Final Summary Report Friction Characteristics of Illinois Pavements

Physical Research Report No. 73

Illinois Department of Transportation
Bureau of Materials & Physical Research

Illinois Department of Transportation

Memorandum

To: Donald R. Schwartz

From: Philip G. Dierstein

Subject: Summary Report--Friction Characteristics of Illinois Pavements, Report No. 73

Date: October 10, 1978

Attached is Report No. 73, Summary Report--Friction Characteristics of Illinois Pavements which is ready for publication.

Philip G. Dierstein

PGD:rfs
Attach.

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16. Abstract

Determining, improving and prolonging pavement friction in Illinois were the principal objectives in this five-phase study, which is summarized in this report. The friction tester developed and modified in Phase 1 measured the friction of pavements evaluated in the remaining phases. Phases 2 and 3 provided considerable insight into the pavement friction characteristics of existing interstate, primary, secondary, and local highways and have outlined geographical areas where a need for upgrading a particular type of pavement is greatest. Phase 4 demonstrated that satisfactory friction characteristics in bituminous sand mixes and in dense-graded bituminous concrete depend on the type, size, and amount of high-friction aggregate used in them, while Phase 5 reported information necessary to reduce wet-weather accidents. A list of published reports and their abstracts, emanating from this study, also is included.

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

SUMMARY REPORT
FRICTION CHARACTERISTICS OF ILLINOIS PAVEMENTS

By

Philip G. Dierstein

Research Study
IHR-86
Skid Resistance of Pavement Surfaces

A Research Study Conducted by
Illinois Department of Transportation
Springfield, Illinois 62764
in cooperation with
U. S. Department of Transportation
Federal Highway Administration

May 1977

CONTENTS

ILLUSTRATIONS

TABLES

FRICTION CHARACTERISTICS OF ILLINOIS PAVEMENTS

INTRODUCTION

Recognizing a need for reducing wet-pavement accidents, the Illinois Department of Transportation in cooperation with the Federal Highway Administration undertook research, in 1966, to determine friction characteristics of existing highways and to find ways of improving friction of new as well as existing highway and street surfaces. The general study objectives were:

(1) To develop new equipment or to improve existing equipment for determining the friction characteristics of highway pavements, intersections and interchanges.

(2) To determine the friction characteristics of existing highway pavements.

(3) To study the polishing characteristics of aggregates used in pavement surfaces.

(4) To develop durable and economical means of increasing pavement friction, and

(5) To assemble a more positive body of knowledge concerning pavement friction characteristics for incorporation in highway design and safety policies.

The study consisted of five phases, each answering one of the objectives. The equipment developed in Phase 1 measured pavement friction of surfaces evaluated in the remaining phases.

FINDINGS AND RECOMMENDATIONS

This study has led to a better understanding of friction testers, pavement friction characteristics, and wet-weather accidents as they relate to the driver-vehicle-pavement system. Since the study was conducted by phases, the findings and the recommendations are summarized by phases.

Phase 1 - Equipment Development and Modification

Prior to 1966, friction testers usually were fabricated in house. This study demonstrated that government agencies can acquire friction testers from commercial fabricators through competitive bidding. The friction tester purchased by Illinois consisted of a two-wheel trailer towed by a two-axle, six-tire truck carrying a 450-gal water tank. Inside the truck cab were mounted power supplies, amplifiers, and recording equipment. The trailer has leaf-spring suspension, electric brakes, and a torque transducer. Originally, water was applied to the pavement in front of the test tire through a nozzle, but later the nozzle was replaced with a brush applicator. During a test, friction between the test tire and the pavement is measured as a function of torque produced in the trailer axle and recorded by an analog oscillograph while the test wheel is locked.

Before routine field work started, major modifications were made to the water system and the recording system. During shakedown testing when several lockups were repeated at short intervals, the electrical current supplied to the water pump motor dropped, causing decreased nozzle discharge. To maintain a uniform flow rate, the electrically powered water pump was converted to two mechanically driven pumps.

The discharge nozzles also were replaced with brush applicators after comparative tests among nozzle to pavement, nozzle to tire, and brush applicator indicated that friction numbers, depending on the method of application, differed significantly. Moreover, the water layer placed by the brush was observed more consistent in width and thickness than that placed by the nozzle.

The recording system was modified to improve the stability of the signal conditioning equipment. An unstable gain in the preamplifiers was corrected by replacing temperature sensitive carbon resistors with precision resistors having a very low temperature coefficient and by lowering the gain at the feedback circuit from 500 to 200. The overall system gain was maintained by increasing the recorder gain, which is capable of operating at a higher level without influencing the stability of the system.

The fluctuation in the excitation voltage was corrected by replacing the shunt-regulated power supply with a transistorized, series-regulated unit, which is capable of supplying an output of 6 volts within $\pm$ 0.1 percent.

Originally, each friction test was evaluated by visually reading the oscillograph trace, but later, an automatic digital printout was developed for recording the average transducer strain during a test, the numerical value of the calibration pulse, and the vehicle test speed. With the use of the automated system, a substantial savings in time for data reduction was realized, and the results were less dependent upon individual interpretation of the chart recordings.

Phases 2 & 3 - Pavement Friction and Aggregate Characteristics

Considerable insight into the frictional characteristics of Interstate, primary, secondary, and local highways was gained in Phases 2 & 3. Illinois has more than 13,000 miles of interstate and primary highways of which one-third are portland cement concrete and two-thirds are bituminous concrete. Another 16,000 miles of highways are designated as county highways, most of which are low-volume, farm-to-market roads whose surface today is either a bituminous concrete mat or a bituminous surface treatment.

The findings indicated that pavement friction of dense-graded bituminous concrete surfaces decreased as one travels from northern to southern Illinois. A similar but more pronounced trend existed at intersections. Conversely, the pavement friction of portland cement concrete surfaces increased as one travels from northern to southern Illinois, and the friction number at intersections closely approximated that found along the open highway.

A wear analysis indicated that most two-lane highways in Illinois can maintain good friction during their service life as long as PCC pavements are free of studded-tire wear and the use of crushed limestone in dense-graded bituminous concrete is restricted or blended in equal parts with slag. On the other hand multilane highways, particularly those in metropolitan areas, probably will need to be upgraded for pavement friction before the end of their structural design life.

Relative to secondary and to local roads and streets, the pavement friction problem seems less severe. The dense-graded bituminous mixture used on these roadways can be expected to retain a satisfactory friction characteristic during their structural design life as long as the ADT does not exceed 500, which involves the major mileage (80 percent) of these roads. For higher-volume roads and streets, the friction number can be improved by eliminating the use of limestone in a bituminous mixture.

Phases 2 & 3 have delineated areas in the State where the particular types of pavement are in greatest need of improvement and have provided sufficient information on which to base practical recommendations for changes that can be made now to improve and to prolong the friction characteristics of new pavements. They have shed more light on the overall complexity of the driver-vehicle-pavement system and have helped to outline specific areas in need of additional information before recommendations for further improvement in friction characteristics can be made.

Within the limit of the work covered in this phase, the following recommendations were offered for consideration for immediate implementation:

(1) For all primary highways and for expressways carrying up to 25,000 vpd on four lanes or 60,000 vpd on six lanes that are to be surfaced with Class I Bituminous Concrete, upgrade the frictional qualities of the coarse aggregate in the surface course mixture by prohibiting the continued use of soft calcareous limestone unless it is blended in equal proportion by volume with air-cooled blast furnace slag.

(2) Require that the coarse aggregate in Class I surface used on expressways carrying more than 25,000 vpd on four lanes or 60,000 vpd on six lanes or more lanes be air-cooled blast furnace slag or a 50-50 blend of this aggregate with crushed dolomite or crushed gravel.

(3) Improve the macrotexture of Class I surface course by using only the 1/2-in. top-size coarse aggregate (CA 13). Discontinue the permissive use of the 3/8-in. top-size (CA 16).

(4) To help compensate for the added cost of upgrading the frictional characteristics of the coarse aggregate as outlined above in (1) through (3), reduce the nominal thickness of Class I surface course from 1 1/2 in. to 1 1/4 in.

(5) Eliminate the use of soft calcareous limestones in Class B surfaces on secondary and local roads and streets having an ADT in excess of 500 unless blended 50-50 with a slag aggregate.

In addition to the above, the following recommendations were offered to further improve the friction characteristics of new pavement surfaces in Illinois:

(1) Adopt better methods for texturing PCC pavement. An experimental texturing study should be completed as soon as possible, and the best method or methods immediately adopted and put into practice.

(2) Continue the experimental construction of open-graded asphalt friction courses utilizing different types of aggregate to obtain the needed construction experience and to properly evaluate this type of surface for possible extended use in Illinois.

(3) Establish a program of experimental construction using the sprinkle treatment method with precoated aggregates. Although the few sprinkle treatments that have been tried in Illinois have not been spectacular, it is believed that this method holds promise as a way of enhancing skid resistance and offers the advantage of utilizing a very minimum of the more expensive high-friction aggregates.

(4) Continue searching for both natural and synthetic aggregates that will improve frictional characteristics in bituminous mixtures.

(5) Continue the search for laboratory tests or other methods that can be used to satisfactorily quantify and rate the frictional characteristics of aggregates produced from various sources used in Illinois.

Phase 4 - Experimental Surfaces

The experimental surfaces examined in Phase 4 were divided into two major categories--sand asphalt mixtures and dense-graded bituminous mixtures--because of the important role texture plays in pavement friction. When vehicle speeds are less than 35 mph, both fine- and coarse-textured surfaces usually can provide adequate friction characteristics, but as vehicle speed increases above 35 mph, only coarse-textured and open-graded surfaces which have good drainage characteristics will allow a tire to grip the roadway at higher speeds.

In sand asphalt mixtures the influence of aggregate type becomes evident as axle applications accumulate. Initially, Gripstop, Tapisable, slag sand, natural sand, trap rock, and stone sand all had acceptable friction (above 36), but after 2 million axle applications, trap rock and stone sand dropped to a marginal level (30 to 36). As the number of axle applications reached five million, the friction number of Gripstop and Tapisable continued to drop but still maintained an adequate level (above 36), while trap rock and stone sand leveled off and continued to maintain a marginal level (30 to 36). Friction tests made on Gripstop, trap rock, and stone sand after 10 million axle passes suggest that earlier trends established after five million applications have continued and that other mixes, which have not yet reached 10 million axle passes, are expected to behave similarly. Although a rubber additive can modify the physical properties of asphalt as temperature changes, its effect on pavement friction was insignificant.

In dense-graded bituminous surface courses, the influence of aggregate type also became apparent as it did in sand asphalt mixtures. When Synopal, slag, and crushed gravel are blended with or are substituted for crushed stone coarse aggregate, they improve the friction characteristics of a dense-graded bituminous surface by raising friction (microtexture) and by improving drainage (macrotexture). For a blend to be effective, the better aggregate should account for 50 percent or more of the coarse aggregate by volume. Apparently, an optimum macrotexture occurs when the top size of coarse aggregate is between 1/2 in. and 3/4 in. (13 mm and 18 mm).

Within the limits of the work covered in this phase, the following recommendations were offered for use in selecting bituminous mixtures with good friction characteristics:

(1) Bituminous concrete surface courses, Class I, although considered a fine-textured surface, are recommended over sand-asphalt mixtures for open highways, particularly where vehicular speeds exceed 45 mph.

(2) Hard angular aggregates that have excellent microroughness (gritty surfaces) should be used in high-friction mixes. Rounded aggregates and aggregates susceptible to polishing should be avoided.

(3) Sand-asphalt mixes may be considered for improving surface friction in urban areas and at other sites where vehicular speeds do not exceed 45 mph. Hard, angular, clean sands that are not susceptible to polishing should be used. Tests indicate that Tapisable, Gripstop, air-cooled blast furnace slag sand, and natural angular sands produce mixtures that provide satisfactory friction. The wear characteristics of Gripstop indicate that it should be limited in use to locations with reasonably low traffic volumes. Sand-asphalt mixes composed of 100 percent limestone sand, which is susceptible to polishing, should not be used.

(4) In lieu of complete replacement of soft, polishing coarse aggregates in bituminous mixtures to produce good frictional characteristics, satisfactory skid-resistant mixtures can be produced by blending hard, polish-resistant aggregates with soft aggregates in approximately equal parts.

(5) Rubber additives did not improve friction, but they may be used to modify the physical properties of the asphalt binder without sacrificing frictional qualities of the mixture.

Phase 5 - A strategy for Reducing Accidents

Vehicle skidding, which involves not only the vehicle but also the pavement and the driver interacting in a changing environment, falls into the situation hazard category. A situation hazard is a combination of conditions with or without object hazards, which may be either fixed or moving. In situation hazards, the elements (vehicle, driver, pavement, and environment) by themselves may not necessarily be hazardous, but when combined, they are treacherous and can cause accidents. During rainfall, for example, driving a vehicle with smooth tires over a polished curving roadway that has insufficient superelevation can create a situation hazard which leads to a number of skidding and single-vehicle, run-off-the-road accidents.

In Illinois the risk of wet-pavement accidents is greater at braking sites, like intersections, railroad crossings and toll plazas; at curves, particularly where they are associated with a downhill grade; and at speed-change areas in interchanges, than along a straight, level highway.

The three friction levels currently used as guides in evaluating pavements at high-accident locations in Illinois are: Above 36, 30-36, and Below 30. When pavement friction is above 36, probably some condition other than pavement friction may be the primary factor causing accidents; when the value lies between 30 and 36, uncertainty exists as to whether pavement friction is the primary factor; but when the value is below 30, pavement friction probably is a contributing factor to the high accidents and should be upgraded as a part of the corrective action.

A long-term strategy for reducing wet-weather accidents involves upgrading as well as prolonging the friction level of pavements in Illinois. Recent changes in design policy limit the use of limestone and provide for three Class I, Bituminous Concrete Surface Course mixture classifications: Mixtures C, D, and E. Mixture C is unchanged from the previous specification. Mixture D is the same as Mixture C, except that the use of limestone as the coarse aggregate is not permitted unless blended 50-50 with slag. Mixture E eliminates the use of limestone completely and requires coarse aggregate to be either slag or a 50-50 blend of slag and crushed dolomite or crushed gravel. A portland cement concrete revision requires that the final finish be obtained by the use of an artificial turf drag immediately followed by a mechanically operated metal-comb transverse grooving device.

The open-graded asphalt friction course has become a popular method of improving surface friction characteristics. The main advantage of this high-void, hot-asphalt plant mix is that it permits rapid drainage of rainfall through the course, which lessens the potential for hydroplaning, especially at curves and in flat vertical sag curves. Other advantages are: reduced tire splash and spray, better visibility of pavement markings in wet weather, and a smooth quiet ride.

Bituminous sand mixes that have gritty textures, which provide high friction but limit drainage, can reduce wet-weather accidents at intersections and on urban highways and streets where operating speeds are less than 45 mph. Their use on rural Interstate and primary highways is not recommended because of insufficient drainage (macrotexture) to prevent hydroplaning.

As new surfaces age, they become worn and polished, lowering their friction characteristics. When low friction is discovered, several alternatives are: (1) Modify the existing surface, (2) apply a new surface, and (3) lower driver-maneuver demand. Under certain circumstances, lowering driver maneuver demand may be an interim counter-measure while some other corrective action is being sought and programed.

Grooving, milling, planing, profiling, repaving, and acid etching are several methods of restoring frictional characteristics in worn pavements. The most common method of upgrading pavement friction of an existing surface is applying a new surface. This can be done with open-graded asphalt friction course, dense-graded bituminous mixtures (Mixture E), and bituminous sand mixtures, depending on the circumstance.

Lowering driver-maneuver demand can be done sometimes by reducing operating speeds. In addition to reducing speed, altering traffic control devices, improving signing, eliminating parking, and altering pavement markings, all which smooth traffic flow, can lower demand. Removing roadside hazards, lengthening sight distance, flatening grades, increasing the radius and superelevation of curves to fit actual operating speeds as well as preventing water from accumulating on the pavement are several other ways of lowering demand.

Review of 226 sites (where wet-pavement accidents normalized with respect to wet and to dry days exceed dry-pavement accidents) indicates that 59 percent of the sites had an FN below 30 while 34 percent ranged between 30 and 36 and 7 percent were above 36. Although no friction number emerged as a point above which a disproportionate number of wet-pavement accidents ceased, a marked increase in high-accident sites occurred when the FN fell below 33, which is only 3 numbers above the current low level of 30. Another equally important finding was that one-third of the high-accident sites not having a disproportionate number of wet-pavement accidents also had friction numbers below 30. Evidently, driver-maneuver demand at these places was lower than the corresponding available pavement friction.

RESEARCH APPROACH

After reviewing information available on existing friction testers, plans and specifications for competitive bidding were prepared in 1967 for a friction tester that was designed in accordance with ASTM Designation: E 274-65T, "Skid Resistance of Pavements Using a Two-Wheel Trailer." A contract for fabricating the system - trailer and tow vehicle - was awarded to Soiltest, Inc., Evanston, Ill., and the completed system was delivered to the Division of Highways in May 1968. After certain modifications and calibration, the system was made operational in July 1969.

Testing for Phases 2 & 3 began in July 1969 and continued through the summer of 1971. To obtain a sample representing the friction characteristics of Illinois highways, the District Engineer in each of the nine highway districts selected as many sites as possible from a site-selection chart, which can be seen in Figure 1. Following this procedure, each District Engineer submitted a cross section of existing pavement surfaces under his jurisdiction, and in turn, the selected test sites, when tabulated for the entire State, provided a stratified sample for study.

The chart (Figure 1) incorporated five factors, pavement type, pavement age, general location, aggregate type, and traffic volume, all which are believed to influence pavement friction to some degree. As can be seen in the figure, the five factors are divided further into sub-factors.

In addition to selecting test sites, each District supplied additional information about each test site for later use in the analyses.

Out of a possible 1880 test sites the Districts selected 404, which are summarized in Table 1 by highway system, by pavement type, and by general location. They comprised straight, level, one-mile open-highway sections and 500-ft approaches to stop intersections. The mean friction number obtained at

State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

CHART FOR SELECTION OF SKID TEST SITES

DISTRICT

TYPE OF PAVEMENT SURFACE	PORTLAND CEMENT CONCRETE (1)											
GENERAL LOCATION	OPEN HIGHWAY (1)						STOP INTERSECTION (2)					
KIND OF COARSE AGGREGATE	GRAVEL (1)			CRUSHED STONE (2)			GRAVEL (1)			CRUSHED STONE (2)		
TRAFFIC VOLUME	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
AGE OF SURFACE (years) 0	●	x	x	x	x	x	●	●	x	x	●	●
1	x	x	x	x	x	x	x	●	●	x	●	x
2	x	x	x	x	x	x	●	●	x	●	x	●
3	●	x	x	x	x	x	●	●	x	●	x	●
5-6	x	x	x	x	x	x	●	x	x	x	x	x
10-12	x	x	x	x	x	x	x	x	●	x	x	x

TYPE OF PAVEMENT SURFACE	BITUMINOUS CONCRETE													
	I-11 (2)						B-5 (3)							
GENERAL LOCATION	OPEN HIGHWAY (1)			STOP INTER-SECTION (2)			OPEN HIGHWAY (1)				STOP INTERSECTION (2)			
KIND OF COARSE AGGREGATE	CRUSHED STONE (1)			CRUSHED STONE (2)			GRAVEL (1)		CRUSHED STONE (2)		GRAVEL (1)		CRUSHED STONE (2)	
TRAFFIC VOLUME	V_1	V_2	V_3	V_1	V_2	V_3	V_4	V_5	V_4	V_5	V_4	V_5	V_4	V_5
AGE OF SURFACE (years) 0	x	x	x	x	x	x	●	x	x	x	●	x	●	●
1	x	x	x	x	x	●	x	●	x	x	●	●	●	x
2	x	x	x	x	x	x	x	x	x	x	x	●	x	●
3	x	x	x	x	x	x	x	x	x	x	x	x	x	x
5-6	x	x	x	x	x	x	x	x	x	x	x	●	x	x
10-12	x	x	x	x	x	x	x	●	●	x	●	●	●	●

TYPE OF PAVEMENT SURFACE	BITUMINOUS SURFACE TREATMENT (Class A) (4)							
GENERAL LOCATION	OPEN HIGHWAY (1)				STOP INTERSECTION (2)			
KIND OF COARSE AGGREGATE	GRAVEL (1)		CRUSHED STONE (2)		GRAVEL (1)		CRUSHED STONE (2)	
TRAFFIC VOLUME	V_4	V_5	V_4	V_5	V_4	V_5	V_4	V_5
AGE OF SURFACE (years) 0	x	x	x	x	x	x	x	x
1	x	x	x	x	x	x	x	x
2	x	x	x	x	x	●	x	x
3	x	x	x	●	x	x	x	x

TRAFFIC VOLUME LEVELS (1967 ADT)

V_1............ Under 2500
V_2............ 2500 - 4999
V_3............ 5000 and Over
V_4............ Under 400
V_5............ 400 and Over

Note: The numbers enclosed by parentheses indicate appropriate code numbers. See coding instructions.

R/D 8-1-68

x Test sites selected.
● No test site selected.

Figure 1.

TABLE 1. SUMMARY OF TEST SITES

Highway System	Pavement Type	Number of Sites: Open Highway	Number of Sites: Stop Intersections	Number of Sites: Total	Percent of Total
Interstate and Primary	PCC Concrete	85	30	115	29
	Bituminous Concrete, Class I	118	56	174	43
	Subtotal	203	86	289	72
County	Bituminous Concrete, Class B	26	14	40	10
	Bituminous Surface Treatment, Class A	45	30	75	18
	Subtotal	71	44	115	28
	TOTAL	274	130	404	100

open-highway sites is the average of 10 tests in each lane, while the friction number obtained at intersections is the average of six tests per lane. When testing four-lane highways, both traffic and passing lanes were tested and reported separately because of a difference in wear between lanes.

Friction numbers obtained by the field crew were analyzed in two ways. First, the mean friction number for each type of surface was related to the number of cumulative axle applications that had passed over that surface for each study factor. Then, the resulting friction number-cumulative axle curves, called wear curves, were compared with one another to determine how each different factor affected skid resistance.

In addition to those comparisons, the wear curve for a particular type of surface was used to predict how long, on the average, that surface can be expected to provide a satisfactory friction number for a particular type of highway and for a given ADT and vehicle composition.

The second analysis involved establishing three friction levels based on information in NCHRP Report 37 and on our own experience. The levels selected were above 36, 30-36, and below 30, and they served as guidelines for evaluating the general quality of pavement friction in Illinois. Mean friction numbers for traffic lanes were sorted into the three friction categories and were compared by three geographical areas - northern, central and southern Illinois. Knowledge gained from these analyses provided a basis for proposing changes to the Standard Specifications.

Between 1965 and 1971, a number of dense-graded bituminous concrete mixtures were placed as experimental overlays at 17 sites and were evaluated in Phase 4. Comparative tests were made usually twice a year at each site. The mean friction numbers obtained from a test section were plotted as a function of time and as a function of accumulated axles that passed over that test section. As trends developed, it became evident which mixes had acceptable (above 36), marginal (30-36) or low (below 30) friction characteristics and why each mix seemed to fit into a particular category. The knowledge gained from these tests was needed by design and by traffic engineers for improving and maintaining pavement friction characteristics, especially at intersections and at curves where stopping and cornering maneuvers are critical.

Beginning in the summer of 1972 friction tests were made at high-accident sites (Phase 5) where vehicle skidding was suspected as a contributing factor in causing a disproportionate number of wet-pavement accidents. Accidents happening on ice- and snow-covered pavements were not considered because they represented a different road surface condition. After the sites were identified, friction tests were made to determine whether the friction level at these places contributed to the wet-pavement accidents.

Sites where wet-pavement accidents normalized with respect to dry and wet days exceeded dry-pavement accidents were selected for further analysis. They were sorted into frequency distributions by friction numbers to determine whether skidding accidents cease above a certain friction level.

IMPLEMENTATION

As findings emerged from this study, they were presented at meetings and conferences. Interim reports were published and were distributed to Districts and Central Bureaus as well as other interested persons. Through cooperative meetings, contractors and aggregate producers have been informed of the findings as well as the Department's position and concern for upgrading the frictional characteristics of Illinois highways and streets.

To upgrade and to prolong the friction characteristic of Illinois pavements, the Division of Highways did three things. First, Design Memorandum No. 75-9 (effective May 5, 1975) was issued. It refers to a special provision containing revised specifications for Class I Bituminous Surface Course Mixtures having improved frictional properties. There are three surface mixture classifications: Mixtures C, D, and E. Mixture C is unchanged from the previous specification. Mixture D is the same as Mixture C, except that the use of limestone as the coarse aggregate is not permitted unless blended 50-50 with slag. Mixture E eliminates the use of limestone completely and requires coarse aggregate to be either slag or a 50-50 blend of slag and crushed dolomite or crushed gravel.

The following policy governs the use of these three mixtures:

1. Mixture C may be used as surfacing on roads and streets, except on the primary system, having a design ADT of 500 or less.

2. Only Mixture D or E should be used as surfacing on secondary and local roads and streets having a design ADT greater than 500, on all two-lane primary highways, 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.

3. Only Mixture E should be used in the Chicago Metropolitan Area as surfacing 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.

Implementing this special provision, which calls for the use of coarse aggregate in bituminous surfaces with higher quality friction characteristics, not only should improve microtexture (friction) and macrotexture (drainage) in bituminous surfaces but, over the long term, should reduce the number of skidding accidents occurring on them.

Second, a special provision for texturing portland cement concrete pavement (effective March 1, 1976, and revised February 1, 1977) was issued and states that the final finish shall be obtained by the use of an artificial turf drag immediately followed by a mechanically operated metal-comb transverse grooving device.

Implementing this special provision has added positive macrotexture (drainage) not previously obtained when either a burlap drag or turf drag was used as the final finish.

Third, as high-accident sites that have a disproportionate number of wet-pavement accidents continue to be identified, friction tests are conducted to determine their friction level. When surface friction drops below 30, restoration of the existing surface is recommended in addition to any other necessary improvements. Restoration can be achieved either by modifying the existing surface or by applying a new surface. As these sites are improved, the friction level of the entire highway system is upgraded.

The long-range goal of this implementation is reducing wet-weather accidents in Illinois.

PUBLISHED REPORTS WITH ABSTRACTS

1. "Selection and Design of a Skid Tester," Kubiak, Edward J., Illinois Division of Highways, Research and Development Report No. 23, (1970).

   Plans and specifications were prepared following the requirements of Designation: ASTM E 274-75 T, "Tentative Method of Test for Skid Resistance of Highway Pavements," so that a skid-test system could be purchased from a manufacturer through competitive bidding. Existing skid-test systems belonging to the Portland Cement Association, Bureau of Public Roads, Florida, Texas, New York, Tennessee, Virginia, Ontario (Canada), and General Motors were evaluated to establish design criteria for the Illinois System. The design was divided into three parts: (1) tow truck and water tank, (2) skid-test trailer and water nozzles, and (3) electrical system. A two-axle six-tire truck capable of supporting a 450-gallon water tank was specified. The design of the trailer called for a leaf-spring suspension, electric brakes and torque-tube transducers. Originally, nozzles for applying water were specified, but later a brush applicator replaced the nozzle. The specifications also required development of a device that sequentially controlled the test cycle after the operator pressed a test button. The torque resulting from the brakes locking the wheel on a wetted pavement is recorded on a two-channel recorder, one channel for each wheel. After receiving the equipment, a number of modifications were made.

2. "Modification and Calibration of The Illinois Skid-Test System," Kubiak, E. J., Dierstein, P. G., and Jacobsen, F. K., Illinois Department of Transportation, Research and Development Report No. 41, (April 72).

   Skid-test equipment was designed according to the applicable parts of ASTM Designation: E 274-75 T, "Tentative Method of Test for Skid

Resistance of Pavements Using a Two-Wheel Trailer", and construction of the equipment was awarded to a commercial fabricator. After delivery, several modifications were made to improve the overall performance of the original equipment, and calibration procedures were established to insure the reliability of the system. Tests performed with three different methods of water application showed system details and method of water application to have a very significant effect on the magnitude of measured skid resistance and a brush-type applicator to be most effective in depositing a water layer of both uniform width and thickness directly in the path of the test tire. The results of the tests suggest a need for establishing a standard method for water application and control of the cross-sectional dimensions of the water layer before a meaningful correlation can be made among the variety of skid trailers now in existence.

3. "Skid-Resistant Characteristics of Existing Pavements in Illinois," Dierstein, P. G., and Schwartz, D. R., Illinois Division of Highways, Physical Research Report No. 56 (January 1975).

Over 8300 skid tests were made between 1969 and 1971 at 404 sites on existing Interstate, primary, and county highways in Illinois. They indicate that textured portland cement concrete surfaces on two-lane highways can provide skid numbers (SN) above 35 throughout most of their 20-year design life as long as studded-tire wear is negligible, but most multilane highways will need rejuvenating by grooving or by adding a friction course sometime during their service life. Bituminous concrete surfaces generally have a lower and a wider range of SN than PCC pavements. In northern and central Illinois most two-lane bituminous concrete surfaces, which usually contain dolomite limestone or crushed gravel, can provide an SN above 35 throughout most of their 15-year design life, while similar surfaces containing soft limestone in southern Illinois will need a hard skid-resistant aggregate blended with limestone to maintain an SN above 35. Also, multilane highways resurfaced with bituminous concrete will need a hard skid-resistant aggregate blended with or substituted for limestone to keep an SN above 35. Specific recommendations are included for improving skid resistance and for obtaining additional information needed for further improvement.

4. "Skid-Resistant Characteristics of Experimental Bituminous Surfaces in Illinois," Dierstein, P. G., Ryan, P. F., and Purcell, W. C., Illinois Department of Transportation, Research and Development Report No. 44, (February 1974).

Skid resistance was among several factors used to evaluate bituminous mixtures which were placed as experimental surfaces at 17 sites in Illinois. Skid tests indicated that surface texture as represented by changes in macroroughness and microroughness substantially controls the skid resistance of a surface. For the same kind of aggregate, dense-graded mixes that have a 1/2-inch top-size aggregate provided higher skid numbers than either sand-asphalt or binder course mixes. On the other hand, when aggregate gradation was held constant, air-cooled slag or Synopal, which have excellent microroughness, gave higher skid numbers than limestone or other aggregates that have less microroughness. Moreover, adding rubber to bituminous mixes or substituting stone sand for natural sand in a regular Class I surface course mix produced little, if any, change in skid resistance. Bituminous surfaces designed for optimum macroroughness and microroughness should continually give adequate skid numbers regardless of wear, and bituminous mixes that produce a smooth surface texture obviously should be avoided.

5. "A Strategy for Reducing Wet-Pavement Accidents in Illinois," Dierstein, P. G., Illinois Division of Highways, Physical Research Report No. 60, (May 1977).

In Illinois a disproportionate number of wet-weather accidents are associated mostly with intersections, curves, hills, railroad crossings, and interchange areas where a driver's maneuver demand exceeds the available pavement friction. Review of 226 such sites indicated that friction numbers (FN) ranged from 18 to 53. Of the total number of sites, 59 percent had an FN below 30, and 34 percent ranged from 30 to 36, while only 7 percent exceeded an FN of 36. An equally important finding was that one-third of the high-accident sites not having a disproportionate number of wet-pavement accidents also had friction numbers below 30.

A long-term strategy for reducing wet-weather accidents involves upgrading and prolonging friction characteristics in new as well as in existing pavements. Recent specification changes limit the use of crushed stone and require either slag or a 50-50 blend of slag and crushed dolomite or slag and crushed gravel in bituminous surface courses, depending on highway class and traffic volume. A portland cement concrete special provision requires that the final finish be obtained by use of an artificial turf drag immediately followed by a mechanically operated metal-comb transverse grooving device. In existing surfaces, friction can be improved by bituminous resurfacings containing coarse aggregates with high friction characteristics or by grooving, planing, milling, profiling, repaving, and acid etching. Sometimes, wet-pavement accidents can be reduced by lowering driver-maneuver demand instead of improving friction characteristics.