were reported by Burke[1]. Future activities will be documented and reported on a yearly basis. Most of the activities were accomplished in cooperation with the Federal Highway Administration and comply with Federal requirements and directives. The information contained in this follow-up report is drawn from detailed reports published by the Illinois Department of Transportation, from unpublished reports and memoranda circulated within the Department, from policies and procedures developed by the Department, and from sources such as the Federal Highway Administration, the Transportation Research Board, other State Departments of Transportation, and various University publications.

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INTRODUCTION

OVERVIEW

In 1964 the Illinois Department of Transportation began systematically upgrading the friction characteristics of its pavements. At that time, knowledge regarding the design and construction of skid-resistant surfaces was limited. As a result, initial efforts were in the form of research and development. As further knowledge was acquired, pavement design, construction, and maintenance practices were reviewed, and changes in practice were introduced where conditions warranted. By 1972, a program of detecting and improving locations with a high incidence of wet-weather accidents was in place and continues to be a part of the Illinois Skid-Accident Reduction Program. Details of the Department's initial efforts may be found in A Summary of the Illinois Skid-Accident Reduction Program 1964-1980, by John Burke(1).

A number of significant changes in the Skid-Accident Reduction Program have taken place since 1980, culminating with Departmental Policy TRA-16. This report highlights the activities occurring from March 1980 until March 1984 when TRA-16 was issued.

Subsequent to this four-year summary, a yearly update (March to March) of the Skid-Accident Reduction Program will be published each June.

REPORT ORGANIZATION

This report is organized into four chapters. Chapter 2 documents the history of the development of the Illinois Skid-Accident Reduction Program. First the evolving Federal requirements are described. Then Illinois compliance with Federal mandates is discussed. The chapter concludes with a summary of Departmental Policy TRA 16 - Illinois Skid-Accident Reduction Program.

Chapter 3 deals with fundamentals. Included are descriptions of (1) the devices used to make skid tests, (2) micro- and macrotexture, (3) fluctuations and changes in friction, and (4) frictional demands.

Chapter 4 discusses program operations and accomplishments. The development of the present field test program and skid number (SN) data base is discussed. Results and findings from experimental projects and studies are updated. Results of a laboratory coarse aggregate evaluation are presented. Changes in practice are discussed. The chapter concludes with a list of future work.

CHAPTER 2

DEVELOPMENT OF THE SKID-ACCIDENT REDUCTION PROGRAM

EVOLVING FEDERAL REQUIREMENTS

Illinois' efforts to improve roadway friction characteristics predates the first national directive concerning skid-resistant surfaces. Since the directive was issued, a series of Federal mandates has shaped the Illinois program. The following chronology of FHWA directives summarizes those evolving mandates.

1967 - HIGHWAY SAFETY PROGRAM STANDARD 12 (HSPS No. 12)

HSPS No. 12, entitled "Highway Design, Construction, and Maintenance," was issued June 27, 1967. Its general objectives were to assure

> "that existing streets and highways are maintained in a condition that promotes safety, and that capital improvements either to modernize existing roads or to provide new facilities meet approved safety standards----."

HSPS No. 12 further directed that each state develop a program providing as a minimum that:

> "There are standards for pavement design and construction with specific provision for high skid-resistance qualities and
>
> "There is 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 surface."

1973 - FHWA INSTRUCTIONAL MEMORANDUM 21-2-73

IM 21-2-73, Subject: "Skid-Accident Reduction," was issued July 19, 1973. This document changed the Federal emphasis from establishing skid-accident reduction programs to evaluating existing programs. The memorandum required each state's program to include:

a. An evaluation of current pavement design, construction, and maintenance practices to ensure that the skid-resistance properties are suitable for the needs of traffic.

b. A systematic procedure for the identification and correction of hazardous skid-prone locations.

1975 - FEDERAL-AID HIGHWAY PROGRAM MANUAL 6-2-4-7, (FHPM 6-2-4-7)

FHPM 6-2-4-7, entitled "Skid Measurements Guidelines for the Skid Accident Reduction Program," was issued December 10, 1975. This directive indicated that each Skid-Accident Reduction Program should be composed of three basic activities.

a. The evaluation of pavement design, construction, and maintenance to ensure that only pavements with good skid- resistance characteristics are used in construction and resurfacing.

b. The detection of locations with a high incidence of wet-pavement accidents by utilizing the State accident record system and local accident record system as applicable, and the development of priorities for correction of the locations.

c. The analysis of skid resistance for all roads with a speed limit of 40 mph or greater, so that skid resistance can be given consideration in the development of priorities for resurfacing and maintenance programs.

1980 - FHWA TECHNICAL ADVISORY T 5040.17

Technical Advisory T 5040.17, issued December 23, 1980, is the latest and most comprehensive guideline provided by the FHWA. It states that each state's Skid-Accident Reduction Program must consist of at least the following three basic activities:

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

   (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 highways systems

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

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

THE EMERGENCE OF FORMAL DEPARTMENT POLICY

DEPARTMENT POLICY AS OF 1980

As of March 1980 the Illinois Department of Transportation had no single document outlining its Skid-Accident Reduction Program. The program did, however, consist of two major activities. The first, identifying and correcting wet-weather high-accident sites, was governed by the Highway Safety Construction Program. The second, assuring newly constructed pavements possess adequate friction qualities, was controlled by "The Special Provision for Skid-Resistant Bituminous Surfaces."

Identifying and Correcting Wet-Weather High-Accident Sites

The Department's Highway Safety Construction Program governing the identification and correction of wet-weather high-accident sites was a joint effort between the Division of Traffic Safety and the

Division of Highways. Once a year, Traffic Safety analyzed its vehicle accident data and located about 2000 sites having the "most critical" rate of accidents. The accident reports at these locations were then examined to determine which sites involved wet-weather skidding accidents. A listing of high-accident sites (including the special category of wet-weather skid sites) was sent to each District. The Districts reviewed the list, and submitted a prioritized list (based on a benefit/cost analysis) of corrective projects to a Highway Safety Construction Committee. This committee then selected as many projects for programming as the separately funded program would allow.

Unfortunately, this program was better at identifying than correcting wet-weather accident sites. The figures for 1980 illustrate the problem. Traffic Safety identified 2000 high-accident sites, 171 of which qualified as possible wet-weather skid sites where friction improvement may have been beneficial. Of these 171 sites, only eight were programmed for correction.

The problem was not with the Highway Safety Construction Program. It was effectively responding to the most critical accident locations in the state by applying the available funds where they would do the most good. The problem was with the Department's attempt to use this program as the only means of correcting wet-weather high-accident sites.

Assuring Adequate Skid Resistance Through Pavement Design, Construction, and Maintenance

Illinois Department of Transportation specifications and procedures, in place in 1980, assured that newly constructed surfaces would possess adequate friction for their design lives. Of specific interest was the Department's policy concerning the type of coarse aggregate allowed in its dense-graded bituminous mixes (Class I). A special provision matched the type of aggregate with the suggested traffic volume. For low-volume routes, limestone could be used; higher-volume routes required dolomite, gravel or chats; the heaviest-volume routes required slag. This policy resulted in a single mix, with uniform friction characteristics being placed from one end of the project to the other.

This policy had two major flaws. First, it did not recognize the need for increased friction at isolated locations along a route where driver demand or accident histories existed. Secondly, the elimination of limestone on all but the lowest-trafficked routes (ADT less than 500) necessitated shipping aggregates increased distances, substantially increasing the cost of our bituminous surface mixtures.

MAJOR POLICY CHANGES 1980-1984

Each year approximately 200 wet-pavement high-accident locations are identified in Illinois. Only a few of these locations ever reach the improvement stage because of the limited funding available through the Highway Safety Construction Program. The Department recognized this situation and developed "A Procedure for Identifying, Analyzing, and Improving Wet-Pavement Accident Locations Within a Rehabilitation/ Resurfacing Project." The two main changes address the identification of wet-pavement cluster sites and increase the use of limestone.

Cluster Site Identification and Correction

The procedure (included as Appendix A) applies not only to Federally and state-funded improvements on the Interstate and primary systems, but also to Federally funded improvements on the Federal-aid secondary and Federal-aid urban systems. A very brief description of the procedure follows:

In the planning stages of each rehabilitation project the District requests the three-year wet-pavement accident history on the route. The District plots the accidents at the appropriate locations along the roadway, looking for patterns of accidents indicating possibly hazardous locations. Traffic Safety has developed a series of tables to determine when the number of accidents within any length of roadway is significantly higher than normal. When the density of the accidents at a location is significant, that location is termed a "cluster site."

Once a cluster site is identified, the District must analyze the site and decide what type of correction should be made at that site. Documentation of that analysis must appear in the location study report for state projects and the project development report for local agency projects.

The cluster-site correction procedures described above often result in one or more isolated locations within a resurfacing project receiving a high friction surface mix, such as a dense-graded slag mix, a sand seal, or an open-graded asphalt friction course. While the inclusion of these special mixes hopefully will reduce the number of wet-weather skidding accidents, it also will increase the cost of the rehabilitation projects.

This systematic procedure for correcting wet-weather accident sites within rehabilitation projects complements the Highway Safety Construction Program.

Increased Use of Limestone

Limestone is an easily polished aggregate and provides relatively low friction values when used in dense-graded bituminous mixes. Prior to the development of the cluster-site procedures, limestone was restricted to roadways with an ADT of less than 500.

However, with the cluster-site procedure for correcting historically hazardous locations, the ADT limit on limestone was increased from 500 to 2000. While appearing to be a step backward, the Department felt that limestone would provide adequate friction for the "historically safe" sections of these roadways.

This increased use of limestone should reduce the costs associated with shipping dolomite into the southern two thirds of the State, offsetting the increased cost of the cluster-site correction.

PROCEDURE CHANGES FOR IDENTIFYING WET-PAVEMENT HIGH-ACCIDENT SITES

The process of detecting, evaluating, and improving isolated wet-weather high-accident locations, one of several elements in the Illinois Highway Safety Construction Program, has been a continuing activity since 1972. This comprehensive highway safety improvement program complies with Federal law and Federal Highway Administration directives. It is described, along with activities of other elements, in a report compiled annually by the State of Illinois, Department of Transportation, Division of Highways, Bureau of Traffic, entitled "Evaluation and Report of Highway Safety Construction Program." The most recent issue of the report is that of August 1983 for fiscal year 1983.

Initial changes

Since 1980, the procedure for identifying wet-pavement, high-accident locations has been modified in two ways: (1)urban, in addition to rural, skid-related high-accident locations are now identified, and (2) criteria to identify skid-related high-accident locations have been modified.

Initially, identification of wet-pavement high-accident locations was limited to rural, state-maintained roadways. Subsequently, a review of wet-pavement accident statistics revealed a majority of wet-pavement accidents occur in urban rather than in rural areas. Consequently, the identification criteria were modified to reflect this finding and to be more sensitive to accidents occurring on wet pavement.

For a high-accident location to qualify as a wet-weather high-accident location in 1980, the following criteria had to be met: (1) approximately 60 percent of the total accidents at the location were of a type that could involve skidding (rear-end accidents, running off the roadway on dry pavement, and all accidents on wet pavement), (2) approximately 33 percent of the total accidents at the location occurred on wet pavments (accidents on snow- or ice-covered surface excluded), and (3) at least three accidents occurred at the location.

Current Criteria

Over the past 3 years, the criteria have been changed several times. Currently, to qualify as a possible skid-related location, a high-accident location must meet the following criteria: (1) over 25 percent in rural areas, or 33 percent in urban areas, of the total accidents at the location occurred on wet pavement surface, and (2) at least three accidents occurred at the location.

TRA-15, SAFETY IMPROVEMENT CONSTRUCTION PROGRAM

On March 29, 1983, the Department of Transportation issued Departmental Policy TRA-15, Safety Improvement Construction Program (formerly Highway Safety Construction Program). This policy states that the Department shall have a program of identifying high-accident locations and conducting a safety program addressing those and other potentially hazardous locations on a priority basis. The policy, which appears in its entirety in this report as Appendix B, outlines the steps necessary to conduct the program. For high-accident locations, available safety improvement funds will be allocated annually to each District on the basis of its percentage of the total number of high-accident locations on the State-maintained highway system. For example, if District 1 had 1000 out of 2500 locations, it would get 40 percent of the available funds. Although the policy still includes the special category of wet-weather skid sites, those locations, as do other locations, have to meet the safety project criteria to be considered.

TRA-15 eliminated the Highway Safety Construction Committee and replaced it with a District multi-discipline team as the group who selects projects for improvement.

TRA-16, SKID-ACCIDENT REDUCTION PROGRAM

On March 15, 1984, the Illinois Department of Transportation issued Departmental Policy TRA-16, Skid-Accident Reduction Program (included as Appendix C). This policy was in direct response to the FHWA Technical Advisory T 5040.17 discussed in the introduction of this report. Just as that technical advisory outlined three basic activities required for a Skid-Accident Reduction Program, TRA-16 describes how those three activities are carried out in Illinois. The following section highlights the significant elements of each activity.

Incorporating Adequate Skid-Resistance During Construction/Rehabilitation

The first activity involves the friction characteristics of newly placed surfaces. Both portland cement concrete and bituminous concrete surfaces are addressed. Portland cement concrete surfaces on roadways with posted speeds of 40 mph or less may be finished using a single longitudinal artifical-turf drag. For roadways posted over 40 mph, a transverse tining is required in addition to the turf drag. For bituminous concrete, the friction characteristics of new surfaces are controlled by matching the allowed coarse aggregate with the projected traffic levels.

Identifying, Analyzing, and Improving Wet-Pavement Locations

The second activity described in TRA-16 concerns the identification and correction of wet-pavement accident locations. Two separate procedures are in place to fulfill this requirement. The Safety Improvement Construction Program (detailed in TRA-15) provides for immediate response to the most critical wet-weather locations.

While this program offers rapid response, funding limitations restrict its effectiveness.

The second procedure is used to identify potential wet-pavement accident locations within rehabilitation/resurfacing projects (cluster sites). When a cluster site is identified, the appropriate corrective treatment is selected for rehabilitation.

Program Evaluation and Reporting

The final program activity described in TRA-16 deals with evaluating and reporting program effectiveness. Five activities are detailed. The Bureau of Materials and Physical Research is responsible for all skid testing and maintenance of the skid-number data base, for evaluation of current design practices relative to skid-resistance properties, and for evaluating experimental projects concerning friction characteristics. The Division of Traffic Safety, in cooperation with the Bureau of Traffic and the Districts, will evaluate the effectiveness of selected countermeasures in reducing wet-pavement accidents. Finally, the Bureau of Materials and Physical Research, in cooperation with the Bureau of Traffic and the Division of Traffic Safety, will prepare an annual report summarizing the activities of the Illinois Skid-Accident Reduction Program.

CHAPTER 3

FUNDAMENTALS

Vehicle skidding involves not only the vehicle but also the pavement and the driver interacting in a changing environment. The elements - vehicle, driver, roadway, and environment - by themselves may not necessarily be hazardous but, under certain circumstances, combinations of these elements can cause accidents. This chapter attempts to put these elements into a proper perspective by answering the following fundamental questions: (1) How is pavement friction measured?, (2) What produces friction in a pavement surface?, (3) How does pavement friction change?, and (4) How much friction is needed?

HOW IS PAVEMENT FRICTION MEASURED?

In Illinois, two types of testers are used to measure pavement friction characteristics. The principal test device is a locked-wheel type skid tester. The other type device is a dynamic pendulum, impact-type tester that measures the energy loss when a rubber slide British Portable Tester (BPT) edge or a small wheel Variable Speed Tester (VST) is propelled over a test surface. The BPT and the VST are suited mostly for laboratory tests but can be used for field tests on flat surfaces.

The ASTM standard test methods for Skid Resistance of Paved Surfaces Using a Full-Scale Tire, Measuring Pavement Surface Frictional Properties Using the British Portable Tester, and Skid Resistance of Paved Surfaces Using the North Carolina State University Variable-Speed Friction Tester, are covered in detail in ASTM Designations: E 274, E 303, and E 707, respectively. Since most testing on paved surfaces involves the locked-wheel skid tester, the balance of this section deals with its operation.

The skid tester is designed to measure the skid resistance of a wetted pavement surface with a full-scale automotive tire. The tester consists of a two-wheel trailer towed by a pickup truck, which carries a water supply and other necessary instruments and equipment. Inside the truck cab are recording equipment (analog and digital), power supplies, amplifiers, and an operator's console. Tests can be made with either wheel. A transducer connects the test wheel to the axle and measures the torque developed when the wheel is locked. Speed is determined from proximity sensors on the unlocked wheel. A water nozzle for wetting the pavement hangs from the frame in line with and in front of the test wheel. Two testers of the same basic design are in service.

A two-man crew is needed for operation. The driver is responsible for maintaining the test speed with a minimum variation and for keeping the test tire centered in the wheelpath. The operator initiates tests as required, and also documents roadway features associated with the testing as well as any other appropriate comments.

The timing sequence controlling individual test functions is shown in Figure 1. A test is initiated by depressing the "start test" button and lasts 7.5 seconds. The water pump supplies water through a nozzle to the pavement in front of the test tire for 5 seconds from 0.5 seconds to 5.5 seconds into the cycle. The recorders are activated at the same time as the water flow, but are turned off at the 7-second point in the cycle. The selected brake is locked for 3.5 seconds beginning 1.5 seconds into the

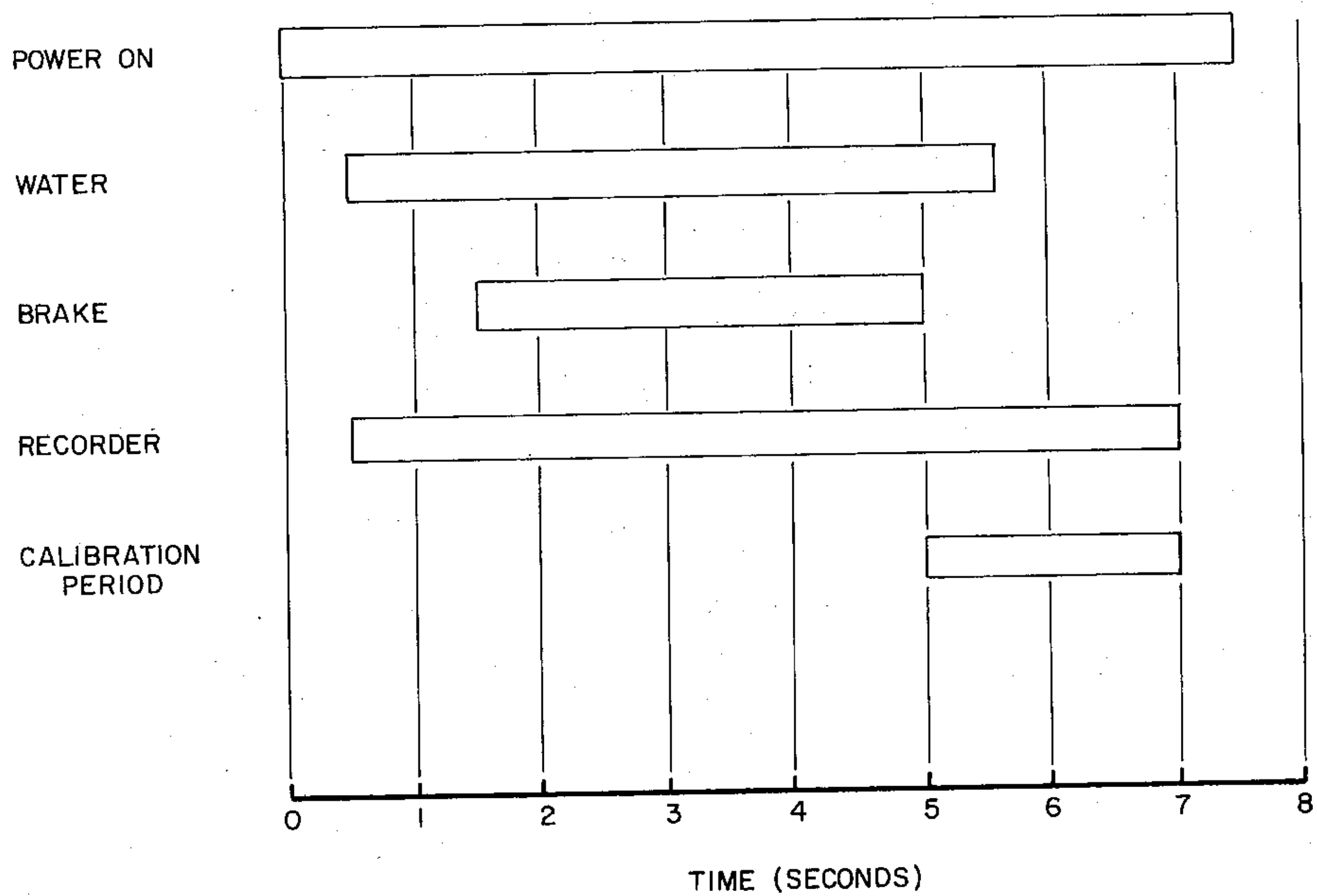

Figure 1. Skid-Cycle Timing Sequence

cycle. Electronic calibration is monitored during the 2 seconds from the 5-second to the 7-second point.

A typical analog output from a test can be seen in Figure 2. The sharp peak of the trace represents the incipient friction just prior to the wheel's locking. Once the wheel locks and sliding occurs, the friction drops to a steady state. The small excursions represent changes mainly in wheel load. A distinct change in the level of the trace represents a change in friction level. A one-second period is being integrated to provide a digital output. The excursion after the brakes unlock is the calibration pulse, which concludes the test cycle.

An example of a digital output from one of the testers can be seen in Figure 3. Viewing the tape from left to right, torque transducer values are shown in the first column on the left, followed by calibration values, speed, test wheel and sequential test number is the far right.

During testing, the truck is driven along a highway, in traffic, at a predetermined target speed, usually 40 mph, and the left trailer wheel is locked at periodic intervals. The distance between lockups varies from one every 0.1 mile to one every 0.5 mile. A standard full-tread test tire meeting the requirements of ASTM E 501 is used and is inflated to 24 psi pressure. The skid resistance of a paved surface is reported as a skid number (SN), which is determined from the force required to slide the locked test tire, at 40 mph, divided by the effective wheel load, and multiplied by 100. The skid number for each skid can range from 0 to 100. For example, an SN_{40} = 50 is the skid number measured at 40 mph and the value of 50 is at the midpoint of the possible range.

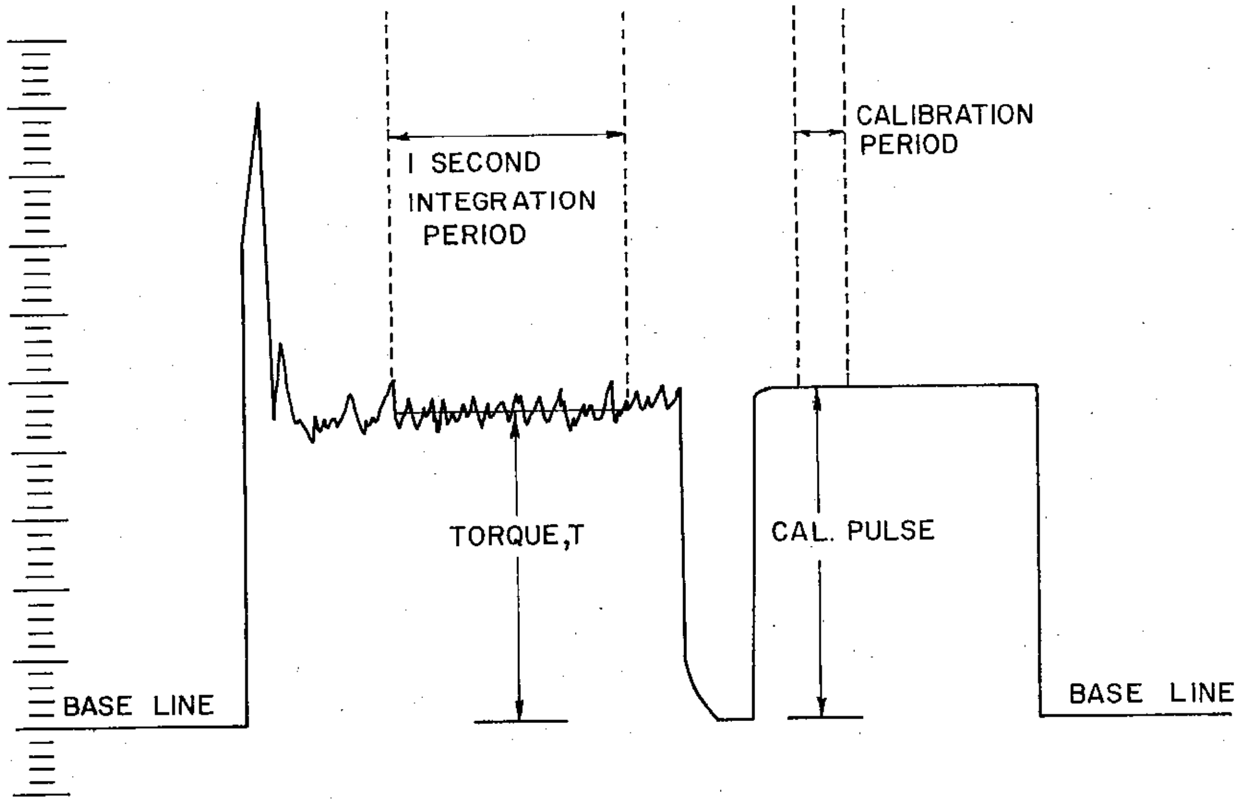

Figure 2. Oscillograph Chart Trace

Torque ft. lbs.	Calibration Pulse	Speed	Test Wheel	Test Number
321	530	40	R	50
349	508	39	L	49
401	530	41	R	48
412	507	40	L	47
398	529	40	R	46

Figure 3. Example of Printer Tape

For research purposes, to be discussed elsewhere in this report, measurements also are made with a standard smooth tire conforming to ASTM E 524 mounted on the right wheel. Lockups are made with alternate wheels through selected test sites.

WHAT PRODUCES FRICTION IN A PAVEMENT SURFACE?

Friction of a pavement surface is created by its surface texture. Surface texture is characterized by its micro and macrotextures. The fine or microtexture refers to the microscopic roughness of individual aggregates and, to a lesser extent, to the surface mortar surrounding the aggregate. The coarse or macrotexture refers to drainage channels associated with voids between aggregates and grooves in the surface.

MICROTEXTURE

Microtexture is that quality of aggregates that makes them feel rough or smooth to the touch. The gritty surfaces penetrate the water film, permitting contact between the tire and the roadway. Microtexture is essential in all road surfaces, but its greatest influence is when operating speed is less than 40 mph.

Microtexture depends upon mineral content, crystal/grain size, hardness, durability, and aggregate size.

<u>Bituminous Surfaces</u> - The friction developed between a locked-wheel tire with good tread and a bituminous surface depends mainly on the microtexture of individual coarse aggregates on roadways with speeds exceeding 40 mph. Both the coarse aggregate and the fine aggregate in the matrix surrounding the coarse aggregate contribute to microtexture on roadways with speeds less than 40 mph.

PCC Surfaces - Microtexture in a PCC surface comes from exposing the fine sand particles in the concrete mortar. For example, one surface with a steel-trowel-like finish when new had an SN of 30 while that for a broomed surface had an SN of 60, yet after 3 years of traffic their respective skid numbers were 50. The broomed finish lost some texture and dropped 10 numbers, while traffic exposed sand particles in the steel-trowel finish, raising its value 20 skid numbers.

As long as the sand mortar is not worn away, exposing coarse aggregates, most PCC surfaces will maintain an SN between 40 and 60 but, as the coarse aggregate becomes exposed, SN's can drop into the low 20's, depending on the type of coarse aggregate and on average daily traffic volume.

MACROTEXTURE

Macrotexture is the frictional characteristic that provides drainage escape paths between the tire and the pavement. The amount of macrotexture developed in a surface can be rated subjectively into three categories: fine, medium, and coarse.

Macrotexture can impact friction significantly during rainfall because it enhances the ability of water to escape from between the pavement surface and a worn tire. Skid-test results over a wide variety of surface textures indicate that the ASTM E 501 treaded tire lacks sensitivity to surface macrotexture. However, the ASTM E 524 smooth-tread tire is sensitive to both surface macrotexture and microtexture. Moreover, as macrotexture increases, smooth-tire skid numbers approach and sometimes surpass treaded-tire values.

The manner in which macrotexture is achieved in bituminous and portland cement concrete surfaces is discussed in the following sections.

Bituminous Surfaces - Aggregate gradation, aggregate blending, and mix design are the key elements in creating macrotexture in bituminous surfaces. Currently, an open-graded friction course (OGFC) is the predominant mix used to provide a coarse texture. Sand mixes, which have a fine texture, are limited to roadways where the posted speed limit is below 40 mph. Dense-graded bituminous mixtures, for the most part, also have a fine texture, but ongoing experimentation has and is expected to develop medium and possibly coarse textures in dense-graded mixtures.

Successful performance of OGFC initially depends on the mix design. Aggregate selection, asphalt content, and aggregate gradation can and do affect the performance of these surfaces. Hard, durable, polish-resistant aggregates, like slags, are essential in an OGFC surface. Asphalt content should be adjusted according to traffic-volume characteristics, site characteristics, and aggregate specific gravity.

Gradation of aggregate also influences OGFC performance. When the percent of fines passing the No. 8 sieve exceeds 15 percent, the void content is reduced, resulting in a loss of permeability. Conversely, when the percent fines passing the No. 8 sieve is near the lower range limit of 5 percent, the void content is increased, adding water-holding capacity, which promotes stripping and freeze-thaw damage.

Sand mixes, which have a fine texture, are especially suited for low-speed roads where high friction is required. Exceptionally high friction can be maintained by blending 70 percent of a hard, angular, natural or manufactured (steel slag) sand with 30 percent of a softer, more wearing sand (crushed stone and air-cooled slag). Again, asphalt contents must be adjusted to reflect traffic-volume characteristics and site characteristics to maintain high friction levels.

In dense-graded mixes, macrotexture can be improved by blending 50 to 70 percent of a hard aggregate with 50 to 30 percent of a softer, more abrading aggregate. However, the expected result will not be achieved unless fines are held to a minimum and the gradation takes into account the packing properties of the specific aggregates used. A 70-30 blend, respectively, of steel slag and air-cooled blast furnace slag can provide both high friction and a medium macrotexture. Substituting steel slag sand, air-cooled slag sand, and traprock sand for natural sands can improve the friction levels and the stability of a dense-graded mix.

Another technique for developing macrotexture and increasing skid resistance in a dense-graded mix is known as a sprinkle treatment. This technique involves first placing a surface course containing locally available aggregate, and then sprinkling a harder skid-resistant aggregate at the rate of 9 to 12 lb/sq yd over the surface before compacting it. Initially, this surface may provide a coarse texture, but after exposure to traffic the surface will change to a medium texture, with the higher rate of aggregate application providing the better macrotexture.

PCC Surfaces - In PCC surfaces, macrotexture in the plastic concrete is attained during final finishing. Currently, this consists of an artificial-turf drag (for microtexture), followed by transverse tining at 3/4-inch intervals. Transverse grooves are preferred over longitudinal grooves because they normally provide more efficient drainage. Whether longitudinal grooving has greater potential for minimizing hydroplaning around horizontal curves has yet to be determined.

Macrotexture can be created in worn PCC pavement by sawing longitudinal grooves. Smooth-tire tests on experimental projects show an SN of 18 on typical worn PCC surfaces. Longitudinal grooving increased the SN to 25, about the same as would be expected from a standard treated tire. Because of complaints from the travelling public, such as excessive noise and handling problems, sawing longituindal grooves to create macrotexture in worn PCC surfaces is no longer recommended for use in Illinois.

A comparison of transverse and of longitudinal tined surfaces on I-72 east of Springfield showed that, initially, transverse tining (SN 65) had better skid resistance than longitudinal tining (SN 53). In three years, the average SN's on both types of surfaces were in the mid 50's.

HOW DOES PAVEMENT FRICTION CHANGE?

As soon as a pavement is open to traffic, the wear process begins. The texture loss that occurs depends not only on traffic characteristics but on type of surface over which the vehicles are travelling.

SEASONAL FLUCTUATION

Pavement friction fluctuates seasonally as well as daily. Daily changes normally are small and are caused partly by changes in temperature and partly by changes in microtexture. Measurements made on cold days tend to be slightly higher than those made on hot days. The temperature effect on bituminous pavement may be greater than on portland cement concrete pavements. So far, no one has developed a satisfactory SN adjustment based solely on temperature.

In heavy industrial areas, plant stacks emit sulfur dioxide and vehicles emit carbon dioxide. When these chemicals mix and dissolve with water particles in the air, rainfall becomes acidic. Acid rainfall attacks carbonates like limestone and dolomite, and enhances their microtesture.

When a November 1975 inventory of Chicago expressways was compared with a repeat inventory in February 1976, mean skid numbers increased from 7 to 12 numbers in a dense-graded bituminous concrete containing dolomite, and from 5 to 10 numbers in a 50-50 blend of slag and dolomite. On the other hand, a long bridge segment having a sand mix (acid-resistant quartz aggregate) surface changed from 2 to 4 skid numbers.

It appears that seasonal variation can be expected to be greatest in surfaces containing carbonate aggregates that are placed on metropolitan area expressways near heavy industrialized areas. Conversely, rural local roads carrying average daily traffic less than 500 should have a much lower seasonal variation.

POLISHING

A pavement surface is worn or polished by the action of traffic. This results in loss of microtexture, and therefore loss of friction. The higher the traffic densities, the greater the loss.

In a tined PCC surface, the highest friction occurs when it is new, and a 10 to 30 percent loss in sand patch texture-depth measurements during the first 12 months is quite common. After this initial loss, the wear rate occurs at a much slower pace.

In bituminous surfaces, the highest friction usually occurs after traffic has worn away the bituminous film coating the coarse aggregate. Then, as traffic wear and polishing continue, friction drops to some equilibrium level, where daily and seasonal variation become responsible for most of the change.

An aggregate's ability to resist polishing is dependent upon its hardness, crystal/grain size, and durability. Optimum friction occurs when a rock contains two or more minerals.

Grain and crystal size also impact friction - the larger the size, the higher the friction. Dolomite, for example, provides higher skid numbers (approximately 10) than limestone. The higher values are attributed partly to larger grain and crystal size and to greater hardness. In carbonate rock, sand-size, acid-insoluble residue, when above 25 percent, accounts for even higher friction. Unfortunately, very few carbonate sources in Illinois have acid-soluble contents in this range. For a typical Illinois dolomite (acid-insoluble residue below 10 percent), variability in friction can be explained mostly by grain size.

Durability is another important aggregate quality. However, friction and durability sometimes oppose each other. For example, materialite, which is an expanded shale, provides skid numbers in the 60's, but it has a low crushing strength and crumbles under heavy truck loads, causing raveling in a bituminous surface. Consequently, its use has been discontinued.

LOCATION

Surface friction frequently is nonuniform, and usually varies between as well as within wheelpaths. Along open highways, inner wheelpaths usually have lower friction than outer wheelpaths, but at intersections either wheelpath has an equal chance of having the lower friction.

After several years of wear, the SN within a wheelpath can vary up to 10 skid numbers. This variation is more pronounced in pavement where high traffic densities promote narrow channeling within a wheelpath. This causes a distinct transverse variation in friction, being lower at the wheelpath centerline where the most polishing occurs, and being higher away from the center of the wheelpath where fewer applications occur.

The friction of a pavement varies longitudinally as well. Even though a paving construction section is thought to be homogeneous in age, design, materials, and construction procedures, considerable variability can exist throughout a new improvement. For example, the final texturing in a PCC pavement can vary appreciably, depending on available mortar and the time the texturing is done. Likewise, variability in asphalt contents and segregation of aggregates in bituminous mixes can affect both microtexture and macrotexture longitudinally along the surface.

Excess asphalt content accelerates void closure and wheelpath flushing. Where asphalt completely fills the voids and becomes a part of the surface, skid numbers are lowered considerably. This occurred on the Stevenson Expressway at California Avenue where the inbound outer lane slag surface is subjected to heavy truck traffic. Here, the SN is 33 as compared to 48 for the same mix in the outbound inner lane, which carries only passenger cars.

In urban areas, lower operating speeds allow longer-duration interactions between each vehicle and the pavement surface. As a result, consolidation of a bituminous surface is accelerated over that which takes place along a rural open highway. Consolidation results in loss of macrotexture. Friction losses progressively increase closer to the stop line of an intersection with traffic control. Highways that regularly experience stopping, standing, and starting traffic, can lose their macrotexture early unless some adjustment is made in the mix design.

HOW MUCH FRICTION IS NEEDED?

NCHRP Report 37 contains detailed discussions of frictional needs of traffic. Tentative recommended minimum requirements were developed. The values were based upon the normal frictional needs of traffic as derived from driver behavior studies.

The variability in frictional needs associated with different vehicle maneuvers can be seen in the following tabulation:

Vehicle Maneuver	Normal Frictional Needs
Constant-speed driving	7-10
Cornering	14
Accelerating from low speed	10-40
Accelerating to pass	28-36
Cornering and braking	36
Cornering and accelerating	36
Deceleration to full stop	39

These data suggest that SN near 40 apparently satisfies the frictional needs of all normal vehicle maneuvers during acceleration, driving, cornering, and deceleration, and does so over a wide speed range (except toward the end of braking maneuvers leading to a full stop).

The data also show that some roadway sections need far less friction than others to prevent skidding accidents. Interstate driving normally requires less friction demand than driving on the primary system because Interstate traffic conditions typically do not require braking and acceleration. On the Interstate, constant-speed driving and cornering are the main vehicle maneuvers. Urban and Metropolitan Interstate, on the other hand, have a higher friction demand than rural Interstate because of more erratic traffic flow and weaving maneuvers resulting from closely spaced interchanges and peak-hour volumes exceeding roadway capacity. These conditions sometimes involve cornering, accelerating, and decelerating vehicle maneuvers.

Unlike the Interstate system, the primary system involves the full range of vehicle maneuvers, which means normal friction demand will be even higher. The level of friction needed, however, will depend upon whether alignment is generally straight or curvilinear, whether the terrain is flat or hilly, whether curvature is uniform, whether traffic volumes are light or heavy, whether access volumes are heavy, etc. Lightly travelled rural roads obviously will have a lower demand than heavily travelled urban roads with a high percentage of vehicles entering and leaving the traffic stream.

So, in one place an SN of 20 may be ample while in another place an SN of 40 may be insufficient. Research has reasonably well documented that skid numbers at specific sites do not correlate well with wet-pavement accident rates; yet, general trends do exist. Adopting a uniform frictional level may be desirable where an economical supply of skid-resistant aggregates is abundant, but it is impractical in a State where most of the aggregate supply is predominantly soft carbonate rock.

Circumstances suggest that it is neither practical nor economically feasible to provide uniformly high pavement friction on all roadways. Friction demand varies continuously. The supply of locally available, hard, durable, skid-resistant aggregates is limited. Inflation and the lack of funds curtail the number of improvements that can be undertaken. A policy plan which concentrates on achieving a uniform risk rather than uniform friction seems reasonable. The policy would require that locally available materials be used at historically safe sites while high-type skid-resistant aggregates be used at sites prone to wet-weather skidding accidents.

Of all the vehicular accidents reported in Illinois, approximately 20 percent occur on wet pavement while 14 percent actually occur during rainfall. Using 1976-1978 accident data, a tabulation of personal injury accidents on wet pavement was made by highway district and by rural and urban highway class. The results of this analysis (Table 1) indicate that almost two thirds of the accidents occurred in District 1, which includes the Chicago Metropolitan Area, where travel exposure is the highest in the State. In District 1, accidents occur most frequently on urban highways (37.1 percent), followed to a lesser degree by city streets (15.2 percent), and by urban Interstate (5.1 percent). This pattern generally holds true downstate. Conversely, accidents occur least frequently on the rural

TABLE 1

ILLINOIS WET-PAVEMENT INJURY ACCIDENTS, 1976-1978 (Percent)

Roadway Classification	District									True Total
	1	2	3	4	5	6	7	8	9	
Urban Primary	37.1	4.0	1.4	2.7	1.7	1.2	0.6	3.3	0.6	52.6
City Streets	15.2	2.8	0.9	2.1	1.7	1.5	0.3	2.0	0.3	26.9
Rural Primary	1.9	1.2	1.0	0.7	0.7	1.0	0.6	1.2	0.8	9.1
County Roads	1.0	0.8	0.8	0.4	0.4	0.6	0.4	0.6	0.4	5.3
Urban Interstate	5.1	-	-	0.1	0.1	-	-	0.2	-	5.5
Rural Interstate	0.1	0.1	0.1	-	0.1	-	0.1	0.1	-	0.6
True Total	60.4	8.9	4.2	6.0	4.7	4.3	2.0	7.4	2.1	100.0

Interstate system where vehicle conflicts are a minimum and where driver friction demands normally are lowest.

In addition to knowing where accidents are occurring, a cursory assessment of their risk by separate highway classification can be gained from the percent of total personal injury accidents occurring on wet pavement. Using 1976-1979 accident data, a tabulation of total injury accidents on wet pavements was prepared by district and by rural urban highway class. Since each highway class is exposed to the same wet time within a geographical area, the percent of total accidents on wet pavement by highway class should give an indication of the relative risk associated with that highway class.

As Table 2 indicates, the percent of personal injury accidents on wet pavement ranges widely from a low mean value of 9 percent for rural Interstate to a high mean value of 25 percent for urban primary. A significant urban-versus-rural pattern exists throughout the State. For example, the percentage of accidents on wet pavement is greater on urban than on rural Interstate routes, is greater on urban than on rural primary routes, and is greater on city streets than on county roads. The evidence clearly establishes that the risk of accidents on wet pavement is higher in urban than in rural areas.

Geographically, variation among districts seems to be associated strongly with travel exposure. District 1, which has the highest percentage of wet-weather accidents, has the highest travel exposure, while Districts 2, 4, and 8, which encompass large urban centers, generate slightly smaller percentages. Regardless of highway class, the risk of

TABLE 2

PERCENT OF TOTAL INJURY ACCIDENTS ON WET PAVEMENT 1976-1979

Roadway Classification	District									Mean
	1	2	3	4	5	6	7	8	9	
Urban Primary	26	24	22	25	22	21	21	22	24	25
City Streets	20	20	16	18	18	18	17	18	16	19
Rural Primary	20	17	16	18	16	17	19	19	20	18
County Roads	15	12	12	12	13	13	15	14	15	14
Urban Interstate	22	14	11	16	10	8	14	15	13	20
Rural Interstate	11	8	9	10	9	6	8	10	7	9
Mean	24	20	18	20	18	18	18	19	17	21

accidents on wet pavement tends to increase as average daily traffic increases.

Another factor associated with average daily traffic and accidents is the number of vehicles entering and leaving the roadway, expressed as a percent of hourly traffic volume. For a rural highway, a high access density ranges between 15 and 30 percent, while that for an urban primary highway is above 40 percent.

In summary, wet-pavement accidents tend to cluster at comparatively few sites along the most heavily travelled highways and streets in any area. As previously indicated, the preponderance of wet-pavement accidents in Illinois happen in the Chicago Metropolitan area.

Because the frictional need varies significantly by roadway class and by area, it seems reasonable to suggest that friction improvements would be most beneficial, first on urban primary and urban Interstate, city streets, rural primary, county roads and, lastly, rural Interstate.

The relative likelihood that a surface will become the site of repeated wet-pavement accidents can be illustrated by relating the SN at an accident site with corresponding values from representative roads in the same area. This procedure serves as the methodology for this evaluation.

A relative frequency distribution of low friction numbers associated with 857 high-accident sites is compared with that for a stratified sample that proportionately represents bituminous (limestone, dolomite, and crushed gravel) and portland cement concrete pavement in Illinois (Figure 4). As the figure reveals, the two distributions differ significantly. The mean SN for the accident sites is 26 as compared to 38 for the

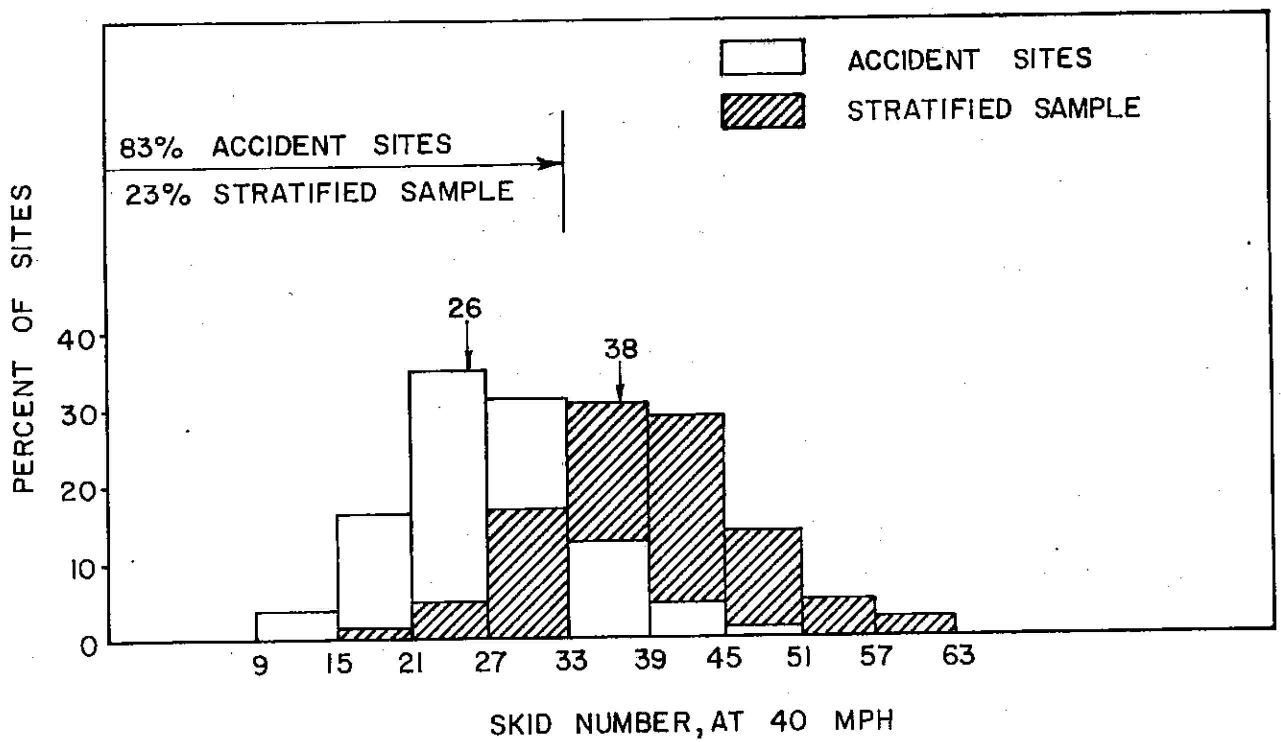

Figure 4. Relative Frequency of Low SN at Accident Sites Compared with SN of Stratified Sample

stratified sample. Eighty-three percent of the accident sites as compared to 23 percent of the stratified sample have SN values below 33.

Using the distribution in Figure 4, a relationship between SN and relative risk of a surface becoming the scene of repeated wet-pavement accidents can be derived using the ratio of the percent of accident sites in each SN cell to the corresponding percentage from the stratified sample. The resulting curve is shown in Figure 5.

While a surface having an SN above 50 may be, by chance, the scene of wet-pavement accidents, the risk of it being the scene of repeated wet-pavement accidents is quite small. This risk becomes measurable when the SN is between 45 and 50, and increases by 20 times when the SN equals 30, and exceeds 200 times when the SN is 18. The relative risk values for the various SN's shown in Figure 5 apply only to intersections, curves, railroad crossings, interchanges, ramps, etc., which are the places where disproportionate numbers of wet-pavement accidents have occurred and are most likely to occur.

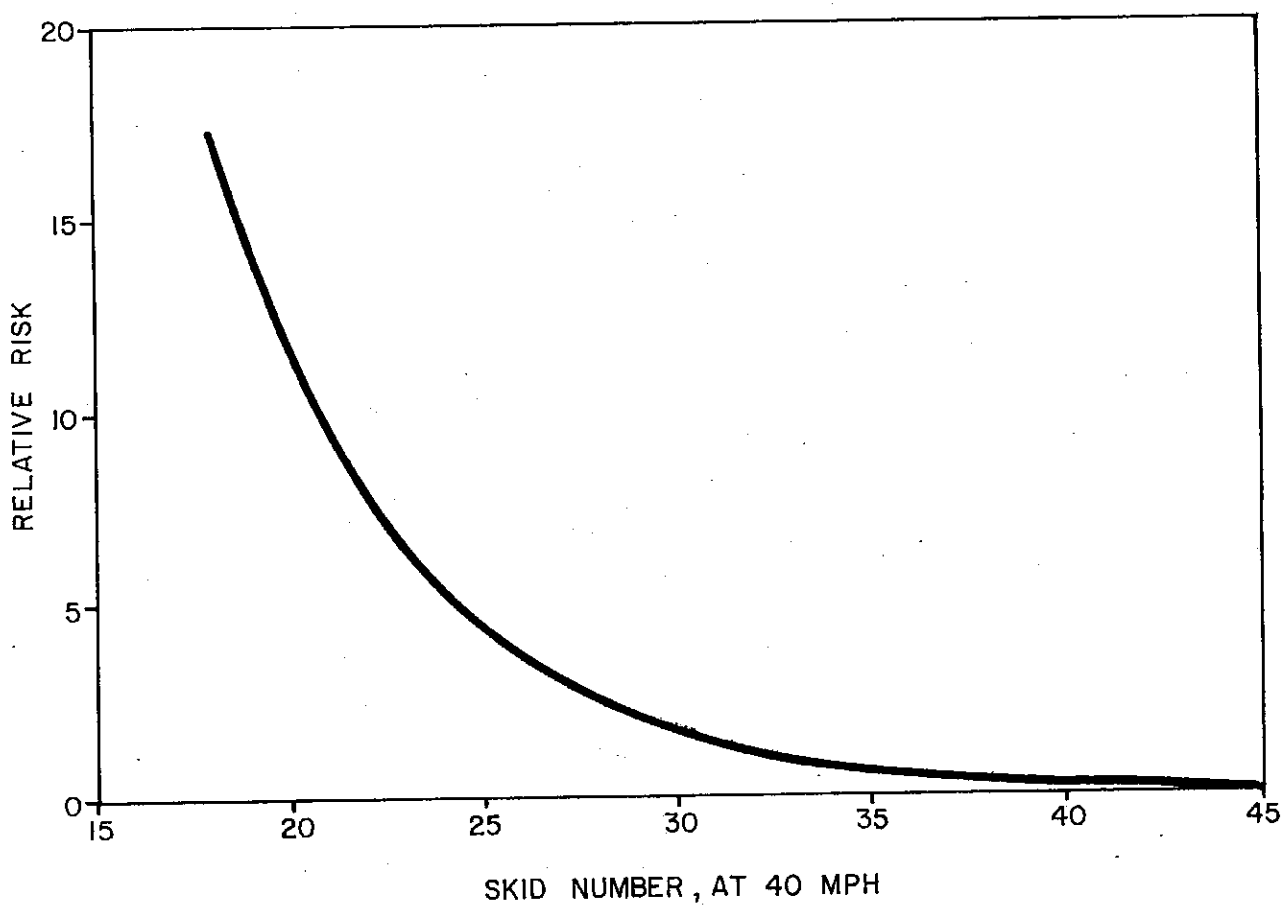

Figure 5. Skid Number versus the Relative Risk of a Surface Becoming the Scene of Repeated Wet-Pavement Accidents

CHAPTER 4

PROGRAM OPERATIONS AND ACCOMPLISHMENTS

FIELD TEST PROGRAM

In FY 1981, the Bureau of Materials and Physical Research entered into an agreement with the Division of Traffic Safety to conduct a friction inventory of Interstate highways and to make the tests at selected high-accident locations under a Highway Safety Project entitled "Identification of Slippery Pavement." Results of the Interstate skid-test program are discussed in the next subsection.

Experience with the Interstate Inventory Program was not good. Low skid numbers were found in some locations, but the low SN's were not sufficient evidence to indicate whether or not a specific place along the road will or will not be the site of a disproportionate number of wet-pavement accidents. Consequently, plans for continuing the systematic and routine inventorying of the entire highway and street network were discontinued in 1981.

Since 1981, skid-test inventories were conducted following the guidelines in the skid-accident reduction policy statement and, eventually, following the guidelines of Department Policy TRA 16.

TRA 16 requires that skid tests be conducted at selected high-accident locations, on cluster sites within rehabilitation/resurfacing projects, on randomly selected new construction projects, and on previously tested new construction projects.

INTERSTATE FRICTION INVENTORY

The Interstate inventory was conducted during October and November in 1980 and April through June in 1981. Measurements were made at 0.5-mile intervals on tangents and at 0.2-mile intervals at curves, bridge decks, and lane-change areas. In some urban areas with closely spaced interchanges, tests were made at 0.1-mile intervals. Overall, nearly 9000 brake lockups were made along the 3200 lane-miles of pavement. This translates into approximateLy three tests per mile. The resulting skid numbers were tabulated by direction and by surface type (bituminous or PCC) for each Interstate route.

LaCroix(2) summarized the overall friction profile of each route inventoried as follows:

I-24 - Surface mainly PCC with SN's in the high 50's to the low 60's. The lowest SN (50) was a bituminous bridge deck.

I-55 - Both PCC and bituminous surface represented, with 70 percent of SN's above 36, 15 percent between 30 and 36, and 15 percent below 30. Of those tests below 30, 95 percent were north of Channahon where ADT ranges from 28,000 to 130,000.

I-57 - Mainly PCC surfaces, except for bituminous surfaces in the Chicago area, 96 percent of SN's over 36, 3 percent between 30 and 36, and 1 percent below 30. The below 30 values occur mainly north of the Kankakee River.

I-64 - Except for bituminous bridge decks, the surface is PCC with SN's mostly in the high 40's to low 50's and with some bridge decks in the 30's.

I-70 - Both PCC and bituminous surfaces represented, with 96 percent of the SN's over 36, 2 percent between 30 and 36, and 2 percent below 30. Most of the below 30 SN's are on bituminous surface between MP 64 and 67.

I-72 - Mostly PCC surface with SN's in the 50's and with some bituminous bridge decks in the 30's and 40's.

I-74 - Both PCC and bituminous surface represented, with 93 percent of SN's above 36, 6 percent between 30 and 36, and 1 percent below 30. Bituminous bridge decks account for most of below 30 measurements.

I-80 - Both PCC and bituminous surfaces represented, with 27 percent of SN's above 36, 64 percent between 30 and 36, and 9 percent below 30. Bituminous bridge decks account for most of the below 30 SN's.

I-94 - New PCC, all SN's 40 or better.

I-180 - PCC pavement except for bituminous bridge decks. All SN's above 36.

I-270 - Mainly PCC pavement with SN's in the 40's. Two bituminous bridge decks had SN's below 30.

I-280 - Mostly PCC pavement, with SN's above 36, except for 12 bituminous bridge decks below 30.

I-290 - Bituminous pavement from Kennedy and Ryan Expressway to Tollway has SN's ranging from high teens to low 20's. From Tollway to Irving Park Road, SN's range from high 20's to low 30's. From Irving Park Road to Tollway, SN's range in the 30 to 36 range, with some tests above 40.

I-474 - Pavement mainly PCC, with SN's in the upper 50's. No test below 39.

In summary, most of the Interstate mileage has adequate skid resistance. Low skid resistance occurred most frequently along Chicago Metropolitan Area expressways, which are the most heavily travelled routes in the State, and at bridge decks having bituminous surfaces. Even though a number of isolated places along the Interstate were identified as having low skid resistance (SN below 30), those low values by themselves were not necessarily sufficient evidence to indicate whether or not a specific place along the roadway will or will not be the site of a disproportionate number of wet-pavement accidents.

ROUTINE SKID INVENTORY

The yearly routine skid-test program requires testing of high-accident sites, cluster sites, new construction projects, and reruns of previously tested new construction. Standard skid numbers for selected high-accident sites and cluster sites are supplied to the Districts for use in determining cost-effective treatments for specific locations. The remaining data are collected as part of the feedback system.

Feedback from the field testing program and analysis to evaluate program effectiveness closes the loop in the management process of the Illinois Skid-Accident Reduction Program. A key factor in implementing the process occurred in 1983 when a skid-number data base was established for filing test results obtained from skid testing of new construction projects.

SN DATA BASE

Late in 1983, the Bureau of Materials and Physical Research established a skid-number data base. So far, it contains information about 231 newly constructed rural and urban pavements, beginning with nine projects constructed in 1980. In addition to skid-test results, the data base contains general project information, ADT values, mix design properties, and fine and coarse aggregate information.

A summary tabulation of the number of projects tested by year constructed, by surface type and by area (rural or urban), is presented in Table 3. As the table indicates, the projects are reasonably well distributed between rural and urban areas. However, bituminous surfaces prevail, with Class I Dense-Graded Bituminous Surface Course, Mixture D, by far being the most commonly constructed surface, followed by Mixture C and Mixture E. At this time, only eight portland cement concrete surfaces are included in the data base. Of the 1983 construction projects submitted, one half (92) were selected for testing. Since only 15 projects were tested late in 1983, the remaining 77 are scheduled for 1984, along with follow-up testing of certain previously tested projects.

Preliminary analysis of projects constructed during 1981 indicated that a wide disparity in skid number existed between rural and urban projects. This also was true for 1982 construction, although not as great. For Class I bituminous surfaces, Mixture D with up to 3 million axle applications, rural projects averaged 48 while urban projects averaged 36, a difference of 12.

TABLE 3

SUMMARY OF NEWLY CONSTRUCTED SURFACES TESTED FOR SKID RESISTANCE IN RURAL AND URBAN AREAS

Surface Type (MISTIC Code)	Year Constructed 1980 Rural	1980 Urban	1981 Rural	1981 Urban	1982 Rural	1982 Urban	1983 Rural	1983 Urban	Total Rural	Total Urban
Class I Mixture C (17503)	--	--	1	2	13	9	--	--	14	11
Class I Mixture D (17504)	3	5	21	26	64	46	10	4	98	81
Class I Mixture E (17505)	1	--	--	--	4	4	--	--	5	4
Plant Mix, Class B (17601)	--	--	1	--	4	--	--	--	5	--
Plasticized Bituminous Hot-Mix Seal (18109)	--	--	--	--	--	1	--	--	--	1
Open-Graded Friction Course (18301)	--	--	1	1	--	--	1	--	2	1
Bit. Mix Special No. 1 - Passing	--	--	--	--	--	1	--	--	--	1
Portland Cement Concrete (21601)	--	--	1	--	6	1	--	--	7	1
Total Projects	4	5	25	29	91	62	11	4	131	100

Portland cement concrete surfaces also suggest similar trends, although the data are limited. The average SN of one urban project was 40 as compared with a 52 to 62 SN range for seven rural projects.

The factors contributing to disparity between rural and urban surfaces have not been clearly established, but two separate interacting phenomena are suspected. One has to do with consolidation of a bituminous mixture and the other with aggregate polishing. Slower travel speed on urban roadways subject the surface to longer duration vehicle vibrations, thus causing more consolidation in urban than in rural bituminous surfaces. This effect, as evidenced by wheelpath rutting, is more pronounced at signalized and stop intersections where more stopping, starting, and standing take place than elsewhere. In this situation, the coarse aggregate becomes depressed so that the coarse aggregate's contribution to microtexture is lessened. The worst situation results when wheelpath flushing occurs. Here the contribution of both fine and coarse aggregate to microtexture is minimal. This explanation, however, does not account for lower skid resistance in urban than in rural areas where the coarse aggregate is not depressed into the surface.

The other phenomenon is simply higher aggregate polishing. For similar traffic volumes, urban sections will experience more polishing actions, such as acceleration, deceleration, and turning movements than will rural sections. Correspondingly, this higher polish results in a lower level of skid resistance in urban than in rural areas. The polishing process is continuous, affecting all surfaces, whereas the effect of the consolidation process is limited to some but not all projects.

TREADED VERSUS SMOOTH TEST TIRE

A working relationship between treaded-tire results and smooth-tire results has long been sought. The treaded-tire results provide a good evaluation of microtexture even on fine-textured surfaces. The grooves provide drainage passages, allowing water to escape, and thus allowing the tire to maintain contact with the pavement surface. Smooth-tire results are sensitive to both micro and macrotexture because the tire has no drainage capabilities.

Results of skid tests made with both tires on a variety of surfaces show that when a surface has little macrotexture the measurements differ by as much as 30 SN's. When the surface has good macrotexture, the smooth-tire numbers approach and sometimes slightly exceed treaded-tire numbers.

Dierstein[3] evaluated surrogate texture-depth indicators in 1982. Sand patch texture-depth measurements were compared to the following seven indicators:

1. Treaded-tire skid number-speed gradient (SN_tG)
2. Smooth-tire skid number-speed gradient (SN_sG)
3. Percent treaded-tire skid number-speed gradient (PSN_tG)
4. Percent smooth-tire skid number-speed gradient (PSN_sG)
5. Smooth-tire skid number (SN_s)
6. Treaded-tire less smooth-tire skid number (SN_{t-s})
7. Macrotexture Index: which is defined as the ratio of the difference to the sum of a treaded tire and a smooth tire skid number plus 1, which eliminates negative values $\frac{SN_t - SN_s}{SN_t + SN_s} + 1$

Of the seven indicators, only four (items 4, 5, 6, and 7) correlated well with sand patch texture depth. Moreover, all four indicators had about the same standard error of estimate (3 to 4 mils) in predicting texture depth. From the viewpoint of predictability and test efficiency, the Macrotexture Index (MTI), based on limited data, showed the greatest promise. Among the indicators studied, MTI was the best predictor of texture depth when applied universally to all types of surfaces and over a wide range of friction (Figure 6). Even though some anomalies, attributed in part to the texture-depth measurements themselves, may occur, the index can differentiate with a high degree of certainty whether a surface has a fine, a medium, or a coarse texture. Mathematical calculations can be eliminated through the use of the nomograph shown in Figure 7. A tentative relationship between MTI values and a corresponding range of sand patch texture-depth values (ASTM E 965-83) are listed below.

Subjective Rating of Macrotexture	MTI	Sand Patch Texture-Depth Range
Coarse	Below 1.01	0.041 and greater
Medium	1.01 - 1.20	0.020 - 0.040
Fine	Above 1.20	0.019 - 0.009

A properly constructed open-graded friction course (OGFC) would be representative of coarse texture, while a well-worn PCC surface or a flushed Class I surface would represent fine texture.

LABORATORY COARSE AGGREGATE EVALUATION

Ever since greater restrictions have been imposed on aggregate producers to improve skid resistance in bituminous concrete mixtures, the pressure for more information about the friction characteristics of individual sources has intensified.

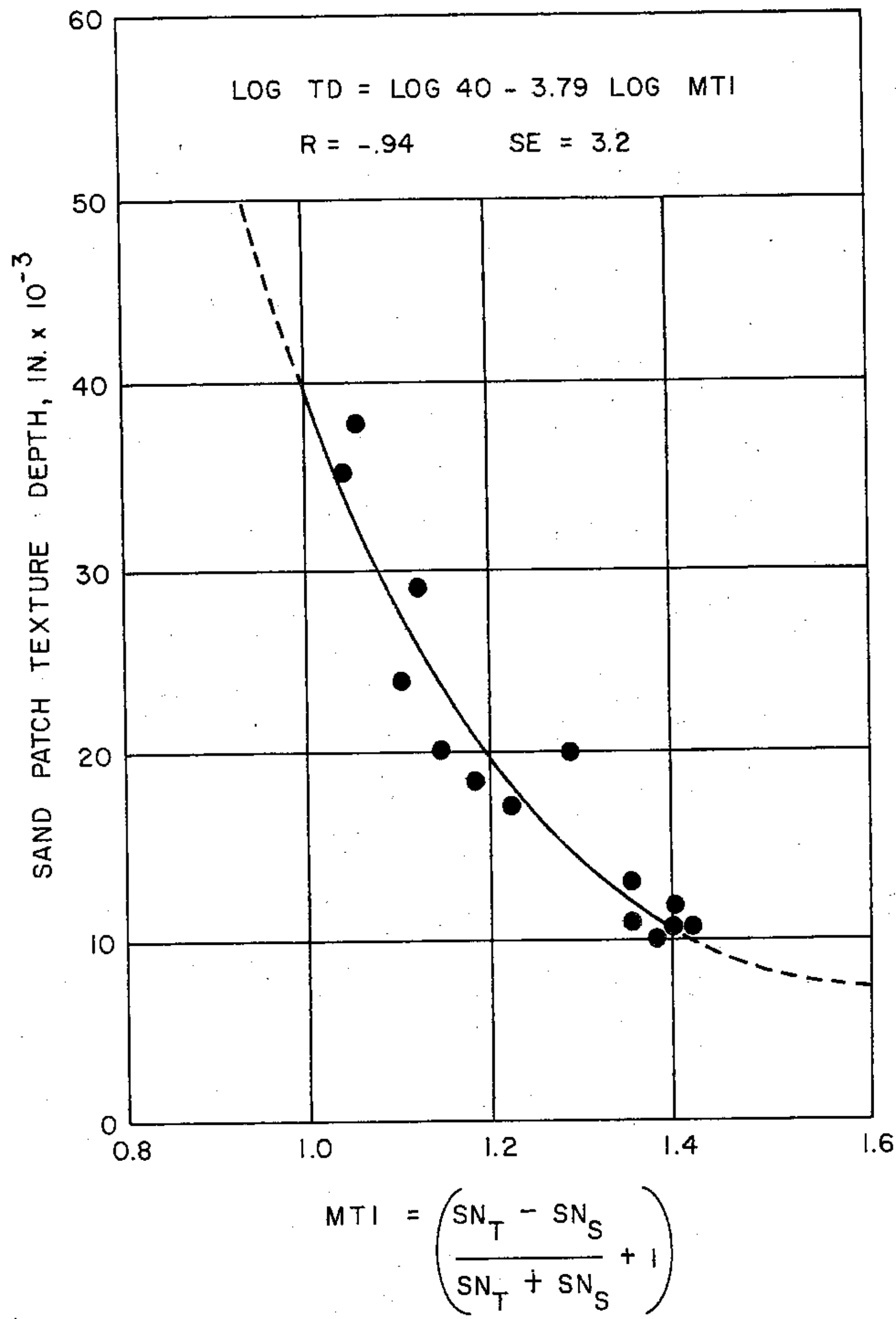

Figure 6. Texture Depth versus Macrotexture Index

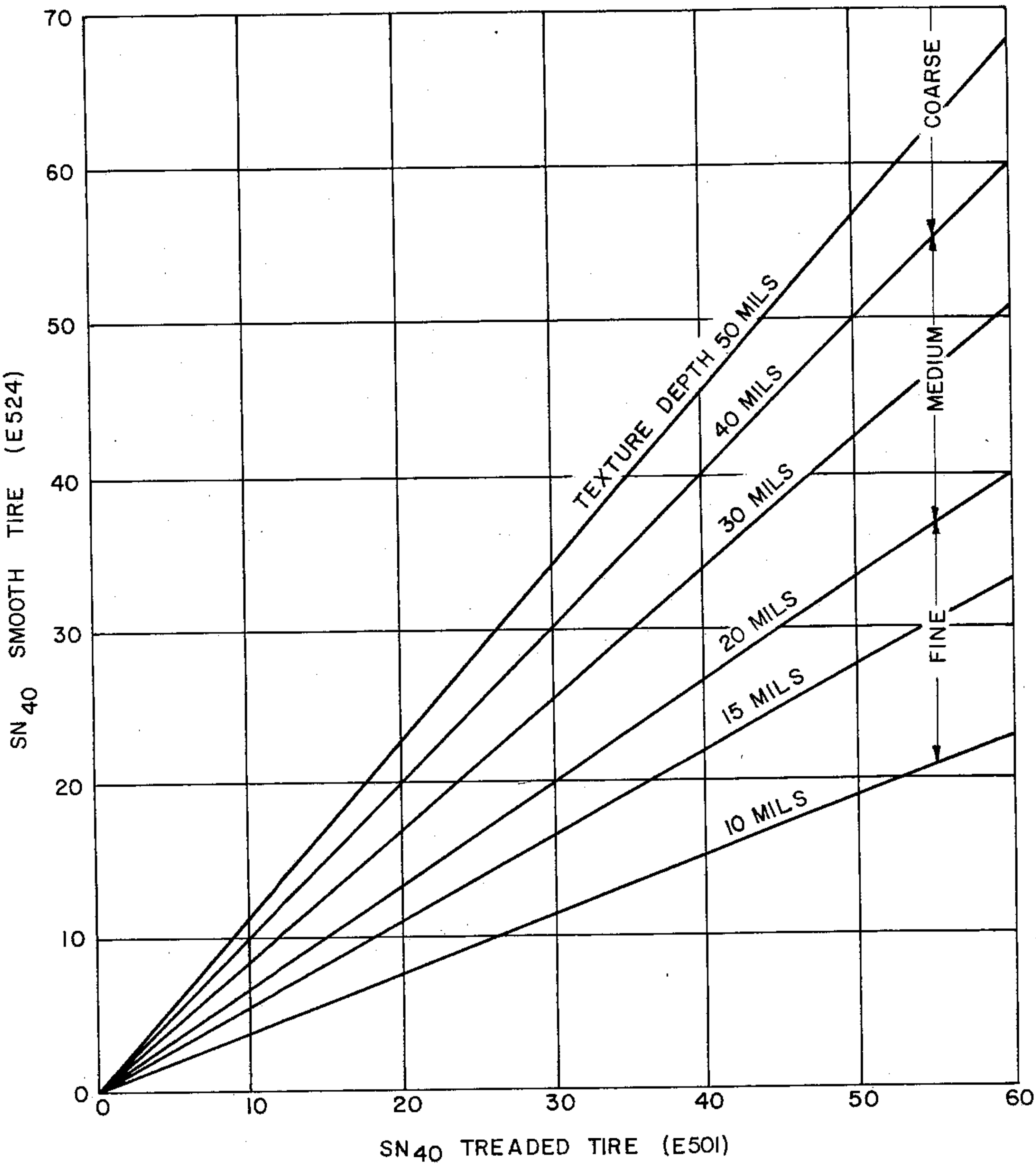

Figure 7. Texture-Depth Nomograph

As a refinement to the current petrological classification, the Illinois Department of Transportation has undertaken a laboratory investigation in an attempt to rank aggregate sources according to their friction characteristics. Laboratory wear and polishing characteristics of ranked aggregates will be related to the friction characteristics of bituminous surfaces containing ranked aggregates as the skid numbers become available. Ultimately, it is hoped that a family of skid number-wear curves can be developed. Then, the design policy established to control the use of the three Class I surface mixtures (C, D, and E) can be evaluated and modified, if necessary, based on a ranking of individual sources rather than on a broad petrological classification. This section looks at the equipment used in conducting the aggregate ranking investigation and presents the findings obtained thus far.

NORTH CAROLINA WEAR AND POLISHING MACHINE

A small-wheel circular track that accelerates the wear and polishing of aggregates on paved surfaces has been fabricated by the Bureau of Materials and Physical Research in Illinois. Construction of this device, which was developed at North Carolina State University, adheres to the applicable provisions of ASTM E 660, Accelerated Polishing of Aggregates or Pavement Surfaces Using a Small-Wheel Circular Track.

Aggregate polishing comes from the scrubbing action of four smooth pneumatic tires, which eliminates as much as possible the variables associated with tire-tread pattern wear. Each wheel can be adjusted for camber and for toe-in and toe-out to provide a scrubbing action for

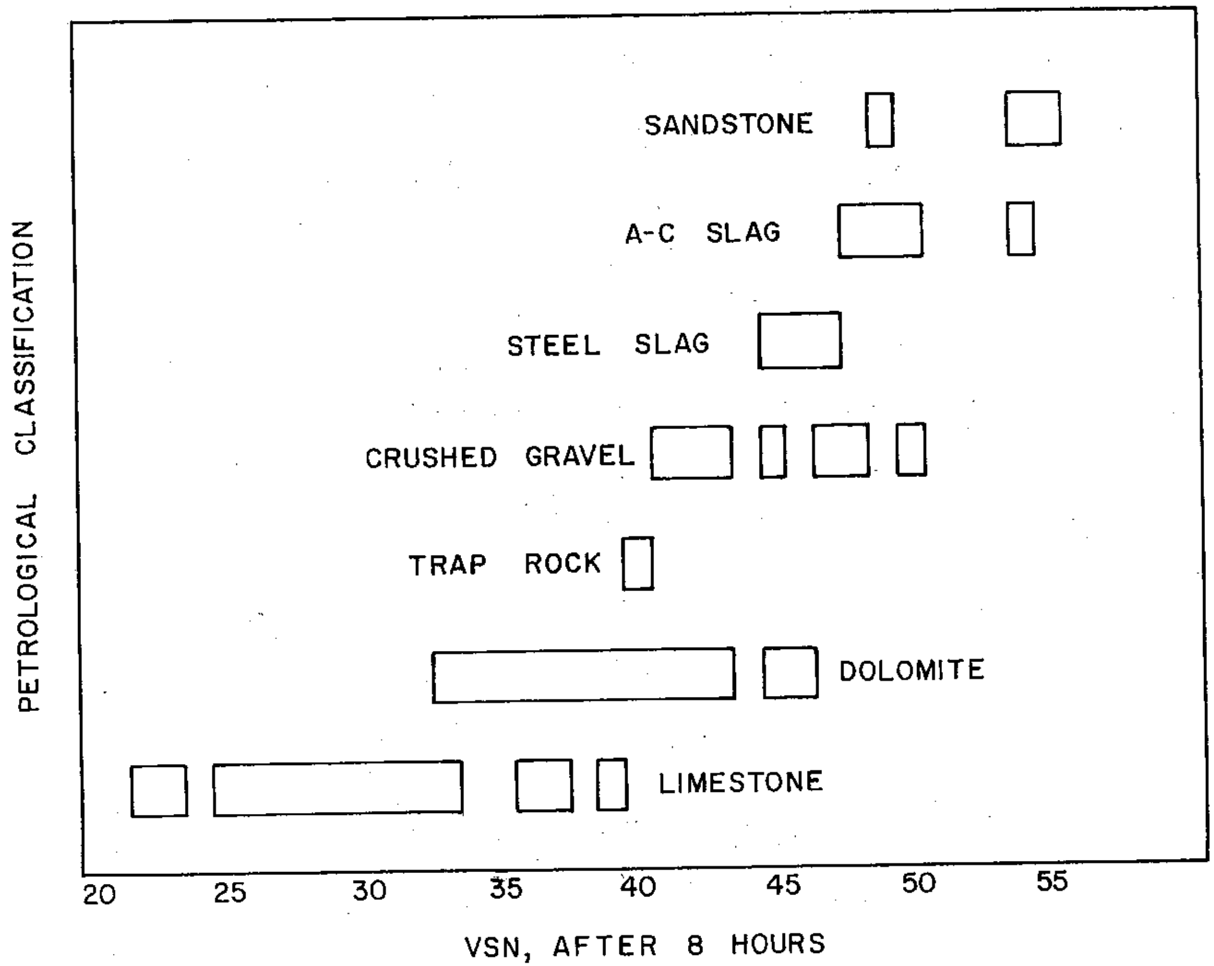

Figure 8. Range of Terminal Polish Values for Aggregates by Petrological Classification

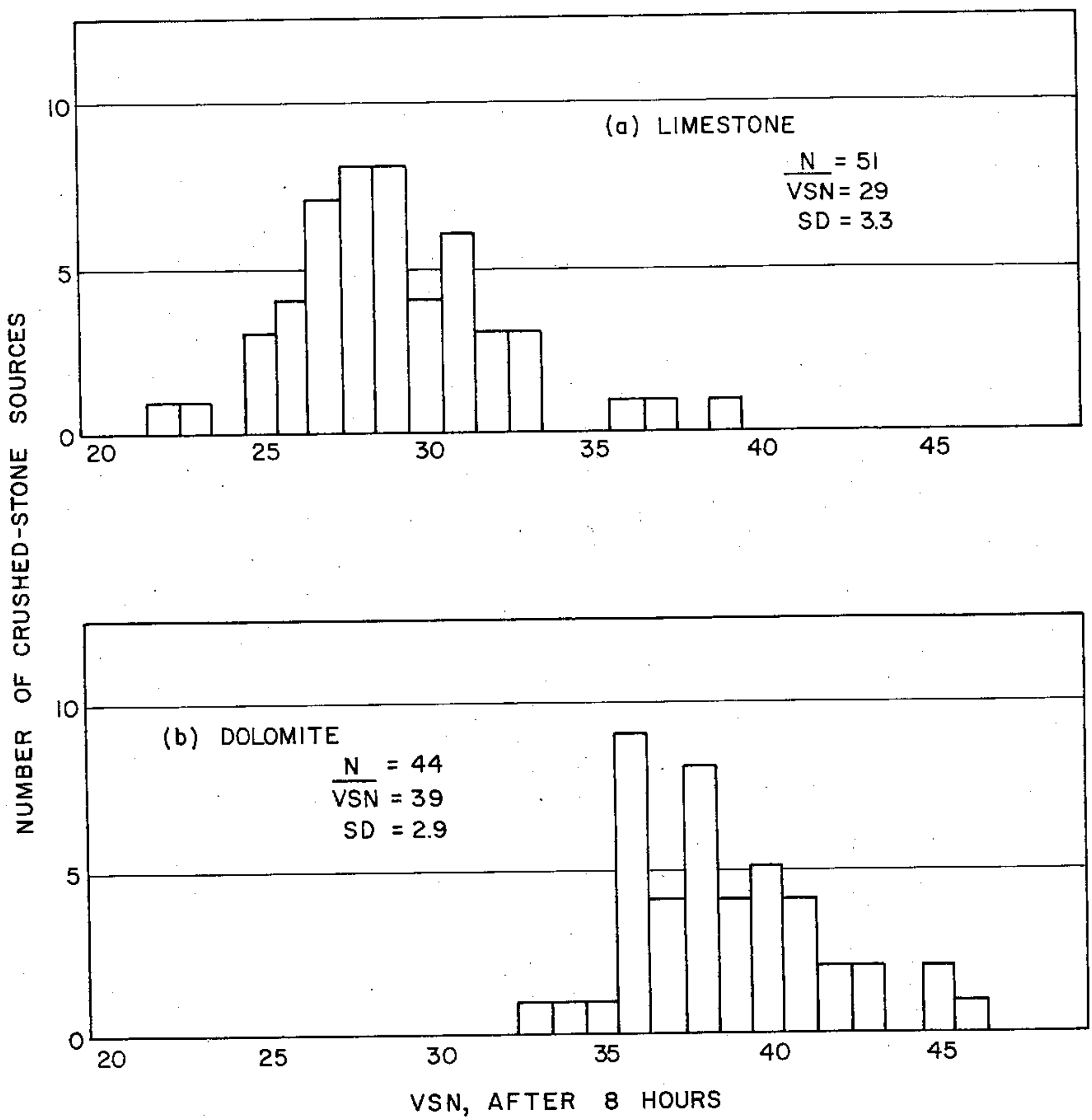

Figure 9. Polish Values for Crushed Stone Sources

accounts for its having a much higher VSN than the normal fine-grain limestone commonly found in southern Illinois.

Referring back to Figure 8, trap rock, a hard fine-grain aggregate from Iron Mountain, Missouri, produced results similar to mid-range dolomites. The crushed-gravel sources contain more siliceous than carbonate rocks, accounting for their higher values. Novaculite (VSN 50) is the best gravel source and usually provides skid numbers in the 50's.

As for slag sources, their VSN's range from a low of 45 to a high of 54. These results indicate that the steel slag sources (VSN 45-47) polished slightly more than the air-cooled blast furnace slag (VSN 48-54). Under the circular track's wear and polishing process, air-cooled slag, because of its vesicular nature, has a better polishing resistance than steel slags. This fact accounts for its VSN being somewhat higher than that for steel slag, which is a dense material more prone to polishing. Slags can be quite variable, and this variability can be affected by the grade of the iron ore, the cooling process, and the use of additives, which can control porosity.

Two sandstone sources, one from Illinois and the other from Kentucky in the Ohio River Valley just north of Paducah, provide excellent friction characteristics. The Kentucky sandstone gave the highest VSN (55) of any aggregate sources tested thus far. These sandstones also meet the LA Abrasion requirements for aggregates used in Class I Dense-Graded Bituminous Surface Course.

POLISHING CURVES

Examination of typical polishing curves for various Illinois aggregate sources can provide further insight into the mechanism of polishing. A family of polishing curves comprising limestone, dolomite, steel slag, air-cooled blast furnace slag, novaculite, and sandstone sources, are shown in Figure 10. As the figure indicates, most of the polishing occurs in the first hour, and by the end of 3 hours the specimens are close to their terminal VSN, which is achieved after 8 hours of exposure.

The ranking of typical sources according to their polishing characteristic suggests that VSN is associated with hardness. Limestone, which has a Moh's hardness of 3, had the lowest VSN while sandstone, which has a hardness of 7, had the highest VSN. Correspondingly, the intermediate sources fit appropriately between the two extremes.

In Figure 10 it can also be seen that there is a relationship between initial (unpolished) VSN and terminal VSN. The higher the initial VSN, the less difference between initial and terminal VSN. A regression analysis of the data from 112 sources yielded the following relationship:

$$\text{VSN (terminal)} = 1.36 \text{ VSN (initial)} - 33$$

with highly significant correlation coefficient of 0.93.

The accelerated polishing of aggregates using a small-wheel circular track appears to be an excellent way of prequalifying and ranking aggregate sources relative to their expected friction characteristic. In the future it may be possible to customize mix designs based on VSN for the most economical use of aggregates with good friction characteristics.

EVALUATION OF NEW MATERIALS, BLENDS, AND MIXES

Illinois DOT has had a varied and ongoing program of field experimentation directed toward upgrading the friction characteristics of its pavements. Experimentation has included studies of aggregates, mixture

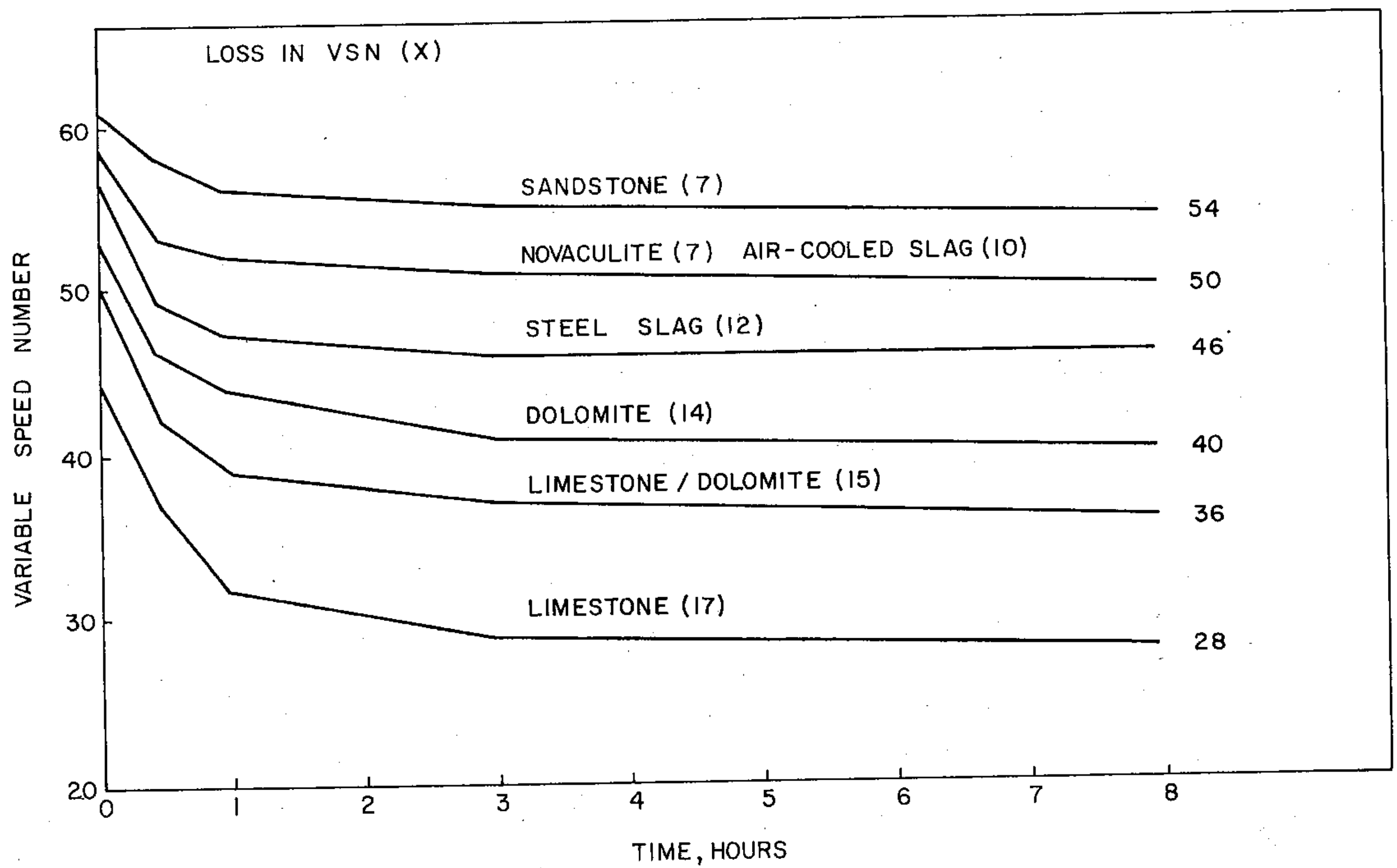

Figure 10. Typical Polishing Curves for Illinois Aggregates

designs, new pavement types, surface texturing of PCC pavements, and other items as well.

As new features have been introduced into practice, evaluations of service performance have provided assurance that the innovations are serving as intended or have led to necessary revisions.

CLASS I DENSE-GRADED BITUMINOUS CONCRETE SURFACE COURSE

Most of the experimentation and performance evaluation work Illinois has done to improve friction quality was, and still is, concerned with Class I bituminous concrete surface course mixtures. Most of the work in this area focuses on the coarse aggregate component.

Mixture D - Contractors constructing Mixture D surfacings have made increasingly more use of slag/limestone blends, crushed-chert gravel, and crushed gravel/dolomite blends than previously.

Slag/Limestone - Slag was first used in a 50-50 blend with limestone on 3 projects in southwest Illinois in 1977. Steel industry representatives were encouraging highway engineers to accept slag as a competitive aggregate for bituminous surfacings. Results of skid tests made on the 3 sites between 1977 and 1981 are shown in Table 4. Initial results were encouraging and led to further experimentation.

Since 1980, a sufficient number of Mixture D surfacings containing slag/limestone blends have been tested so that a wear curve could be determined for roadways in rural areas. Similarly, a sufficient number of Mixture E surfacings containing air-cooled blast furnace slag have been tested so that a wear curve for rural roadways also could be determined. A comparison

TABLE 4

SKID RESISTANCE OF CLASS I SURFACE COURSE, MIXTURE D
50-50 STEEL SLAG/LIMESTONE IN DISTRICT 8

Location	Year Completed	ADT	SN Test Dates	AVG. SN in Traffic Lane
Ill. 159 (south Collinsville to I-64 - 50 percent steel slag/50 percent limestone)	1977	12,200	8-77 6-78 7-79 7-80	49 35 31 32
Collinsville Beltline (50 percent steel slag/50 percent limestone)	1977	10,000	7-79 6-80	36 33
Ill. 177 (Hoyleton to New Mindin - 50 percent steel slag/50 percent limestone)	1977	1,150	9-81	53

of these two curves as well as one for limestone can be seen in Figure 11. As can be seen in the figure, the curve for slag/limestone blend, with skid numbers ranging mainly between 35 and 45, lies between the slag and the limestone curves. The slag/limestone blend tends to behave more like a slag mix than a limestone mix, but it is approximately 10 skid numbers below the all-slag mix.

Crushed Gravel/Crushed Dolomite - During 1979, a Mixture D surface containing a 50-50 blend of crushed gravel and crushed was placed on I-74 from St. Joseph to east of Urbana. The average daily traffic on this segment of Interstate is 13,000. The results of friction tests taken from October 1979, when the surface was new, through July 1982, are given in Table 5. After 3 years of service, the treaded-tire skid numbers remain in the upper 40's. Corresponding smooth/treaded-tire measurements taken during 1980 imply that the surface provides a medium macrotexture. As long as the average daily traffic along this segment of Interstate remains the same, the skid numbers probably will remain in the 40's.

Subsequently, in 1980 a Mixture D experimental feature project was constructed on I-70 (ADT 10,900) from the State Line to Ill. 1. The project contained three variables:

a. 50-50 blend crushed gravel and Lehigh dolomite

b. 50-50 blend crushed gravel and Newton dolomite

c. 100 percent crushed gravel

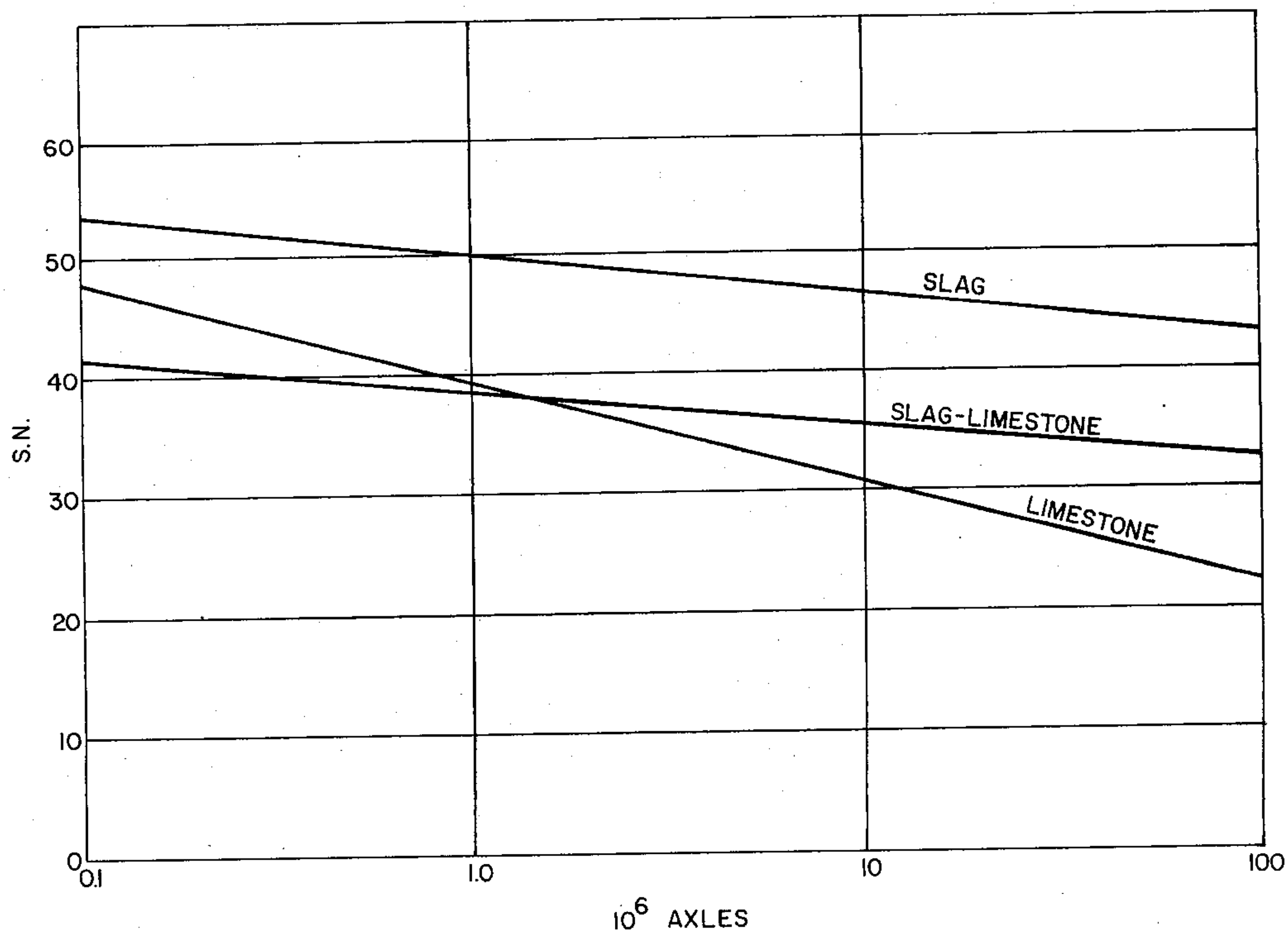

Figure 11. Wear Curves for Slag, Limestone, and Slag/Limestone Blends

TABLE 5

SKID RESISTANCE OF CLASS I SURFACE COURSE MIXTURE D
CONTAINING DOLOMITE/CRUSHED GRAVEL COARSE AGGREGATE

I-74 East of Urbana to St. Joseph

Date Tested	Test Tire	Average SN_{40} in Traffic Lane
10-79	Treaded	52
5-80	Treaded	57
5-80	Smooth	50
10-80	Treaded	42
10-80	Smooth	34
4-81	Treaded	50
7-82	Treaded	48

I-70 State Line to Ill. 1

	Westbound		Eastbound					
	Mix 1		Mix 1		Mix 2		Mix 3	
Date Tested	Treaded	Smooth	Treaded	Smooth	Treaded	Smooth	Treaded	Smooth
10-80	45	45	49	50	49	53	50	51
6-81	44	31	47	30	45	28	47	33
9-82	40	--	42	--	42	--	44	--

Mix 1 - 50/50 Crushed Gravel - Lehigh Dolomite

Mix 2 - 50/50 Crushed Gravel - Newton Dolomite

Mix 3 - Crushed Gravel

The results of friction tests on I-70 also can be seen in Table 5. After 2 years of service, the skid numbers of these surfaces are in the low 40's, with no significant difference in skid resistance among the three mixtures. Smooth-tire skid tests initially indicated a medium-to-coarse-textured surface, which is typical of new Class I surfaces. However, subsequent test results indicate that traffic consolidated the surface, causing a marked reduction in drainage (macrotexture) from the initial measurement. For some unknown reason, the I-74 surface has better macrotexture than the I-70 surface.

Novaculite - Mixture D surfaces, containing novaculite (VSN 50) coarse aggregate, have been placed at a number of places in Districts 7 and 9. The results of skid tests for one project in District 7 and six projects in District 9 range in SN between 44 and 57.

Sulfur-extended asphalt cement - Sulfur-extended asphalt cement has been used in a Class I Mixture D surface, with dolomite as the course aggregate, to learn something about its performance characteristics before a shortage in asphalt cement becomes acute. This experimental feature was included as a part of a 1979 resurfacing project located in District 3 on Ill. 49 between US 24 and US 45. The Average Daily Traffic along this section of Ill. 49 is 1800.

A summary of skid-test results for the various test sections is listed in Table 6. As the table indicates, the projects contain 10 test sections, five northbound and five southbound.

TABLE 6

SKID RESISTANCE OF SULFUR-EXTENDED ASPHALT
RESURFACING OF ILL. 49 BETWEEEN US 24 AND US 45

Test Section	Direction	Bituminous Mixture	Average SN 1979	Average SN 1980
1	Northbound	Class I (Control)	47(6)	57(8)
2	Northbound	20% Sulfur 80% AC-10, Silicone	48(6)	60(2)
3	Northbound	30% Sulfur 70% AC-10, Silicone	48(8)	62(7)
4	Northbound	30% Sulfur 70% AC-5, Silicone	47(8)	59(6)
5	Northbound	40% Sulfur 60% AC-5, Silicone	47(8)	57(7)
6	Southbound	40% Sulfur 60% AC-5	44(5)	51(6)
7	Southbound	30% Sulfur 70% AC-5	42(8)	55(5)
8	Southbound	30% Sulfur 70% AC-10	43(6)	58(4)
9	Southbound	20% Sulfur 80% AC-10	46(6)	62(5)
10	Southbound	Class I (Control)	44(16)	59(13)

( ) Denotes number of tests

Control sections were established in both directions of travel. In the remaining test sections, 20 percent and 30 percent sulfur was blended with AC-10, while 30 percent and 40 percent sulfur was mixed with AC-5. The table also indicates that silicone was added to the mixtures in the northbound lane but not to the ones in the southbound lanes. Skid numbers, which were initially in the mid 40's have increased, after 1 year of service, to the upper 50's and low 60's. So far, the test results are inconclusive as to whether the use of sulfur has any impact on skid resistance. Skid tests are scheduled for the summer of 1984.

Mixture E - Where Mixture E is specified, most contractors select either air-cooled slag or steel slag as an aggregate. So far, the use of slag/dolomite, slag/gravel, or air-cooled slag/steel slag combinations has been very limited. One site on I-55 and 74 near Bloomington was constructed in 1982 with a 50-50 blend of steel slag/crushed gravel. SN in 1982 and 1983 averaged 49.

Mixture E all-slag surfaces, until recently, have been constructed mostly on roads and streets in the Chicago Metropolitan Area. During the past 3 years its use has spread downstate to several heavily travelled primary and Interstate roadways. Summary results of skid testing are shown in Table 7. Follow-up testing indicates that, on high-volume roads, the level of skid resistance basically remains unchanged. Skid resistance of newer projects compares favorably with that of the older projects. These results verify that Mixture E

TABLE 7

SKID RESISTANCE OF CLASS I SURFACE COURSE MIXTURE E
CONTAINING ALL-SLAG COARSE AGGREGATE

District	Location	Date Completed	ADT	Tested	Average SN_{40} in Traffic Lane
1	Dempster (Crawford to Skokie)	5-77	30,000	7-77	40
				7-78	30
				9-79	34
				8-80	34
				11-81	37
				6-82	42
1	I-55 NB (0.4 m S. to 0.7 m W. I-80)	9-77	29,400	7-78	47
				9-79	42
				8-80	40
				9-81	46
				8-82	51
1	US 20 (Itasca to Mill Rd.)	9-76	20,000	7-78	40
				9-79	34
				8-80	39
				9-81	42
				8-82	46
1	Western Ave. (87th to 99th Sts.)	8-77	23,000	7-78	38
				9-79	37
				8-80	36
				9-81	38
				8-82	38
1	Ill. 83 (bridge deck over DesPlaines River)	8-78	22,200	9-79	42
				8-80	35
				9-81	51
				9-82	47
1	Lake Shore Drive (Roosevelt Rd. to 53rd St.)	11-79	102,500-53,600	6-80	47
				8-82	47
1	Lake Shore Drive (53rd St. to 71st St.)	11-79	53,600-23,000	6-80	46
				8-82	41
1	130th St. (Cal Sag to Torrence Ave.)	1980	11,000	5-81	50
				6-82	46
				9-83	53

District	Location	Date Completed	ADT	Tested	Average SN_{40} in Traffic Lane
1	I-80 (Will-Kendall Co. Line to I-55)	11-80	17,700	10-80 7-81 10-81 7-82	53 56 52 53
1	I-80, Kingery (Penn Central RR to State Line)	11-80	92,200	11-80 8-82	47 47
1	US 14, Dempster (I-294 to Merrill Ave.)	8-82	33,900	4-83	46
1	US 34, Ogden Ave. (Belmont to Cumor St.)	7-82	27,000	7-83	40
3	I-80 (Rest Area to Kendall-Will Co. Line)	11-80	14,900	10-80 7-81 10-81 7-82	38 44 42 48
4	I-74 (Ill. 121 to I-474	1980	27,000	6-81	54
6	Ill. 97, Jefferson St. (Sunnyside Dr. West)	10-82	8,500	6-83	44
6	Ill. 10 and 121 (Lincoln)	10-82	11,300	9-83	39
7	US 51 (Sandoval to Junction City)	7-83	7,000	10-83	46

all-slag surfaces can and do maintain a high level of skid resistance on the most heavily travelled roads and streets in Illinois.

OPEN-GRADED ASPHALT FRICTION COURSE

Prior to 1980, the placement of open-graded asphalt friction courses was limited mainly to short segments less than one-half mile in length. High-accident sites accounted for a majority of the projects while experimental projects rounded out the remaining number of sites. Since that time, 10 projects have been constructed. Of these ten, seven projects (five Interstate and two primary) ranged from 2 miles to 10 miles in length, substantially longer than any previously constructed projects. A summary of skid-test results for the Interstate projects is listed in Table 8. Slag, trap rock, and crushed gravel were the coarse aggregates, and their skid numbers ranged from a low of 40 to a high of 54. Initial skid numbers obtained from open-graded asphalt friction courses frequently are slightly lower than expected until traffic wears off the heavy bitumen coating surrounding the aggregate.

SAND-ASPHALT MIXTURES

Sand-asphalt mixes are recommended as a countermeasure in urban areas because of their fine, gritty surface texture, which normally provides better grip between the tire and the pavement at lower speeds than do open-graded mixes. A sand-asphalt mixture is a hot plant mix composed of bitumen and special sand whose maximum size is in the No. 4 sieve (3/16-inch or 1/4-inch) range. Sand-asphalt mixtures frequently can be advantageous as a resurfacing material where a reasonably sound pavement structure already exists, and all that is needed is a thin layer of material to improve smoothness as well as skid resistance.

TABLE 8

SKID RESISTANCE OF OPEN-GRADED FRICTION COURSES
ON INTERSTATE ROUTES

District	Location	Year Completed	ADT	Tested	Average SN_{40} in Traffic Lane
1	I-94 (Montrose to Lawrence - traprock)	1980	60,000	8-81	44
3	I-80 (Ill. 47 to Rest Area - slag)	1980	14,900	9-80	46
				10-80	46
				10-81	51
				11-81	51
				7-82	54
3	I-74 (Carlock to US 150 - slag)	1982	11,500	7-82	40
5	I-74 (Ill. 47 to I-57 - crushed gravel)	1981	13,400	11-81	45
				7-82	46
8	I-270 (Ill. 159 to Ill. 157 - traprock)	1979	17,400	6-81	45

Kankakee - 1979 - In September 1979, a 5/8-inch Plasticized Bitumen Hot-Mix Seal overlay was placed on 1.3 miles of Ill. 17 in Kankakee to correct premature surface raveling of a Class I surface course placed in October 1978. Ill. 17 has an ADT of 18,700 on four lanes at this point, with 550 commercial vehicles, of which 200 are multiple units. The project (to date) has been successful in correcting the surface deficiencies, and the skid-resistance history is shown in Figure 12. In the 4th year, skid tests were made in April at a high point in the seasonal cycle of variability.

Broadway - 1979 - When the City of Aurora and District 1 decided in 1979 to include Plasticized Bitumen Hot-Mix Seal in an FAU project in downtown Aurora, a Category 2 Experimental Feature was established to cover that portion of the project. The project is identified as FAU 2503 (Ill. 25, Broadway), Project IX-5172(20), Section 1977-418-TS, Kane County.

Broadway, within the limits of the improvement, carries an ADT of approximately 13,000 over a four-lane (undivided) street. Cross streets occur at approximately 460-foot intervals, and each is signalized.

Because of the late-season construction, initial skid-resistance testing was delayed until the following spring. In June 1980, at the age of 7 months the average SN was only 34. However, the surface was in good structural condition, with only the normal amount of reflective cracking observed.

In July 1982, the average SN was only 30. As before, the structural condition was still satisfactory. In April 1983, the

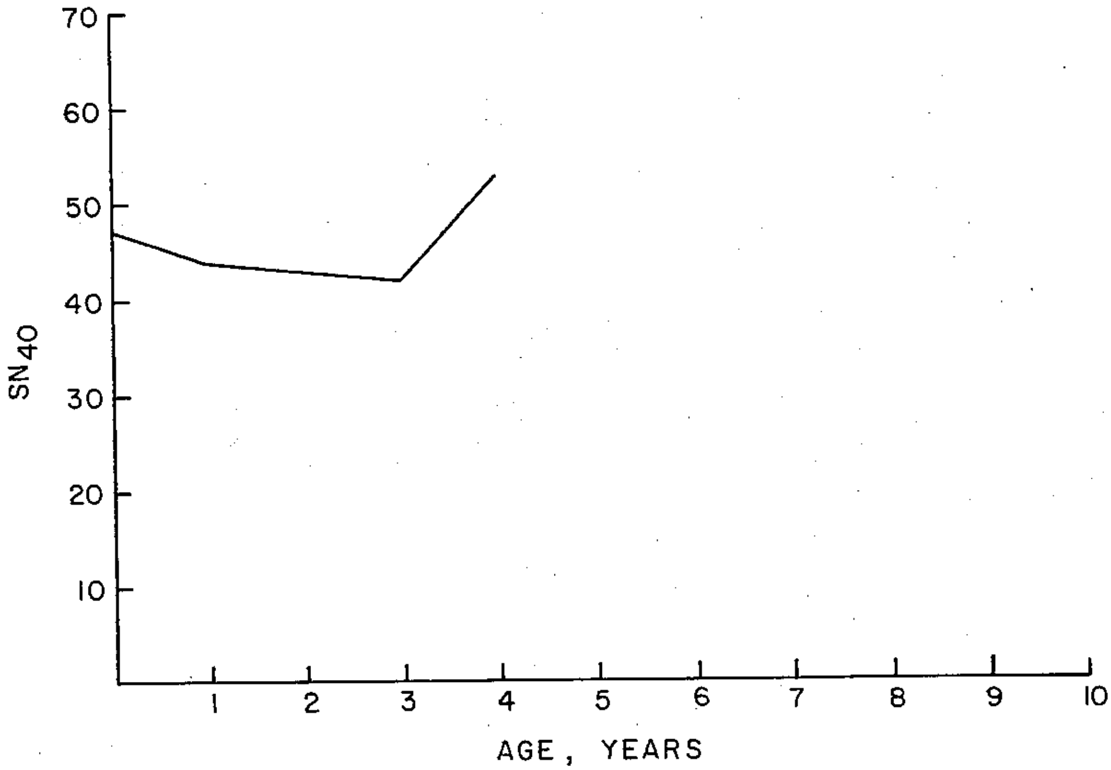

Figure 12. Kankakee Bituminous Hot-Mix Seal Overlay

average was 35. The results of all skid tests taken on the project are shown in Figure 13, along with the average results of other projects previously reported. As can readily be seen, the Broadway results plot as much as 15 SN's below the average of the earlier results.

In an effort to determine the reason(s) for the relatively poor skid resistance of this project, the project was inspected and the City project files were searched in August 1982. Also, the pavement was cored in October 1982. Extractions were performed, gradations were determined, and visual estimates of the blend proportions were made.

The structural performance of Broadway has been satisfactory despite the fact that the overlay is thicker than usually is considered desirable for a sand mix. However, the surface never has had the gritting texture characteristic of the mix. Apparently, the mechanism of differential wear to constantly renew a skid-resistance surface has not been operative.

The various fractions of aggregate from the extractions were examined to determine visually whether a reasonable amount of natural sand was present. Few natural sand particles were observed in any of the fractions extracted from the Broadway cores. From this it was concluded that the mix placed on Broadway most likely is comprised of all softer, more wearing manufactured aggregate (stone sand, stone screenings). This explains the low skid numbers that were obtained.

Tapisable - All of the early hot-mix seal projects contained a workability additive named Tapisable. The additive was understood to

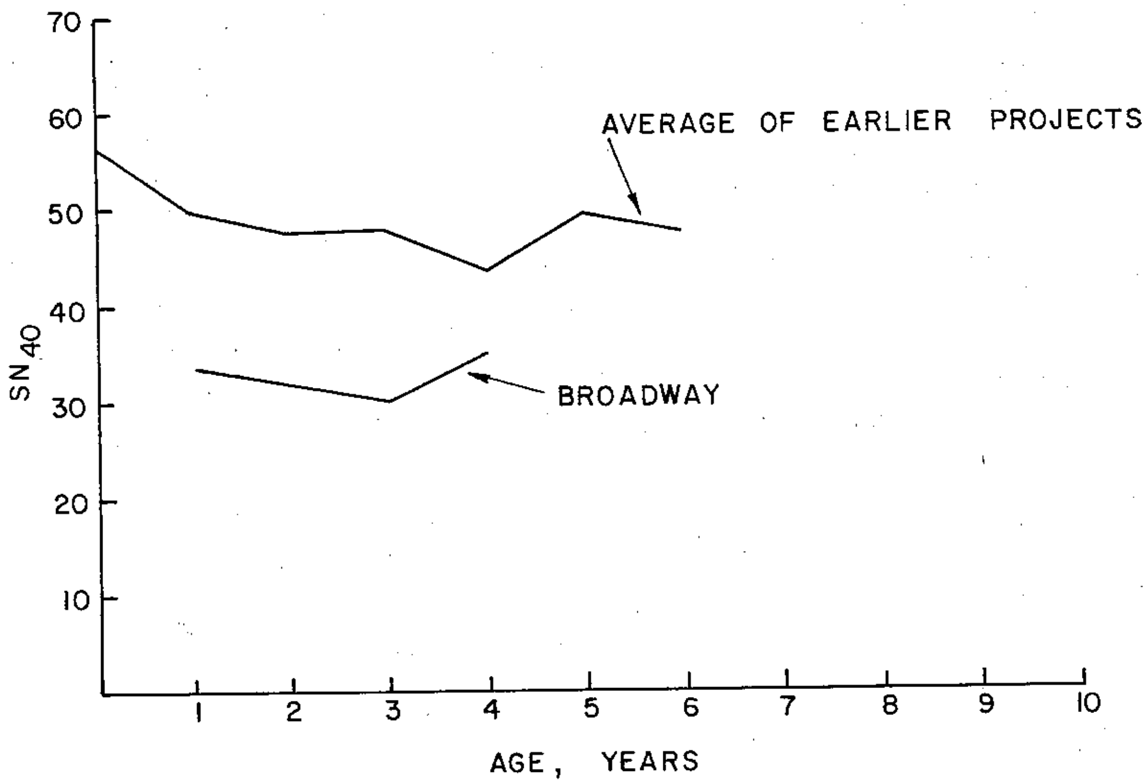

Figure 13. Broadway Hot-Mix Seal versus the Average of Earlier Hot-Mix Seal Overlay Projects

consist of approximately 80 percent liquid coal tar and 20 percent undisclosed active ingredients. The dosage was 0.55 percent by weight of dry aggregate or approximately 10 lbs. of additive per ton of mix.

The Tapisable additive was claimed to provide several benefits: elimination of the need for a tack coat, prevention of stripping, and greatly increased workability. All of these claimed benefits were confirmed by experience, either directly or indirectly.

The Tapisable jobs all were accomplished without tack coats and with no observed difficulty in obtaining adequate bond to the old surface. The Plasticized Bitumnen Hot-Mix Seal specification never has required a tack coat. The relatively high asphalt content of the mix tends to minimize the need for a tack coat compared with drier mixes such as often are used for thicker overlays.

No stripping has been reported on any Tapisable projects.

The beneficial influence of the additive on workability is not understood; however, it definitely is recognized. The suppliers of the workability additives claim that it is the additive that makes the mix work; without the additive, the mix would be so difficult to lay that it would lose its attractiveness. Two contractors have reported attempts to place the mix without the additive, and both found the mix difficult to lay. Specifically, compaction was more difficult, and mats of normally specified thickness were subject to tearing when placed at normal paving speeds.

Recopave - Tapisable was the only workability additive known to be available in Illinois for this mix prior to 1977 when Recopave became available. Recopave, manufactured by Mulco, Inc., Montreal, Canada was claimed to be identical to Tapisable. A chromatographic analysis of the two products indicated that they were similar; consequently, in September 1977 Recopave was permitted as an equal to Tapisable.

From 1978 to 1980, Plasticized Bitumen Hot-Mix Seal projects were completed using both Tapisable and Recopave, and no differences between the two or between jobs utilizing the two were observed. Only Recopave has been available in Illinois since 1981.

SPRINKLE TREATMENT

Sprinkle treatment is a method of improving skid resistance by using a minimum amount of high-quality aggregate, which may be limited in supply and which often is expensive. The process involves sprinkling aggregate on and rolling it into a freshly placed asphaltic concrete mat. Sprinkle treatment provides the designer with an efficient and economic alternative for providing improved skid resistance at wet-pavement accident cluster sites within rehabilitation/resurfacing projects. Using this process, both hazardous and non-hazardous areas within a project receive appropriate levels of skid resistance in one construction operation.

This section updates observations, test results, and analyses reported by Saner(5)(6) pertaining to 1980-81 projects constructed at East Dubuque, Vandalia, and Elizabeth, and gives initial information for eight 1983 projects.

East Dubuque - Additional data for the oldest job at East Dubuque continues to confirm the value of the sprinkle treatment in improving safety. In comparing a 35-month period before construction with a 35-month period after construction, the following was found: wet-weather accidents

- 39 before and 11 after; total accidents (not ice/snow) - 87 before and 46 after. This translates into a 72 percent reduction in wet-weather accidents and a 47 percent reduction in total accidents.

Vandalia - The Vandalia project is 8.8 miles of flat, straight roadway with ADT of 1500. In a 34-month period, 5 wet-weather accidents occurred before construction while 2 occurred after. Although the accident rate was reduced by 60 percent, the number of accidents for a project of this length was insufficient to draw significant conclusions about the value of the sprinkle treatment.

Elizabeth - At Elizabeth, although the results are short term, the value of the sprinkle treatment in providing a safe riding surface is again proven. For a 22-month period before and a 22-month period after, the following was found: wet-weather accidents - 13 before and 5 after; total accidents (not ice/snow) - 23 before and 11 after. This is a significant reduction in accidents, with a 62 percent decrease in wet-weather accidents and a 52 percent decrease in total accidents.

Average skid numbers through 1983 for East Dubuque, Vandalia, and Elizabeth have changed little from those in 1982 (see Table 9). A difference of less than 10 between smooth- and treaded-tire SN's is shown. This can be compared with a difference between smooth- and treaded-tire SN's that range from 17 to 27, with an average of 22 for seven Class I surfaces mixes, which were built in 1981 and 1982 and tested in October 1982. A concrete pavement with an astro-turf drag and transverse tine texture was found to have an SN difference of 5 between smooth and treaded tire. The sprinkle treatment has maintained medium macrotexture. Some

TABLE 9

AVERAGE SKID NUMBERS FOR SPRINKLE TREATMENT PROJECTS

EAST DUBUQUE (Traprock)

	Treaded	10 lb/sq yd Smooth	Difference
08/13/81 (12 mo.)	36	32	4
07/16/82 (23 mo.)	39	32	7
10/19/83 (38 mo.)	36	33	3

VANDALIA (Traprock)

	6 lb/sq yd			9 lb/sq yd			12 lb/sq yd		
	Treaded	Smooth	Difference	Treaded	Smooth	Difference	Treaded	Smooth	Difference
06/30/81 (9 mo.)	43	33	10	42	35	7	43	38	5
05/19/82 (20 mo.)	44	34	10	42	35	7	42	39	3
10/11/83 (37 mo.)	42	34	8	40	36	4	41	36	5

ELIZABETH (Air-Cooled Blast Furnace Slag)

	Treaded	10 lb/sq yd Smooth	Difference
07/16/82 (10 mo.)	54	47	7
10/19/83 (25 mo.)	50	43	7

chip orientation to the flat side up positions has been noted, but very little chip loss and little additional chip embedment has been noted.

Information for the six sprinkle treatment projects built during 1982 is presented in Table 10. As the table indicates, one steel slag and two crushed gravel projects resulted in low skid numbers, but they do have medium macrotexture. The reason for the low SN has yet to be determined.

CHIP SEAL COATS

Chip seal coats afford the highway designer with an economical alternative for improving the skid resistance of an otherwise structurally sound pavement located on rural, low-to-moderate traffic-volume roadways.

During 1979 and 1980, seal coats were applied to five curve locations in District 6 to improve skid resistance. Findings from this investigation were reported by Saner[7]. Instead of using either pea gravel or crushed stone, the normal seal coat aggregates, unconventional aggregates, such as wet-bottom boiler slag, crushed chert gravel, and steel slag, were specified to determine their effect on friction at these isolated areas.

None of the projects were completely effective. However, a properly designed and constructed chip seal coat should and can improve friction characteristics on low-to-moderate traffic-volume roads. Summary results of friction tests for these five projects are tabulated in Table 11.

Rushville-Plymouth - The Rushville and Plymouth projects contained wet-bottom boiler slag, which gave skid numbers in the mid 30's. While both of these projects had good aggregate retention, the sand-size particles provided very little macrotexture, as indicated by the wide spread between treaded- and smooth-tire SN. A curve on a high-speed rural

TABLE 10

1982* SPRINKLE CONSTRUCTION

District	1	3	4	6	7	8
City	Burnham	Roanoke	E. Peoria	Staunton	Robinson	Collinsville
County	Cook	Woodford	Tazewell	Macoupin	Crawford	Madison
Route	US 30	Ill. 116	Ill. 29	Ill. 4	Ill. 33	Ill. 159
Length (mi)	0.79	6.21	0.63	0.58	4.54	1.35
ADT	18,500**	1900	25,000**	3900	7000	17,000
Tons Sprinkle Chips	33	327	125	50	302	151
Cost $/yd***	0.46	0.90	0.44	0.79	0.40	0.60
Chip Type	Steel Slag	Crushed Gravel	Steel Slag	Crushed Gravel	Crushed Gravel	Steel Slag
Date Tested	4/14/83	9/28/83	9/29/83	8/1/83	7/19/83	7/18/83
Avg. SN Treaded	39	44	46	29	27	31
Avg. SN Smooth	34	42	40	24	23	26
Difference	5	2	6	5	4	5

*All of the jobs built in September and October except District 8 in July and District 7 in August

**Four-lane undivided

***Cost is for chips complete in place, only does not include C surface mix cost

TABLE 11

SUMMARY RESULTS OF SKID TESTS OF
SEAL COATS USING UNCONVENTIONAL AGGREGATES

Location (Aggregate)	Date Completed	ADT	Tested	Average SN Traffic Lane
Rushville - US 24 (wet-bottom boiler slag)	7-79	2000	8-79	33
			9-79	36
			11-79	35
			6-80	36
			4-81	35
			6-82	36
			9-83	33 (20 smooth tire)
Plymouth - Ill. 61 (wet-bottom boiler slag)	7-79	1550	9-79	45
			11-79	39
			6-80	37
			4-81	36
			6-82	35
			9-83	32 (18 smooth tire)
Mendon - Ill. 61 (crushed chert gravel)	9-80	1650	9-80	62
			10-80	53
			4-81	39
			8-82	32
Nauvoo - Ill. 96 (crushed chert gravel)	9-80	1900	9-80	62
			10-80	55
			4-81	50
			6-82	41
			9-83	37 (32 smooth tire)
LaHarpe - Ill. 9 (steel slag)	9-80	1550	9-80	66
			10-80	58
			4-81	56
			6-82	53
			9-83	50 (46 smooth tire)

road needs a 1/2-inch to 5/8-inch aggregate chip to provide adequate macrotexture for drainage.

Mendon-Nauvoo - Initially, the Mendon and Nauvoo projects had skid numbers above 50, but these values dwindled into the 30's as the aggregate chips became dislodged from the surface. By 1982, no evidence of a chip-seal remained at the Mendon site. Even though chip retention at Nauvoo also was poor, it was better than that at Mendon.

The loss of chips was attributed to two factors. First and primary, the emulsion application rate (0.26 gal/sq yd) was lower than the best current design rate (0.30 gal/sq yd). The other factor was the brittleness of the asphalt in cold temperature. The 87 penetration asphalt fractured under the action of both traffic and snowplowing.

LaHarpe - The last project, at La Harpe, has performed best in terms of both chip retention and skid resistance after 3 years of service. Even though well over half of the applied aggregate (large chips) was lost, the remaining finer chips are providing a medium-texture surface. A good-quality seal coat requires a clean, pre-coated, one-size chip.

An accident analysis was performed for each location for the longest period of time available. Accident data were available through June 1983. An equal time period before construction was compared with an equal time period in months after construction, all ending with June 1983. For example, a total period of 86 months was analyzed for Rushville, which included 43 months before and 43 months after construction. Both wet-weather and total accidents were looked at as is shown in Table 12.

No conclusions can be drawn from the accident analysis because of the few accidents occurring at these locations, especially the wet-weather

TABLE 12

ACCIDENT DATA

Location	Date Built	Analysis Period Mo.	Wet Accidents Before	Wet Accidents After	Total* Accidents Before	Total* Accidents After
Rushville	7/16/79	86	0	0	6	3
Plymouth	9-09/79	84	3	2	10	8
Mendon	9/11/80	66	0	1	6	1
Nauvoo	9/11/80	66	2	0	5	6
LaHarpe	9/11/80	66	2	2	6	6

*wet and dry pavement only; does not include ice/snow accidents. Total accident data provide even less information. The best performing location (La Harpe) shows no change, while the poorest location in terms of durability and chip retention (Mendon) has the greatest reduction in accidents.

Demonstration Seal-Coat - Neunaber[8] reported on a demonstration seal-coat project that was constructed in 1982 to verify whether skid resistance could be improved while extending the service life of a deteriorating bituminous concrete surface. A section of Ill. 133 in Douglas County, approximately 30 miles south of Champaign, was selected as the project site. The pavement was structurally sound but needed surface maintenance.

The project comprises 24 test sections ranging from 0.5 mile to 1.0 mile in length. The variables were asphalt binder, coated and uncoated chips, aggregate type, and single and double application. Asphalt cement, emulsified asphalt, and rubberized asphalt were the binders, while limestone, dolomite, crushed gravel, and crushed steel slag were selected as aggregate.

After more than 1 year of service and observations, the single-seal-coat application containing coated chips has performed well, as have most of the double-seal-coat applications. Except for double-seal-coat applications, segments containing uncoated chips had difficulty retaining them because the actual binder application rate was less than the design application rate. The CRS-2 emulsion and AC-5 binder usually gave the same performance, but the AC-5 had a tendency to bleed in warm weather. Both the CRS-2 and AC-5 binders outperformed the rubberized binders.

All segments gave improved skid resistance, with crushed gravel and steel slag giving higher levels than dolomite and limestone.

ROTO-MILL PROFILING

The Roto-Mill Profiler is a self-propelled machine that can either remove an existing bituminous surface and resurface it to specified limits or reprofile and texture existing portland cement concrete and bituminous concrete surfaces to restore surface properties.

In 1976, a Roto-Mill Profiler restored the profile, cross section, and texture of an otherwise structurally sound bituminous pavement. The restoration took place on a segment of US 36 in Douglas County that was badly rutted (3/4 inch), and that had skid numbers in the mid 20's.

After 3 years of monitoring the restored bituminous concrete surface, Mascunana[9] reported the following observations:

1. The skid resistance of the pavement surface increased after profiling from an average SN_{40} of 26 to 53 on the eastbound lane and 26 to 57 on the westbound lane.
2. One month after profiling, the average SN_{40} dropped to about 40 and has continued to fluctuate from the middle 30's during fall to about 40 in late spring.
3. The texture created by profiling was wearing off in the wheelpaths after 3 years of service, but the friction number appeared to have stabilized in the seasonal range indicated above.

CHANGES IN PRACTICE

Since 1980, changes in practice have been made to improve the skid resistance of newly constructed pavements. Evaluation of the effectiveness of some of the changes is still in progress.

STEEL SLAG

During the late 1970's, steel industry representatives encouraged highway engineers to accept steel slag as a competitive aggregate for Class I dense-graded bituminous surface courses.

Based on data shown elsewhere in this report, together with similar data from other agencies, the Illinois Highway Development Council recommended that steel slag be permitted as a coarse aggregate in Class I surface courses. A special provision permitting the use of crushed steel slag in Class I dense-graded bituminous surface course was issued November 1, 1983. In Mixture D, it can be blended with equal parts of limestone. In Mixture E, it can serve as the sole aggregate or it can be blended in equal parts with crushed gravel, chats, or crushed stone other than limestone. Its use in binder and base course was not recommended because steel slag tends to expand as it ages.

OPEN-GRADED FRICTION COURSE

Open-graded asphalt friction courses have been effective in improving friction characteristics of wet-pavement accident cluster sites that require better surface drainage. But, their performance along high-volume truck routes has been disappointing. Raveling and flushing are commonly found on surfaces subject to these conditions. Raveling results in excessive loss of aggregates, which reduces the benefits of the open-graded asphalt friction course. Flushing is caused by heavy truck traffic drawing the free asphalt to the surface, filling the voids. Macrotexture is lost and microtexture is lessened.

The Illinois Highway Development Council approved the use of latex rubber to modify open-graded asphalt friction courses to reduce raveling and flushing. Addition of styrene butadiene rubber latex to the mix alters the properties of the asphalt cement and has been found cost effective, especially along high-volume roads and streets involving heavy truck turning movements. A special provision for Heavy Duty Latex Modified Open-Graded Asphalt Friction Course was issued February 2, 1982.

DENSE-GRADED BITUMINOUS CONCRETE SURFACE COURSE, MIXTURE C

The policy governing the use of Mixture C was modified. Prior to January 31, 1983, Mixture C was permitted as the surface course only on roads and streets having design ADT of 500 or less. With the implementation of the new friction policy which calls for high-friction surfaces at wet-pavement accident cluster sites within rehabilitation/resurfacing projects, Mixture C can be placed as a surface course in the remaining nonhazardous areas of roads and streets having design ADT of 2000 or less. Raising the ADT level for nonhazardous areas, which have lower friction demands than cluster sites, is not expected to affect the wet-accident risk adversely in those areas. Evaluation of projects built under this policy should verify whether this risk has changed.

CONCRETE PAVEMENT RESTORATION

Concrete pavement restoration for improving riding quality by grinding the surface of a structurally sound pavement was completed on a contract during 1983. A badly faulted section of Interstate 80 west of the town of Morris was ground longitudinally against the flow of traffic. The diamond blade, self-propelled grinder created grooves 0.09 in. to 0.13 in. wide, spaced 0.075 inch to 0.125 inch apart, leaving peak of ridges about 1/16 inch above the bottom of the grooves. Grinding was completed in 3-foot-wide increments.

In addition to improving surface smoothness, the grinding also improved its skid resistance. This surface previously had been subjected to studded-tire wear as well as heavy truck traffic wear and polishing. Prior to grinding, the surface had virtually no macrotexture and had average SN's in the lower 30's. After grinding, SN's averaged in the upper 30's eastbound and in the middle 40's westbound. A similar pavement restoration project is in progress on Interstate 55 north of Springfield.

PCC FINAL FINISH

The 1979 Illinois Standard Specifications for Road and Bridge Construction regarding the final finish applied to portland cement concrete were revised in 1983. Transverse tine spacing was increased to 3/4-inch centers.

Specifications required that a final finish be applied to the plastic PCC surface using an artificial-turf carpet followed by a mechanically operated metal comb. The carpet is dragged longitudinally. The tining device was operated to produce transverse grooves spaced at approximately 1/2-inch centers, 1/8 to 3/16 inch deep and 0.100 to 0.125 inch wide. Grooves obtained using the 1/2-inch spacing were sometimes eliminated by mortar flow.

Research by others suggests that grooves produced by wider tine spacings are less susceptible to elimination by mortar flow, and there tends to be less disruption of the surface between the grooves. Both 1/2-inch and 3/4-inch spacings are commonly used in texturing a PCC surface.

The recommendation to increase tine spacing from 1/2 inch to 3/4 inch was made to lessen the chances of producing undesirable texturing. The change became effective in the Standard Specifications for Road and Bridge Construction adopted October 1, 1983.

SAND-ASPHALT FRICTION COURSE

Hot sand-asphalt mixture with additives to improve workability has been used to protect and restore riding quality and to provide good skid resistance. The mix was called "Tapisable," named for the additive used. The Tapisable mix has been known officially as "Plasticized Bitumen Hot Mix Seal" since 1972, and has been used extensively on city and county projects.

Fowler[10] summarized the Department's experiences with Plasticized Bitumen Hot-Mix Seal. Although little use has been made of this mix on State projects, because most State projects involve relatively thicker overlays, its use has become increasingly attractive as a minimum-cost overlay to improve skid resistance.

As a result of the Department's experiences and observations, the original specification was modified to eliminate the possibility of a producer providing an improper aggregate blend. The proposed Special Provision for Sand-Asphalt Friction Course also leaves the use of Tapisable, Recopave, or other approved equal asphalt additive to improve workability at the option of the contractor.

Under the Illinois Skid-Accident Reduction Program, the sand-asphalt friction course is permitted for use at wet-pavement accident locations in urban areas with speed limits not exceeding 40 mph, and it can be considered for use in rural areas at stop intersections. On November 23, 1983, when the FHWA approved the Illinois Skid-Accident Reduction Program subject to several conditions, they did not approve the use of sand-asphalt friction course for Federal-aid projects having design speeds exceeding 40 mph.

THE FUTURE

BITUMINOUS PAVEMENTS

A monitoring and evaluation of the overall performance of dense-graded bituminous concrete surfaces constructed under Class I, Mixtures C, D, and E specifications, open-graded asphalt friction courses, sand-asphalt friction courses, and sprinkle treatments will continue.

During 1984 and 1985, approximately five experimental sand-asphalt friction courses (SAFC) will be placed on roads having high speeds and heavy traffic volumes. The specific objectives are to (1) document performance of SAFC under heavy traffic, exceeding 5000 ADT, (2) compare performance of SAFC with Class I, Mixtures C and D for high-speed rural areas, and (3) determine the dependency of SAFC on the workability additive for proper and efficient placement and compaction. Completion of the final report is scheduled for June 1987.

The search will continue for alternate aggregates and aggregate combinations that will provide stable, durable, and skid-resistant bituminous surface.

PORTLAND CEMENT CONCRETE PAVEMENTS

Monitoring and evaluating the performance of representative portland cement concrete surfaces textured in accordance with the currently specified artificial turf/transverse tining process will continue. Testing will be done with both the standard treaded tire and the smooth-treaded tire to evaluate changes in both microtexture and macrotexture.

The concrete restoration projects on I-80 and I-55 will be retested to evaluate wear characteristics of roadways with coarse aggregates exposed to traffic by grinding the surface to improve riding quality.

LABORATORY COARSE AGGREGATE EVALUATION

Preliminary evaluations suggest that wear curves based on aggregate ranking can be developed for roads in both rural and urban areas. Curves will be established as SN data become available. Once the wear curves have been developed, revisions to the design policy regarding the use of Mixtures C, D, and E can be recommended.

One anticipated benefit expected from the laboratory coarse aggregate study was the ability to predict field skid numbers based on laboratory evaluation of aggregate sources. An attempt will be made to develop a satisfactory correlation between SN and VSN. Evaluation of aggregate blends in the laboratory also will continue so that economical local aggregate combinations can provide adequate skid resistance in bituminous surfaces.

REPORTS

An annual report will be prepared by the Bureau of Materials and Physical Research during the fourth quarter of each fiscal year. The report will summarize feedback and research activities. This report, in conjunction with the report entitled "Evaluation and Report of Highway Safety Construction Program," prepared by the Bureau of Traffic, should provide a comprehensive summary on an annual basis of the entire Illinois Skid-Accident Reduction Program.

I. Identify Wet-Road Surface High-Accident Locations

The identification of wet-road surface high-accident locations is divided into two categories - state and local. Separate categories are necessary because of the difference in accident-reporting levels.

A. State Locations

The State category involves locations found under the jurisdiction of the Division of Highways. The Division of Traffic Safety (DTS) will furnish, upon request, a listing of wet-road surface accident tabulations required by this procedure. Requests for accident data should be made by the Highway Districts immediately following a decision to rehabilitate/ resurface a roadway. Accident listings show the number of wet-road surface accidents (excluding accidents occurring on snow and ice) by route number and mile-station that have occurred using the latest three years' accident data. The Districts use the accident data in conjunction with a traffic-volume map to identify wet-road surface high-accident sections of highway (includes intersection accidents).

In order to simplify the highway districts' determination of wet-road surface high-accident sections, tables have been prepared based on the critical wet-road surface accident rate determined by the formula:

$$Rc = Ra + K\sqrt{\frac{Ra}{M}} - \frac{1}{2M}$$

Where Rc = Critical wet-road surface accident rate, in accidents per hundred million vehicle miles of travel (HMVM).

Ra = Average wet-road surface accident rate on a specified category of highway in accidents per HMVM.

M = Vehicle miles of exposure for the study period (3 years) at the location.

K = A constant, the value of which determines the level of probability. A "K" value of 1.645 is used to provide a 95 percent level of confidence.

Average wet-road surface accident rates for the latest three years of accident data are computed annually for the following categories of state-marked routes:

Urban State Routes
District 1
Districts 2 through 9

Rural Non-Municipal State Routes
District 1
Districts 2 through 9

Urban Full Access Controlled Routes
District 1
Districts 2 through 9

Rural Full Access Controlled Routes
District 1
Districts 2 through 9

Rural Municipal State Routes
District 1
Districts 2 through 9

Separate average wet-road surface accident rates were developed for District 1 and for Districts 2 through 9 because a statewide-average rate overidentifies locations in District 1 while it underidentifies locations in Districts 2 through 9.

Use of this "quality-control method" insures that the accident rate in the identified section is greater than the critical rate upon which the tables are based. Each table contains the critical number of accidents for various combinations of ADT and length of roadway. The critical number of accidents is the number of accidents required to produce an accident rate greater than the critical accident rate for that section of highway. The locations of sections of highways that have higher-than-critical wet-road surface accident rates can be determined by using the appropriate tables. Detailed guidelines, with examples, for identifying these locations begin on page 104. Any questions concerning the use of these procedures should be directed to the Division of Traffic Safety, Chief of Traffic Statistics Unit.

B. Local Agency Locations

The local category involves locations on the Federal-aid system under the jurisdiction of a local agency. The identification of wet-road surface high-accident locations on these systems will be the responsibility of each respective local agency. Upon request, DTS will assist a local agency and the Bureau of Local Roads and Streets to determine the availability of any accident data and will provide that data to the requesting local agency. Information about wet-road surface accidents may require searching the agencies' own accident records. Moreover, each local agency will need to develop its own criteria for identifying wet-road surface high-accident locations on roads and streets under their jurisdiction.

II. Analyze Wet-Road Surface High-Accident Locations

Locations within the limits of a proposed rehabilitation/resurfacing project that are identified as wet-road surface high-accident sites must be analyzed further. The first step is to relate the mile stations of such locations to the on-site conditions (i.e., intersections, curves, etc.). Another early step in the investigation is to request collision diagram printouts and, for intersections, collision diagram plots from the Division of Traffic Safety for the mile stations identified as wet road surface high-accident locations. The printouts will provide information regarding the type of collision, date and time of day, maneuver and involvement codes, and other information helpful in analyzing the accident problem. The Districts and local agencies also should consider requesting the Central Bureau of Materials and Physical Research to conduct friction tests of the locations if they believe friction numbers would be helpful in determining the cause of the accidents and the appropriate improvement.

The analysis of wet-road surface high-accident locations should begin with a search for a pattern or patterns of accidents that could identify the wet-road surface problem. This analysis also should include a review of the following operational conditions:

A. Review of Traffic Operations

The analysis of wet-road surface accident locations through the use of accident records can be supplemented by an on-site review of traffic operations. These field observations may not only help determine the problems and appropriate countermeasures at wet-road surface accident locations but may also identify other skid-prone sites that should receive special attention. The review may consider the following items:

1. It may be desirable to drive through the project several times to observe operating problems, especially during darkness and rainfall. This may reveal hazardous situations that otherwise might not be evident in daylight. Impaired vision from splash and spray and from glare and poor reflectance should be noted.
2. During rainfall, surface runoff may pond for lengths greater than 30 feet in sag vertical curves, at the beginning and end of horizontal curves, and along the low side of a three-or-more lane superelevated curve. These are potential hydroplaning areas.
3. Wheelpath rutting that exceeds 3/8 inch obstructs surface runoff and should be noted. Long stretches of standing water increase the opportunity for hydroplaning, intensify splash and spray, and sometimes cause drivers to avoid the normal wheelpath of a lane. In addition to bituminous concrete consolidation, tipped widening strips frequently obstruct surface runoff.
4. Several pavement skid marks near an intersection or some other roadway feature may indicate a place where frictional demand is high.

5. Evidence of damaged guardrail and delineator posts indicates places where drivers have lost control, perhaps because of difficult geometrics as well as low friction.
6. The visibility of warning and regulatory signs, pavement marking, and signals should be noted, as well as the adequacy of the signal timing, phasing, and clearance intervals.
7. The following geometrics, which produce high friction demand, can be noted.
   a. Curves
      (1) Short radii (note whether or not proper advisory speed limit is posted).
      (2) Compound curves (where the first radius is significantly longer than the second radius).
      (3) Nonuniform curvature (radius and length).
      (4) Insufficient superelevation.
      (5) Long, steep grades.
      (6) Hilly terrain.
   b. Poor sight distance
   c. Intersections
      (1) High number of conflicts.
      (2) Left-turn problems.
      (3) Capacity problems.
   d. Interchanges
      (1) Ramps.

(2) Weaving areas upstream of deceleration lanes, downstream from acceleration lanes, and at cloverleaf interloop ramps.

(3) Mainline lane drops.

The need for frictional resistance increases as the ADT increases, is higher in urban than in rural areas, and is greater on primary than on Interstate routes because of more traffic disruptions (turns into driveways, etc.). Erratic traffic flow, which causes a high friction demand, should be noted. Such flow may result from driver confusion, local distractions, inadequate highway capacity, or strip commercial development. Frequent brake-light application may indicate these kinds of problems.

Operational problems or difficult geometrics, considered in conjunction with available accident information, may indicate where frictional demands must be reduced or a high-friction mixture provided. If practical, it is better to plan improvements that lessen the dependence on high frictional resistance rather than merely provide a high-frictional mixture, although in some cases it may be appropriate to do both.

B. Conduct Friction Tests

Upon request by the Districts and by local agencies, the Bureau of Materials and Physical Research will conduct friction testing of established or potential wet-road surface high-accident locations.

Both directions of travel will be tested at 40 mph in the left wheelpath as follows:

1.	Two-lane highways	each traffic lane
2.	Four-lane highways	outer traffic lane
3.	Six-lane highways	middle traffic lane
4.	Eight-or-more-lane highways	right-middle traffic lane

Sections that exceed 0.2 mile in rural areas and 0.1 mile in urban areas will be tested at those intervals. Shorter sections will be tested at only one location. Resulting friction numbers, together with appropriate comments, will be tabulated by mile station and sent to the requesting agency.

Friction numbers can, in a general way, indicate the risk of intersections, railroad crossings, curves, ramps, interchange areas, etc., becoming the scene of repeated wet-road surface accidents. As friction numbers decrease, wet-road surface accident risk increases and, when friction numbers drop below 30, the risk increases significantly.

III. Select Appropriate Countermeasures

When information concerning wet-road surface accidents, traffic operations, and friction tests is available, all of it should be considered to determine probable causes. Sometimes a cause may not be evident but, when it is determined, the chances are that alternative countermeasures will be available.

For example, if water ponding in wheelpaths causes a problem, it may be corrected either by milling or by a proposed overlay without further improvements. At other wet-road surface sites, perhaps better pavement drainage may be needed to eliminate hydroplaning. However, if a problem at a curve results from inadequate superelevation or from the curve being compounded or too sharp, those deficiencies, if possible, should be improved before deciding whether or not a high-friction mixture is also necessary.

Where improved friction characteristics are required, three alternatives are available. They are:

A. 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.

B. Plasticized bituminous hot-mix sand seals or sand-asphalt mixes containing blends of stone screenings and natural sands. To insure the adequacy of frictional characteristics, the materials and blends are to be approved by the Bureau of Materials and Physical Research prior to their use.

C. Open-graded asphalt friction course (OGAFC).

Each of the above has special characteristics which make its use desirable for certain types of application but eliminate its use for others. Sand-asphalt mixes, because of their fine, gritty surface texture (microtexture), normally provide better grip between the tire and pavement at lower speeds than do open-graded mixes. Thus, they are excellent for use at wet-road surface high-accident locations in urban areas with posted speed limits not exceeding 40 mph, and can be considered for use in rural areas at stop intersections.

Class I Bituminous Concrete Surface Course, Mixture E, with 100 percent crushed slag coarse aggregate and minimum CA-13 size, is intermediate between OGAFC and sand-asphalt mixes in both macrotexture and microtexture. It can be used as an alternate for either open-graded or sand-asphalt mixes.

OGAFC has the greater macrotexture, which enhances its surface drainage characteristics and makes it a primary candidate for high-speed locations (posted speed limits above 40 mph). OGAFC should be given primary consideration as the corrective high-friction mixture for wet-road surface high-accident locations on high-speed highways, such as at horizontal and vertical sag curves, interchanges, lane-reduction and heavy-weaving areas. OGAFC is exceedingly difficult to place by hand, and therefore locations requiring an appreciable amount of handwork should be avoided.

It is not the intent of this procedure to create a patchwork surface course on rehabilitation/resurfacing projects through the intermittent use of special high-quality friction mixes at wet-road surface high-accident areas and the use of conventional bituminous surfaces at all other areas. Thus, if special treatment is required at more than one place, and if the distance between special treatments is less than 1000 feet, the high-quality friction mix should continue through both locations. In addition, if special treatment is required over 50 percent or more of the length of a project, the high-quality friction mix should be used throughout.

As a general rule, it is better to reduce a high frictional need at an accident location (for instance, by increasing inadequate superelevation or improving traffic flow) than to use a high-friction mixture to provide for such demand. At a signalized intersection the high frictional need resulting in above-average wet-road surface accident frequency could be a signal-visibility or clearance-interval problem that should be corrected.

Each identified accident location must be individually analyzed to determine the appropriate countermeasure. This evaluation should be documented and become a part of the location study report for state projects and project development report for local agency projects.

DIVISION OF TRAFFIC SAFETY
GUIDELINES FOR IDENTIFYING WET-ROAD SURFACE
HIGH-ACCIDENT LOCATIONS

PROCEDURAL STEPS

(1) Select the appropriate table (1 through 10) based upon the following categories:

(A) Urban State Routes (Tables 1 and 2)

(B) Rural Non-Municipal State-Marked Routes (Tables 3 and 4)

(C) Urban Full Access Control Routes (Tables 5 and 6)

(D) Rural Full Access Control Routes (Tables 7 and 8)

(E) Rural Municipal Routes (Tables 9 and 10)

The criteria identifying locations is a combination of traffic volume, length of section, and the number of wet-weather accidents. The tables show discrete values of accidents, and interpolation and engineering judgment must be considered in using them.

(2) Scan the computer listing and look for clusters of wet-weather accidents that meet the following criteria:

(A) Determine the maximum length of section required for the minimum critical number of accidents (4 is the lowest number of accidents).

(B) Determine individual clusters that meet the criteria.

(C) Extend or combine sections based on judgment.

(D) Verify that the critical number of accidents is met for any extended or combined section of roadway.

(E) In many cases, it may be necessary to lengthen a section in order to reach the critical number of accidents needed. If no sections are found in steps A through D, check for longer segments that meet a tabled value. If the critical accident number shown in the appropriate table (attached) is less than the accident cluster number from the computer listing, a high-accident location has been identified.

EXAMPLE NUMBER 1

A rural downstate non-municipal state-marked route had two accidents at mile stations 6.62 and one at 8.87 with an ADT of 2,100. The minimum critical number (from Table 4) is four accidents in a three-mile section. If at mile station 9.94 there are another two accidents, the section from mile station 6.62 to mile station 9.94 would be 3.32 miles in length with five accidents. The section, while not satisfying the minimum criteria, if lengthened would be a wet-road surface high-accident location, based upon the critical number of accidents for that length (5 accidents within 4 miles).

Mile Station 6.62	Mile Station 8.87	Mile Station 9.94
2 acc.	1 acc.	2 acc.

On either urban or rural routes, accident clusters may make a wet-road surface high-accident location in a very short section length. For example, an intersection occurrence may have enough wet-weather accidents to qualify. If a short distance away another accident cluster appears, it may be advantageous to lengthen the section to take in the entire group of accidents. When extending the length of a section, if there is a gap having a length greater than the minimum criteria with few accidents, the section should be terminated. <u>There is no set criteria for whether a section should be terminated.</u>

<u>EXAMPLE NUMBER 2</u>

The following example shows how not only an entire section but also how segments of the section can qualify for wet-road surface high-accident locations (computer listing attached). US Route 67 between mile station 10.15 and mile station 12.09, with an ADT of 11,500 is under study. Table 2 is selected. The project length is 1.94 with 130 wet-weather accidents.

Using Table 2, the minimum critical number of accidents is four in a 0.1-mile section. Mile station 10.15, an intersection, has 33 wet-weather accidents, which qualifies it as a wet-road surface high-accident location. The 0.1-mile lengths from 10.21 to 10.30, 10.31 to 10.40, 10.41 to 10.50, and from 10.51 to 10.60, will also qualify. The remaining length from mile station 10.61 to mile station 10.76 also qualifies, even though it is slightly longer than the minimum length. By combining all segments, the entire section from mile station 10.15 to mile station 10.76 will qualify as a wet-road surface high-accident location (Section 1). There are only three accidents from mile station 10.76 to but not including mile station 11.09. This area would not be included in Section 1.

The next cluster of accidents (16) is between mile station 11.09 and mile station 11.11. From that point there are only three additional accidents to mile station 11.53. Therefore, Section 2 would include from mile station 11.09 to mile station 11.11.

Section 3 (identified similar to Section 1) includes from mile station 11.53 to mile station 11.85 and has 24 accidents. Section 4 is identified as mile station 12.09.

Combining the lengths of all four sections, 0.99 miles of wet-road surface high-accident locations have been identified for corrective action.

ACCUMULATED TOTAL FOR COUNTY 081
** 1979-1981 RAST060 DATA REQ. 119 **
ROUTE 1067

ROAD CLASS	MILE STATION	RD SURF WET 2		
5	9.81	1		
5	9.83	1		
5	9.84	1		
5	9.98	3		
5	10.00	3		
5	10.01	1		
5	10.13	1		
5	10.14	1		
5	10.15	33		
5	10.21	1		
5	10.22	1		
5	10.23	3		
5	10.24	1		
5	10.26	1	13	
5	10.27	2		
5	10.28	2		
5	10.29	2		
5	10.33	3		
5	10.35	1	6	
5	10.36	1		
5	10.39	1		
5	10.41	1		
5	10.42	1		
5	10.43	1		77 (Section 1)
5	10.44	2	8	
5	10.46	1		
5	10.48	1		
5	10.49	1		
5	10.50	3		
5	10.52	1		
5	10.55	1	9	
5	10.57	1		
5	10.59	3		
5	10.61	1		
5	10.62	1		
5	10.70	1		
5	10.72	1	8	
5	10.73	1		
5	10.74	2		
5	10.76	1		
5	10.88	1		
5	10.89	1		
5	10.97	1		
5	11.09	12		
5	11.10	1		76 (Section 2)
5	11.11	3		
5	11.24	1		
5	11.29	1		
5	11.34	1		
5	11.53	8		

ACCUMULATED TOTAL FOR COUNTY 081
** 1979-1981 RAST060 DATA REQ. 119 **
ROUTE 1067

ROAD CLASS	MILE STATION	RD SURF WET 2	
5	11.55	3	(Section 3)
5	11.56	1	
5	11.60	1	
5	11.65	1	
5	11.75	1	
5	11.76	1	24
5	11.79	1	
5	11.81	1	
5	11.82	1	
5	11.84	3	
5	11.85	2	
5	11.92	1	
5	12.09	6	6 (Section 4)
5	12.12	1	
5	12.18	1	
5	12.19	1	
5	12.36	1	
5	12.39	1	
5	12.42	1	
5	12.49	2	
5	12.54	1	
5	12.57	1	
5	12.62	1	
5	12.64	1	
5	12.67	1	
5	12.79	3	
5	12.87	7	
5	12.89	1	
5	12.94	1	
5	13.01	1	
5	13.04	1	
5	13.19	1	
5	13.29	10	
5	13.32	1	
5	13.34	4	
5	13.35	1	
5	13.40	1	
5	13.42	6	
5	13.50	1	
5	13.51	3	
5	13.54	7	
5	13.57	1	
5	13.75	2	
5	50.04	1	
5	50.08	1	
5	50.11	1	
5	50.23	1	
5	50.32	1	
5	99.03	1	
RT TOTAL		334	

TABLE 1
CRITICAL NUMBER OF WET ROAD SURFACE CONDITION ACCIDENTS
BASED ON THREE YEARS DATA
REQUIRED FOR SPECIAL CONSIDERATION ON
R/R PROJECTS BASED ON 1979 - 1981 ACCIDENT DATA
URBAN STATE ROUTES
DISTRICT 1

AVERAGE RATE = 339
(ROAD CLASS = 5)

ADT	LENGTH - MILES											
URBAN STATE	3.0	2.0	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
2,000	30	21	12	11	10	9	8	7	6	5	4	4
4,000	56	39	21	19	18	16	14	12	10	8	6	4
6,000	80	56	30	27	25	22	19	17	14	11	8	5
8,000	105	72	39	35	32	28	25	21	18	14	10	6
10,000	129	88	47	43	39	34	30	26	21	17	12	7
12,000	153	105	56	51	45	40	35	30	25	19	14	8
14,000	176	121	64	58	52	46	40	34	28	22	16	9
16,000	200	137	72	65	59	52	45	39	32	25	18	10
18,000	224	153	80	73	65	58	51	43	35	27	19	11
20,000	247	169	88	80	72	64	56	47	39	30	21	12
22,000	271	184	97	88	79	70	61	51	42	33	23	13
24,000	294	200	105	95	85	75	65	56	45	35	25	14
26,000	318	216	113	102	92	81	70	60	49	38	27	15
28,000	341	232	121	109	98	87	75	64	52	40	28	16
30,000	364	247	129	117	105	92	80	68	56	43	30	17

TABLE 2
CRITICAL NUMBER OF WET ROAD SURFACE CONDITION ACCIDENTS
BASED ON THREE YEARS DATA
REQUIRED FOR SPECIAL CONSIDERATION ON
R/R PROJECTS BASED ON 1979 - 1981 ACCIDENT DATA
URBAN STATE ROUTES
DISTRICTS 2 - 9

AVERAGE RATE = 133
(ROAD CLASS = 5)

ADT	LENGTH - MILES											
URBAN STATE	3.0	2.0	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
2,000	14	10	6	5	5	4	4	4	4	4	4	4
4,000	24	17	10	9	8	7	7	6	5	4	4	4
6,000	35	24	14	12	11	10	9	8	7	5	4	4
8,000	45	31	17	16	14	13	11	10	8	7	5	4
10,000	55	38	21	19	17	15	14	12	10	8	6	4
12,000	64	45	24	22	20	18	16	14	11	9	7	4
14,000	74	51	28	25	23	20	18	15	13	10	7	4
16,000	84	58	31	28	26	23	20	17	14	11	8	5
18,000	93	64	35	32	29	25	22	19	16	12	9	5
20,000	103	71	38	35	31	28	24	21	17	14	10	6
22,000	112	77	41	38	34	30	26	23	19	15	11	6
24,000	122	84	45	41	37	33	29	24	20	16	11	7
26,000	133	90	48	44	39	35	31	26	22	17	12	7
28,000	141	96	51	47	42	37	33	28	23	18	13	7
30,000	150	103	55	50	45	40	35	30	24	19	14	8

TABLE 3
CRITICAL NUMBER OF WET ROAD SURFACE CONDITION ACCIDENTS
BASED ON THREE YEARS DATA
REQUIRED FOR SPECIAL CONSIDERATION ON
R/R PROJECTS BASED ON 1979 - 1981 ACCIDENT DATA
RURAL NON-MUNICIPAL STATE ROUTES
DISTRICT 1

AVERAGE RATE = 60
(ROAD CLASS = 4)

ADT	LENGTH - MILES										
RURAL NON-MUNI	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.5
1,000	11	10	9	8	7	6	5	4	4	4	4
2,000	19	17	16	14	13	11	9	7	5	4	4
3,000	27	25	22	20	17	15	13	10	7	4	4
4,000	35	32	29	25	22	19	16	13	9	5	4
5,000	42	39	35	31	27	23	19	15	11	6	4
6,000	50	45	41	36	32	27	22	17	13	7	4
7,000	57	52	47	42	36	31	25	20	14	8	5
8,000	64	59	53	47	41	35	29	22	16	9	5
9,000	72	65	59	52	45	39	32	25	17	10	6
10,000	79	72	64	57	50	42	35	27	19	11	6
11,000	86	78	70	62	54	46	38	29	21	12	7
12,000	93	85	76	67	59	50	41	32	22	13	7
13,000	101	91	82	73	63	53	44	34	24	13	8
14,000	108	98	88	78	67	57	47	36	25	14	8
15,000	115	104	93	83	72	61	50	39	27	15	9

TABLE 4
CRITICAL NUMBER OF WET ROAD SURFACE CONDITION ACCIDENTS
BASED ON THREE YEARS DATA
REQUIRED FOR SPECIAL CONSIDERATION ON
R/R PROJECTS BASED ON 1979 - 1981 ACCIDENT DATA
RURAL NON-MUNICIPAL STATE ROUTES
DISTRICTS 2 - 9

AVERAGE RATE = 31
(ROAD CLASS = 4)

ADT	LENGTH - MILES										
RURAL NON-MUNI	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.5
1,000	6	6	5	5	4	4	4	4	4	4	4
2,000	11	10	9	8	7	6	5	4	4	4	4
3,000	15	14	13	12	10	9	7	6	4	4	4
4,000	20	18	16	15	13	11	9	7	5	4	4
5,000	24	22	20	18	15	13	11	9	6	4	4
6,000	28	25	23	20	18	15	13	10	7	4	4
7,000	32	29	26	23	20	18	15	12	8	5	4
8,000	36	33	29	26	23	20	16	13	9	5	4
9,000	40	36	33	29	25	22	18	14	10	6	4
10,000	44	40	36	32	28	24	20	15	11	6	4
11,000	47	43	39	35	30	26	21	17	12	7	4
12,000	51	47	42	37	33	28	23	18	13	7	4
13,000	55	50	45	40	35	30	25	19	14	8	5
14,000	59	54	48	43	37	32	26	20	15	8	5
15,000	63	57	51	45	40	34	28	22	15	9	5

TABLE 5
CRITICAL NUMBER OF WET ROAD SURFACE CONDITION ACCIDENTS
BASED ON THREE YEARS DATA
REQUIRED FOR SPECIAL CONSIDERATION ON
R/R PROJECTS BASED ON 1979 - 1981 ACCIDENT DATA
URBAN FULL ACCESS CONTROLLED ROUTES
DISTRICT 1

AVERAGE RATE = 51
(ROAD CLASS = 2)

ADT	LENGTH - MILES											
URBAN FULL	3.0	2.0	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
10,000	23	17	9	9	8	7	6	6	5	4	4	4
15,000	33	23	13	12	11	10	9	8	6	5	4	4
20,000	43	30	17	15	14	12	11	9	8	6	5	4
25,000	53	37	20	18	17	15	13	11	9	8	6	4
30,000	62	43	23	21	19	17	15	13	11	9	6	4
35,000	71	49	27	24	22	20	17	15	12	10	7	4
40,000	80	56	30	27	25	22	19	17	14	11	8	5
45,000	90	62	33	31	27	24	21	19	15	12	9	5
50,000	99	68	37	33	30	27	23	20	17	13	9	6
55,000	108	73	40	36	33	29	25	22	18	14	10	6
60,000	117	80	43	39	35	31	27	23	19	15	11	6
65,000	126	87	46	42	38	34	29	25	21	16	12	7
70,000	135	93	49	45	40	36	31	27	22	17	12	7
75,000	144	99	53	48	43	38	33	28	23	18	13	8
80,000	153	105	56	51	46	40	35	30	25	19	14	8
85,000	162	111	59	53	48	43	37	32	26	20	15	8
90,000	171	117	62	56	51	45	39	33	27	21	15	9
95,000	180	123	65	59	53	47	41	35	29	22	16	9
100,000	189	129	68	62	56	49	43	37	30	23	17	9

TABLE 6
CRITICAL NUMBER OF WET ROAD SURFACE CONDITION ACCIDENTS
BASED ON THREE YEARS DATA
REQUIRED FOR SPECIAL CONSIDERATION ON
R/R PROJECTS BASED ON 1979 - 1981 ACCIDENT DATA
URBAN FULL ACCESS CONTROLLED ROUTES
DISTRICTS 2 - 9

AVERAGE RATE = 26
(ROAD CLASS = 2)

ADT	LENGTH - MILES											
URBAN FULL	3.0	2.0	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
10,000	13	10	6	5	5	4	4	4	4	4	4	4
15,000	19	13	8	7	6	6	5	5	4	4	4	4
20,000	24	17	10	9	8	7	6	6	5	4	4	4
25,000	29	20	12	11	10	9	8	7	6	5	4	4
30,000	34	24	13	12	11	10	9	8	6	5	4	4
35,000	39	27	15	14	13	11	10	9	7	6	4	4
40,000	44	31	17	16	14	13	11	10	8	6	5	4
45,000	49	34	19	17	16	14	12	11	9	7	5	4
50,000	53	37	20	19	17	15	13	12	10	8	6	4

TABLE 7
CRITICAL NUMBER OF WET ROAD SURFACE CONDITION ACCIDENTS
BASED ON THREE YEARS DATA
REQUIRED FOR SPECIAL CONSIDERATION ON
R/R PROJECTS BASED ON 1979 - 1981 ACCIDENT DATA
RURAL FULL ACCESS CONTROLLED ROUTES
DISTRICT 1

AVERAGE RATE = 10
(ROAD CLASS = 1)

ADT	LENGTH - MILES										
RURAL FULL	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.5
2,000	5	4	4	4	4	4	4	4	4	4	4
4,000	8	7	7	6	5	5	4	4	4	4	4
6,000	11	10	9	8	7	6	5	4	4	4	4
8,000	14	13	11	10	9	8	7	5	4	4	4
10,000	16	15	14	12	11	9	8	6	5	4	4
12,000	19	17	16	14	13	11	9	7	5	4	4
14,000	22	20	18	16	14	12	10	8	6	4	4
16,000	24	22	20	18	16	14	11	9	7	4	4
18,000	27	25	22	20	17	15	13	10	7	4	4
20,000	30	27	24	22	19	16	14	11	8	5	4
22,000	32	29	26	24	21	18	15	12	8	5	4
24,000	35	32	29	25	22	19	16	13	9	5	4
26,000	37	34	31	27	24	20	17	13	10	6	4
28,000	40	36	33	29	25	22	18	14	10	6	4
30,000	42	39	35	31	27	23	19	15	11	6	4

TABLE 8
CRITICAL NUMBER OF WET ROAD SURFACE CONDITION ACCIDENTS
BASED ON THREE YEARS DATA
REQUIRED FOR SPECIAL CONSIDERATION ON
R/R PROJECTS BASED ON 1979 - 1981 ACCIDENT DATA
RURAL FULL ACCESS CONTROLLED ROUTES
DISTRICTS 2 - 9

AVERAGE RATE = 6
(ROAD CLASS = 1)

ADT	LENGTH - MILES										
RURAL FULL	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.5
2,000	4	4	4	4	4	4	4	4	4	4	4
4,000	5	5	4	4	4	4	4	4	4	4	4
6,000	7	7	6	5	5	4	4	4	4	4	4
8,000	9	8	8	7	6	5	4	4	4	4	4
10,000	11	10	9	8	7	6	5	4	4	4	4
12,000	13	11	10	9	8	7	6	5	4	4	4
14,000	14	13	12	11	9	8	7	5	4	4	4
16,000	16	15	13	12	10	9	8	6	4	4	4
18,000	17	16	15	13	11	10	8	7	5	4	4
20,000	19	17	16	14	13	11	9	7	5	4	4
22,000	21	19	17	15	14	12	10	8	6	4	4
24,000	22	20	18	17	15	13	10	8	6	4	4
26,000	24	22	20	18	16	13	11	9	6	4	4
28,000	25	23	21	19	17	14	12	9	7	4	4
30,000	27	25	22	20	17	15	13	10	7	4	4

TABLE 9
CRITICAL NUMBER OF WET ROAD SURFACE CONDITION ACCIDENTS
BASED ON THREE YEARS DATA
REQUIRED FOR SPECIAL CONSIDERATION ON
R/R PROJECTS BASED ON 1979 - 1981 ACCIDENT DATA
RURAL MUNICIPAL STATE ROUTE
DISTRICT 1

AVERAGE RATE = 119
(ROAD CLASS = 3)

ADT	LENGTH - MILES											
RURAL MUNI.	3.0	2.0	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
1,000	7	5	4	4	4	4	4	4	4	4	4	4
2,000	12	9	5	5	4	4	4	4	4	4	4	4
3,000	17	12	7	7	6	5	5	4	4	4	4	4
4,000	22	16	9	8	8	7	6	5	4	4	4	4
5,000	27	19	11	10	9	8	7	6	5	4	4	4
6,000	31	22	12	11	10	9	8	7	6	5	4	4
7,000	36	25	14	13	12	11	9	8	7	5	4	4
8,000	40	28	16	14	13	12	10	9	8	6	4	4
9,000	45	31	17	16	14	13	11	10	8	7	5	4
10,000	49	34	19	17	16	14	12	11	9	7	5	4
11,000	54	37	21	19	17	15	13	12	10	8	6	4
12,000	58	40	22	20	18	16	14	12	10	8	6	4
13,000	63	43	24	22	20	18	15	13	11	9	6	4
14,000	67	46	25	23	21	19	16	14	12	9	7	4
15,000	71	49	27	24	22	20	17	15	12	10	7	4
16,000	76	52	28	26	23	21	18	16	13	10	8	4
17,000	80	55	30	27	25	22	19	17	14	11	8	5
18,000	84	58	31	29	26	23	20	17	14	11	8	5
19,000	88	61	32	30	27	24	21	18	15	12	9	5
20,000	93	64	33	31	28	25	22	19	16	12	9	5

TABLE 10
CRITICAL NUMBER OF WET ROAD SURFACE CONDITION ACCIDENTS
BASED ON THREE YEARS DATA
REQUIRED FOR SPECIAL CONSIDERATION ON
R/R PROJECTS BASED ON 1979 - 1981 ACCIDENT DATA
RURAL MUNICIPAL STATE ROUTE
DISTRICTS 2 - 9

AVERAGE RATE = 85
(ROAD CLASS = 3)

ADT	LENGTH - MILES										
RURAL MUNI.	3.0	2.0	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
1,000	6	4	4	4	4	4	4	4	4	4	4	4
2,000	9	7	4	4	4	4	4	4	4	4	4	4
3,000	13	9	6	5	5	4	4	4	4	4	4	4
4,000	17	12	7	6	6	5	5	4	4	4	4	4
5,000	20	14	8	8	7	6	6	5	4	4	4	4
6,000	23	17	9	9	8	7	6	6	5	4	4	4
7,000	27	19	11	10	9	8	7	6	5	4	4	4
8,000	30	21	12	11	10	9	8	7	6	5	4	4
9,000	33	23	13	12	11	10	9	8	6	5	4	4
10,000	37	26	14	13	12	11	9	8	7	6	4	4
11,000	40	28	16	14	13	12	10	9	7	6	4	4
12,000	43	30	17	15	14	12	11	9	8	6	5	4
13,000	46	32	18	16	15	13	12	10	8	7	5	4
14,000	49	34	19	17	16	14	12	11	9	7	5	4
15,000	53	37	20	18	17	15	13	11	9	8	6	4
16,000	56	39	21	19	18	16	14	12	10	8	6	4
17,000	59	41	22	20	19	17	15	13	10	8	6	4
18,000	62	43	23	21	19	17	15	13	11	9	6	4
19,000	65	45	25	22	20	18	16	14	11	9	7	4
20,000	68	47	26	23	21	19	17	14	12	9	7	4

APPENDIX B

Illinois Department of Transportation
Departmental Policies

TRA-15
March 29, 1983

SAFETY IMPROVEMENT CONSTRUCTION PROGRAM

1. Policy

The Department shall have a program of identifying high accident locations and conducting a safety construction program addressing those and other potentially hazardous locations on a priority basis.

2. Purpose

The purpose of this Policy is to describe the procedures for utilizing high-accident location information to develop, implement, and evaluate an annual safety program of cost-effective improvements.

3. Guidelines for Implementation

a. General Funding Allocation Procedures

1) The Department will allocate a portion of its total highway construction funding for safety improvements, utilizing the most appropriate mixture of State and Federal funds.

2) The allocation of funds will be determined annually by the Directors of the Office of Planning and Programming, the Division of Highways, and the Division of Traffic Safety. The basis of the allocation will be an analysis of the priority and cost of backlog needs at correctable high accident locations in relation to priorities and costs of all backlog needs for physical and traffic service deficiencies on State-maintained highways.

3) The Office of Planning and Programming will annually notify each District of the size of its safety improvement program.

b. Procedures for Rail-Highway Grade Crossing Safety Improvements

1) If Federal appropriations include specific allocation of funds for safety improvements at rail-highway grade crossings, the Office of Planning and Programming in cooperation with the Bureaus of Design and Local Roads and Streets shall determine the funds available for improvements which will be selected in accordance with the following procedures:

a) Guidelines and priorities will be developed by the Bureau of Traffic in cooperation with the Bureaus of Design and Local Roads and Streets and the Division of Traffic Safety to ensure current grade crossing safety needs are addressed.

b) The Bureaus of Design and Local Roads and Streets will assess the comparative needs on the State and local systems based on those guidelines, and select projects that are consistent with the funding allocation, and priorities.

2) If Federal appropriations do not include a specific allocation, or a minimum percentage of allocation for rail-highway grade crossing safety improvements, the desired projects will be considered as a part of the total safety program, meeting all of that program's criteria.

c. Procedures for State and Local Agency High Accident Location Safety Improvement Projects

1) Approximately 10 percent of Federal HES Categorical Safety Funds will be allocated to the Bureau of Local Roads and Streets for distribution to local agencies. In the absence of dedicated Federal safety funds, the local agencies will be responsible for funding their own safety programs.

2) The balance of available safety improvement funds will be allocated to each District on the basis of its percentage of the total number of high accident locations on the State maintained highway system. The allocations to be utilized will be determined by the Office of Planning and Programming, Division of Highways and the Division of Traffic Safety.

3) Safety Project Selection Procedures

a) High Accident Location - Identification

(1) The Division of Traffic Safety will annually identify locations that had an accident rate higher than the critical rate for that category of highway.

(2) The affected locations will be shown as red, green, and yellow spots or sections on high accident rate maps. The colors represent, in descending order, the level of probability that the accidents at the location did not occur by chance alone.

(3) High Accident Location maps and related information will be provided by the Division of Traffic Safety to the Districts, normally in the third quarter of the calendar year following the year for which the rate maps are prepared. These data will be the basis for selection of projects to be included in the following fiscal year's construction program.

(4) The Bureau of Traffic will coordinate the identification and skid testing of high accident wet-pavement locations with the Division of Traffic Safety, the Central Bureau of Materials and Physical Research, and the District Offices.

b) High Accident Location - Analysis

(1) The Districts shall review and analyze, in detail, those locations meeting the following criteria:

(a) Red or green spots and short sections on the most recent map.

(b) Yellow spots and short sections that appear on the most recent map and at least one other map in the past three years.

(2) Collision diagrams should be studied to determine accident patterns.

(3) The District analysis shall include appropriate countermeasures and benefit-to-cost ratios.

c) High Accident Location - Criteria for Selection

(1) Safety Program Criteria:

(a) A maximum of 60 percent of the District's allocation may be used for improvements with an individual project cost in excess of $350,000. The balance of the allotment will be used for individual projects costing less than $350,000.

(b) Standard Department procedures will be used for programming, developing, and scheduling of projects included in the annual safety improvement program.

(2) Safety Project Criteria:

(a) The project must be a current high accident location on the maps prepared by the Division of Traffic Safety.

(b) The project must have a benefit-to-cost ratio greater than 1.0 computed in accordance with procedures developed by the Division of Traffic Safety.

(c) The project must be selected by a multi-discipline team comprised, at a minimum, of representatives from the District Bureaus of Traffic, Maintenance, Planning and Design.

(d) A District must use a minimum of 85 percent of its safety improvement allocation funds for projects that meet the safety project criteria,

d) Low Cost Safety Improvements

A District may use a maximum of 15 percent of its total safety improvement allocation for raised pavement markers, curb markers, roadside object removal, or skid-proofing projects. These projects do not have to meet the safety project criteria. Railroad crossing improvements and removal of abandoned crossings may be included if Federal categorical funds for rail-highway grade crossing improvements are not available. The skid-proofing projects are to be selected and programmed in accordance with the most recent Department procedures defining methods of selecting isolated skid-reduction safety projects.

d. Safety Program Evaluation and Reporting

1) The Districts on request shall provide the Division of Traffic Safety and the Central Bureau of Traffic all project information on their program.

2) The Division of Traffic Safety will prepare a report for the Directors of Highways and Office of Planning and Programming on the Districts' overall safety efforts. All informational requests to the Districts will be channelled through the Director of Highways.

3) The Bureau of Traffic, working with the Division of Traffic Safety, will prepare an annual report to the FHWA on the Department's highway safety activities. The report will include evaluation data from the Division of Traffic Safety for work that has been completed and has one-year or two-year "after" data available. The results of the evaluations, as well as current traffic engineering research and developments, will be provided to all concerned for consideration in the preparation of future safety improvement programs.

4. Responsibilities .

a. The Directors of Highways, Planning and Programming, and Traffic Safety are responsible for assuring that their Divisions and Offices comply with the procedures set forth in this Policy.

b. The Bureau of Traffic is responsible for the maintenance, updating, and dissemination of this Policy.

5. Accessibility

Copies of this Policy may be obtained from the Central Bureau of Traffic, Room 116, Administration Building.

Approval:

H W Mouroney
Director of Highways

Mar 29, 1983
Date

E. R. McCormick
Director of Planning and Programming

March 29, 1983
Date

Melvin H Smith
Director of Traffic Safety

March 29, 1983
Date

APPENDIX C

Illinois Department of Transportation
Departmental Policies

TRA-16
March 15, 1984

SKID-ACCIDENT REDUCTION PROGRAM

1. Policy

The Department shall establish a program designed to minimize wet-pavement skidding accidents. This shall be accomplished by ensuring that new roadway surfaces have adequate, durable skid resistance properties, and by identifying and improving sections of roadway with high or potentially high skid-accident incidence.

2. Purpose

The purpose of this policy is to describe and outline the procedures that will provide a cost-effective skid-accident reduction program. This policy will apply to all federal and state funded projects on the interstate, primary, federal-aid secondary, and federal-aid urban systems, except maintenance and intermittent resurfacing projects.

3. Guidelines for Implementation

a. Primary Activities

1) The first activity (3b) consists of incorporating adequate, durable skid-resistant roadway surfaces during construction and rehabilitation of highway pavement segments.

2) The second activity (3c) involves identifying, analyzing, and improving two categories of wet-pavement accident locations.

a) One category is high-accident locations with overrepresented wet-pavement accidents that are improved as part of the safety improvement construction program.

b) The other category is wet-pavement accident locations (cluster sites) within rehabilitation/resurfacing projects improved as part of the regular construction program.

3) The third activity (3d) concerns feedback from field testing and analysis to evaluate the effectiveness of previous skid-accident reduction efforts.

b. Incorporation of Skid-Resistant Surfaces During Construction and Rehabilitation

1) Portland Cement Concrete

a) Final finishing on highways with posted speed limits in excess of 40 mph shall be obtained by the use of a longitudinal artificial turf drag followed immediately by a mechanically operated metal tine transverse grooving device as specified for Type A final finish in the Standard Specifications.

b) Final finishing on highways with posted speed limits not exceeding 40 mph may be obtained by the use of a single longitudinal artificial turf drag as specified for Type B final finish in the Standard Specifications or by a combination of longitudinal artificial turf drag and transverse tining as specified for Type A final finish.

2) Bituminous Concrete

New surface courses shall have, as a minimum, friction qualities equivalent to or greater than those provided by the following guidelines.

a) Mixture C should be used as the surface course on roads and streets having a design ADT of 2000 or less.

b) Mixture D should be 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 greater) highways having a design ADT of 60,000 or less.

c) Mixture E should be used as the surface course 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.

The Special Provision for Skid-Resistant Bituminous Surface describes Mixtures C, D, and E.

c. Identifying, Analyzing, and Improving of Wet-Pavement Accident Locations

1) High Accident Wet-Pavement Locations

The procedures for identifying, analyzing, and improving high-accident locations that have an overrepresented rate of wet-pavement accidents are included in the "Illinois Safety Improvement Processes" and Departmental Policy TRA-15, dated March 29, 1983, which cover the Safety Improvement Construction Program.

2) Wet-Pavement Accident Locations (Cluster Sites)

a) Identification of Cluster Sites

When a route is selected for rehabilitation/resurfacing, the wet-pavement accident records, furnished by the Division of Traffic Safety/local agency, shall be analyzed for the entire project. The identification of cluster sites shall be as outlined in Section I of "A Procedure for Identifying, Analyzing, and Improving Wet-Pavement Accident Locations Within Rehabilitation/Resurfacing Projects," which is included in the "Illinois Safety Improvement Processes."

b) Analysis of Cluster Sites

Each cluster site that is identified must be analyzed by District/local agency personnel. The analysis shall comply with Section II of "A Procedure for Identifying, Analyzing, and Improving Wet-Pavement Accident Locations Within Rehabilitation/Resurfacing Projects."

c) Corrective Treatment for Cluster Sites

After analyzing each cluster site, the District/local agency shall select the appropriate corrective treatment in accordance with Section III of "A Procedure for Identifying, Analyzing, and Improving Wet-Pavement Accident Locations Within Rehabilitation/Resurfacing Projects."

d) Documentation of Process

The identification, analysis, and improvement of each cluster site must be documented and become part of the location study report for State projects and project development report for local agency projects.

d. Evaluating and Reporting on Effectiveness of the Program

1) The Bureau of Materials and Physical Research will continue to evaluate current pavement design practices to ensure that skid resistance properties are durable and suitable for the needs of traffic.

2) The Bureau of Materials and Physical Research will develop a friction-test data base for retrieval and for subsequent data analysis.

3) The Bureau of Materials and Physical Research will continue evaluation of experimental projects which provide a broad body of knowledge concerning frictional characteristics applicable to Illinois surfaces.

4) The Division of Traffic Safety, in cooperation with the Bureau of Traffic and the Districts, will determine whether selected countermeasures on rehabilitation/resurfacing projects have been effective in reducing wet-pavement accidents. The results of the evaluation will be furnished to the Bureau of Materials and Physical Research for inclusion in their annual report.

5) The Bureau of Materials and Physical Research, in cooperation with the Bureaus of Traffic and Local Roads and Streets and the Division of Traffic Safety, will prepare an annual report summarizing activities of Illinois' Skid Accident Reduction Program on both the State and local agency highway systems.

6) The Bureau of Traffic will include in their annual "Evaluation and Report of the Highway Safety Construction Program," data on wet-pavement accident locations improved under the Safety Improvement Program.

4. Responsibilities

a. The Directors of Highways and Traffic Safety are responsible for assuring that their Divisions comply with the procedures set forth in this Policy.

b. The Bureau of Traffic is responsible for the maintenance, updating and dissemination of this Policy.

5. Accessibility

Copies of this policy may be obtained from the Bureau of Traffic, Room 104, Administration Building.

Approval:

H W Mourroney — Director of Highways — March 15, 1984 (Date)

Director of Traffic Safety — March 15, 1984 (Date)

REFERENCES

1. Burke, J. E., "A Summary of the Illinois Skid-Accident Reduction Program 1964-1980," Bureau of Materials and Physical Research, PR Report 90 (1981), 209 pp.

2. LaCroix, J. E., "1981 Friction Inventory of the Illinois Interstate Highway System," Bureau of Materials and Physical Research, (unpublished) (1982), 35 pp.

3. Dierstein, G., "A Study of PCC Pavement Texturing Characteristics in Illinois," Bureau of Materials and Physical Research, PR Report 95 (1982), 59 pp.

4. Dierstein, P. G., and Schwartz, D. R., "Skid-Resistant Characteristics of Existing Pavement Surfaces in Illinois," Bureau of Materials and Physical Research, PR Report 56 (1975), 68 pp.

5. Saner, J. L., "Sprinkle Treatment of Asphalt Surfaces, Fayette County, Illinois," FHWA Demonstration Project No. 50, Initial Report No. FHWA-DP-50-11 (1982), 22 pp.

6. Saner, J. L., "Addendum to "Sprinkle Treatment in Illinois, August 1982," Bureau of Materials and Physical Research, Administrative Report, (1983), 4 pp.

7. Saner, J. L., "An Investigation of Seal Coats Using Unconventional Aggregates," Bureau of Materials and Physical Research, (unpublished) (1984), 20 pp.

8. Neunaber, B. I., "Illinois' Demonstration Seal Coat Project," Annual meeting paper, Asphalt Emulsion Manufacturer's Association, Orlando, Florida, (1984), 13 pp.

9. Mascunana, I. C., "An Evaluation of the Roto-Mill Profiler," Bureau of Materials and Physical Research, (unpublished) (1982), 12 pp.

10. Fowler, D. D., "Final Report - Plasticized Bitumen Hot Mix Seal," Bureau of Materials and Physical Research, (unpublished) (1983), 31 pp.